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TNO-rapport

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Meerjaren Speurwerkprogramma 2015-2018
Voortgangsrapportage 2015
Thema High-Tech Systemen en Materialen

Datum	1 februari 2016
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Regievoerend Department	Ministerie EZ
Financierend Departement	Ministerie EZ
Aantal pagina's	68 (incl. bijlagen)

Inhoudsopgave

1 Introduction

This report describes the developments of TNO's Demand Driven Programs (called VP: Vraaggestuurd Programma) over the year 2015 and contributions to the different Roadmaps of HTSM. This yearly progress report (as well as the yearly update of the plans) is mandatory for TNO to account for the usage of Public Funding (called Rijksbijdrage TNO). The audience of this report are the Ministry of Economic Affairs and the Topsector HTSM with its Roadmaps, while this report will be published by TNO on its website as well.

The Ministry of Economic Affairs has allocated additional budget in 2015 for the TO2 organizations in order to a) stimulate further cooperation and b) partly compensate for the reduction of governmental funding. The projects performed within this scope will be reported by the leading TO2 organization. One Theme (Inclusieve Maatschappij) is related to the current progress report and includes two projects: Smart Industry and Multi Material Additive Manufacturing. These projects will be reported in a separate chapter (# 10). The Smart Industry project is linked to the HTSM Roadmap Manufacturing and Mechatronics, which will be transferred early 2016 in a Smart Industry Roadmap. The Multi Material Additive Manufacturing project is linked to the HTSM Roadmap Printing.
The Ministry of Economic Affairs has allocated additional budget in 2014-2016 for the so called TTI transitions. One transition (TTI Materials) is related to the current report. The progress of this work is reported in the materials paragraph of the VP Flexible and Freeform Products (# 8.6).
The table below shows the relations between TNO's Demand Driven Programs and the HTSM Roadmaps. The QuTech initiative and the Embedded Systems Institute (ESI) are indicated. The activities of the Holst Centre are described in the VP Flexible and Freeform Products, specifically for the HTSM Roadmaps Components and Circuits, Lighting and Solar.

HTSM Roadmap / TNO Demand Driven Program (VP)	Security	Components and Circuits	Manufacturing and Mechatronics	Automotive	Nano-technology	HighTech Materials	Space	Advanced Instrumentation	Semiconductor Equipment	Lighting	Solar	Printing	Healthcare	Embedded Systems
Security	X													
Defense Related Industry	X	X												
Automotive Mobility Systems				X										
Human Health RM Nano					X									
Space and Scientific Instrumentation							X	X						
High-Tech Semicon					X (QuTech)				X					
Flexible and Freeform Products		X				X (TTI)				X	X	X	X	
ESI														X
TO2 Inclusieve Maatschappij			Smart Industry									Multi-material AM		

The plans for 2015 were described in TNO's report 'Speurwerkprogramma 2015-2018 Thema High-Tech Systems and Materials' of September 26th, 2014.

2 VP Security

2.1 Roadmap Security

2.1.1 Introductie

Het VP Security is gefocust op technologische uitdagingen die kunnen bijdragen aan de veiligheid in onze samenleving en sluit aan op de HTSM Roadmap Security (zie: http://www.hollandhightech.nl/htsm/Roadmaps/Security). We kijken zowel naar oplossingen die bijdragen aan het voorkomen dan wel het beheersen van criminaliteit en terrorisme, alsook naar oplossingen die de schadelijke effecten van incidenten (crises, rampen) beperken. De doelgroepen en de beoogde impact zijn:

Deelroadmap	Beoogde impact
System of systems	• Publieke veiligheidsorganisaties: verbetering efficiency en effectiviteit operationele taken. • Leveranciers van systemen, tools en diensten: internationaal onderscheidende en erkende producten.
Cyber risk management & system resilience	• Eigenaars van ICT-systemen uit bedrijfsleven en overheid: kosten efficiënte beheersing cyberrisico's. • IT-bedrijven: nieuwe concepten en tools voor cyber resilience van systemen.
Sensoren	• Publieke veiligheidsorganisaties: verbetering efficiency en effectiviteit waarnemingstaken. • Producenten van hard- en software voor sensorsystemen: nieuwe producten.

2.1.2 Programma 2015

In de kennisarena met bedrijven en publieke veiligheidsorganisaties op 3 juni 2015 zijn de resultaten gepresenteerd en zijn suggesties voor het vervolg verkregen; breed gedragen was de vraag om meer aandacht voor internationale samenwerking.

Systems of systems

Voor een geïntegreerde aanpak van de operationele taken op het gebied van crisisbeheersing en openbare orde, veiligheid en beveiliging is ontwikkeling van een 'systeem van systemen' essentieel. In 2015 is ingezoomed op het ontwikkelen van robuuste oplossingen voor Real Time Intelligence en voor Beveiliging van complexe, multi-stakeholder-locaties. Samen met de politie en de KMar zijn innovatierichtingen en een aantal daarop gerichte ontwikkelingen geïnitieerd. Crisismanagement in het kader van het efficiënt beheersen van overstromingsdreigingen kreeg minder aandacht en de ontwikkeling van predictive policing meer.

Cyber risk management & system resilience

De toenemende kwetsbaarheid van de bedrijfsvoering bij bedrijven en overheden voor cyber risico's vraagt om kosteneffectief vergroten van de cyberresilience en de bestrijding van cybercrime.
In 2015 is de focus gelegd op het robuust functioneren van de IT-systemen met een efficiënte, privacy compliant interactie met klanten en met samenwerkingspartners een essentiële voorwaarde. Er is meer aandacht gegeven aan nieuwe concepten en tools voor dreigingsintelligence en uitwisseling van informatie met ketenpartners. Aan smart meters is in verband met tanende belangstelling van marktpartijen minder onderzoek gedaan.

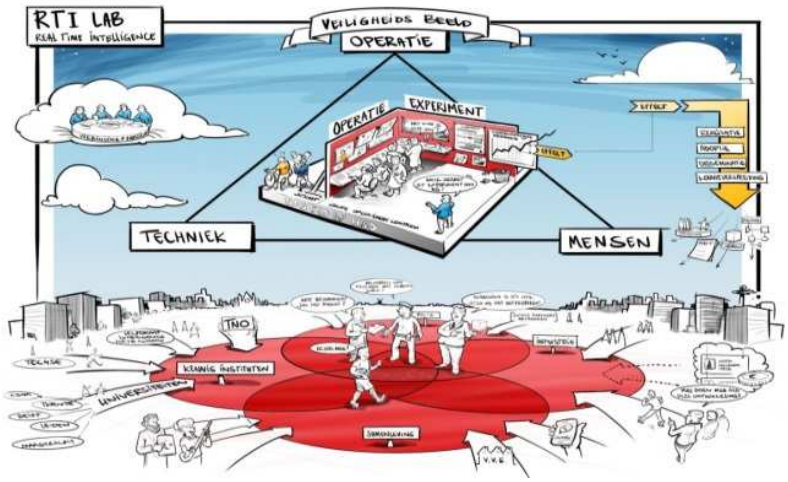
Sensoren
Voor toezicht en beveiliging zijn waarnemingen met sensoren cruciaal. Zowel actieve als passieve sensortechnologieën zijn van belang:

- Met verder verfijnde actieve sensoren (radars) zijn intelligentere systemen realiseerbaar. Over de kennisontwikkeling voor uitbouw van de excellente positie op de toegankelijke wereldmarkt in samenwerking Defensie, bedrijfsleven, TNO en TU Delft wordt gerapporteerd in het VP Defensie Gerelateerde Industrie.
- Om de snel groeiende datastroom uit passieve sensoren te kunnen verwerken vinden ontwikkelingen plaats op het gebied van intelligente sensoren en zelflerende systemen.

2.1.3 Resultaten

Systems of systems
De 'Initiatiefgroep RTI-lab' - bestaande uit politie, The Hague Security Delta, de Landelijke Meldkamer Organisatie (LMO) en TNO - heeft in 2015 een goede start gemaakt met het inrichten van een experimentele faciliteit voor Real Time Intelligence. In samenwerking met de partners zijn de volgende resultaten gerealiseerd:

- Een raamwerk voor het relateren van experimenten aan het veiligheidsbeeld: de RTI-Challenge.
- Een RTI-Experience om het concept van RTI beleefbaar te maken. De Experience bestaat uit een scenario en een interactieve demonstratie-omgeving.
- De RTI-Radar om door een verkenning van trends en ontwikkelingen de basis te creëren voor de RTI Roadmap.



Visieplaat RTI-Lab

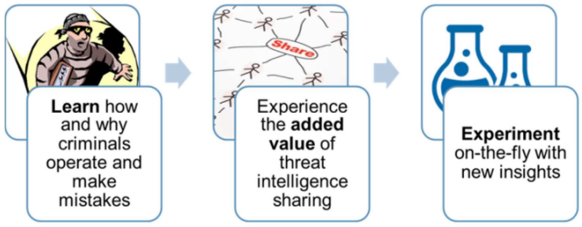
- Een eerste experiment rond het SGBO van Leids Ontzet op 2/3 oktober: het articuleren van behoeftes rond Real Time Intelligence in de meldkamer op een multi-touch table.

Naast de ontwikkeling van het RTI-lab is in 2015 voortgang geboekt bij het in consortia ontwikkelen van:

- Het project 'Internationale zone'. In 2015 is onderzocht hoe informatie-uitwisseling kan leiden tot versterking van de informatiepositie en werkwijze van de politie in een gebiedsgerichte samenwerking met andere Publieke en Private Partijen.

- De integratie van systemen en processen voor burgerparticipatie bij handhaving en opsporing: Burger Alertering Real Time (BART). Samen met TU-Delft, CGI en de Nationale Politie kreeg deze ontwikkeling gestalte.

Cyber risk management & system resilience
De samenwerking met nationale en internationale marktpartijen heeft geleid tot een architectuur, waarin informatie van het clearweb en van het darkweb betreffende witwassen van geld kan worden gecombineerd met financiële transactiedata en met opsporingsinformatie; de ambitie ook een link te leggen met Telecomgegevens. Het ontwikkelschema voor deze architectuur kent als stappen: Leren, Verrijken en Begrijpen (zie onderstaande figuur).



De uitwisselingsstandaarden die nodig zijn om veelsoortige informatie geautomatiseerd te kunnen verwerken, zijn nog in ontwikkeling. Wel is in samenwerking met een IT-leverancier het platform geschikt gemaakt voor het kunnen uitwisselen van informatie op basis van de STIX standaard. Met de opgebouwde kennis speelt TNO een belangrijke rol op het gebied van security informatie-uitwisseling.

In het Shared Research Program Finance wordt samengewerkt met alle grote Nederlandse banken aan de ontwikkeling van Computer Security Incident Response Teams (CSIRTs). Denk hierbij aan het functioneel ontwerp van technische infrastructuren met essentiële operationele computer systemen, zoals bijv. Intrusion Detection Systems en firewalls. Een bijzondere categorie systemen waar kennis van is opgebouwd betreft enkele gangbare Threat Intelligence Platforms, waaronder Malware Information Sharing Project en SoltraEdge, ontwikkeld binnen het Financial Service Information Sharing & Analysis Center (FS-ISAC). Verder is onderzoek verricht naar de automatisering van processen binnen deze CSIRTs en zijn use cases beschreven.

Sensoren
Er is in 2015 een doorbraak gerealiseerd voor het geautomatiseerd, real-time herkennen van afwijkend gedrag bij cameratoezicht in complexe drukke omgevingen. In een door NCTV gefund samenwerkingsproject met de KMar, Schiphol, douane, Qubit B.V. en Bosch is een prototype ontwikkeld en beproefd met veelbelovende resultaten. Deze ontwikkeling bouwt voort op de kennispositie van TNO en wordt actief met patenten beschermd. Ook voor toezicht in het gevangeniswezen bestaat nationaal en internationaal grote belangstelling. De resultaten van dit project kunnen breed worden toegepast, zowel binnen het veiligheidsdomein als daarbuiten.

In 2015 is ook onderzoek gedaan naar de interpretatie van sensorinformatie vanaf mobiele en ad hoc waarneemplatformen. Daartoe is o.a. voor bodycams video content analyse-technologie ontwikkeld. Het is de verwachting dat deze in de nabije

toekomst ook voor opsporing en handhaving gebruikt kan gaan worden. Dit biedt perspectief op het efficiënter benutten van de waarnemingen met bodycams.

2.1.4 Overzicht samenwerking

De ontwikkeling van PPS-consortia voor strategische innovatietrajecten heeft zich in 2015 gunstig ontwikkeld. Onderstaande tabel geeft een overzicht van de stand van zaken en de vooruitzichten.

Deel-roadmap	**Stand van zaken ontwikkeling PPS-consortia voor strategische innovatietrajecten:**	Ontwikkeling TKI-grondslag (k€/jr)*)	
		2015	2018
Systems-of-systems	1. Onderzoekproject Real Time Intelligence in twee consortia: Internationale zone (Siemens, Thales, TNO, gemeente Den Haag, Eurojust e.a.) en Burgerparticipatie (CGI, politie, TNO, TU Delft). 2. Ontwikkeling R&D faciliteit Real Time Intelligence tools en concepten (vervolg in VP-VM ism Politie e.a.).	0	pm**)
Cyber-security	1. SRP Cybersecurity is in 2015 gestart. In 2016 uitbouw naar nog een à twee sectoren (Opties: Telcom, Internet Service Providers, Fysieke vitale infra). 2. Initiatief veilige publieke communicatiesystemen (UWV/Belastingdienst, Rola, Dataexpert) in het kader onderzoek naar de realisatie van 'Visie Rijks-SOC'.	260	1000
Passieve sensoren	1. Ontwikkelen concepten voor bewaken en beveiligen in twee consortia: automatische herkenning incidenten/risk based toezicht (Schiphol, KMar, QVI e.a.) en Inzetconcepten voor mobiele sensoren, UAV's (politie, KMar e.a.). 2. Initiatief gezamenlijk EU-testbed surveillance (UK Home Office, ERNCIP, lobby H2020).	70	300
Actieve sensoren	Uitvoering gezamenlijke Roadmap Radar en geïntegreerde sensorsuites (2010-2020) in samenwerking Defensie, Thales, TNO, TU Delft; aanhaken andere suppliers.	500	1500

*) Er vindt ook TNO Security onderzoek in opdracht van publieke veiligheidsorganisaties plaats, dat volgens de vigerende regelgeving niet voor TKI grondslag in aanmerking komt, maar wel van groot maatschappelijk en economisch (hogere orde effecten) belang is.
**) Vervolgtrajecten zijn in ontwikkeling en zullen naar verwachting wel resulteren in TKI-grondslag.

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3 VP Defense Related Industry

3.1 Roadmap Security and Roadmap Components and Circuits

3.1.1 Introduction

The VP Defence Related Industry started in 2014 and is linked to the HTSM Roadmap Security and the HTSM Roadmap Components & Circuits.

De running activities in this VP are carried out in the scope of the:

- The national Roadmap *Radar en Geïntegreerde Sensorsuites.*
- Platform Nederland Radarland that is founded in 2002 by Thales Netherlands, TNO, TU Delft, and the Ministries of Defence and Economic Affairs.
- D-RACE, the Dutch Radar Centre of Expertise a strategic alliance between Thales Netherlands and TNO regarding radar and integrated sensor suites.

The activities are fully embedded in the HTSM Roadmaps Security and in the HTSM Roadmap Components and Circuits. The system oriented activities of this VP are carried out with the Roadmap Security. The activities related to high frequency integrated circuits are done within the context of the Roadmap Components and Circuits.

3.1.2 Contribution to the Roadmap Security

A start is made to extend the scope of the VP. In particular activities in the fields radio networks and passive sensor technologies that are of importance for the product and export position of our national industry and/or SMEs in this area are started within this VP. A revised scope and program will be in effect starting in 2016. And will contribute to the Roadmap Security.

The impact of the VP is aimed at strengthening the global leadership and competitiveness of our national defence industry and related technology suppliers. We aim to achieve this by strengthening the market and knowledge position of the national defence industry, the related industries in the supply chain hereof and of TNO respectively. To accelerate the speed of innovation is one of the major goals. We do this by consistency in joint roadmaps, an open exchange of knowledge and by increasing the scale.

The products and technologies in this domain distinguish themselves compared with others due to the nature of the defence domain. Therefore, the cooperation is crucial in a Triple Helix[1] between knowledge institutions, industries and supplying technology companies and military stakeholders (both national and European level), whereby all together at an early stage can be incurred for the development of an optimal knowledge base that innovative, trend-setting and leading the way is.

In fact, we should add to the Triple Helix definition the term ‘monopsony’ as defined by Joan Robinson in 1933[2]. After all, if there is 1 customer (in our field of work the

[1] The concept of the Triple Helix of university-industry-government relationships initiated in the 1990s by Etzkowitz (1993) and Etzkowitz and Leydesdorff (1995), encompassing elements of precursor works by Lowe (1982) and Sábato and Mackenzi (1982), interprets the shift from a dominating industry-government dyad in the Industrial Society to a growing triadic relationship between research-industry-government in the Knowledge Society.

[2] In 1933 in her book The Economics of Imperfect Competition, Robinson coined the term "monopsony," which is used to describe the buyer converse of a seller monopoly.

Royal Netherlands Navy), and there are multiple providers, there has been a monopoly customer. If you fill out the Triple Helix Government role from that point of view, or form the point of view as a launching customer, then it is clear that the only appropriate success formula to increase the earning power of The Netherlands in this technology domain (after all one of the main objectives of HTSM policy) is a formula like *Platform Nederland Radarland*.

3.1.3 Contribution to the Roadmap Components and Circuits

TNO has a long standing world class position in the area of the design of monolithic microwave integrated circuits (MMICs) which forms an important part of this VP and are embedded in the Roadmap Components and Circuits. These MMICs are crucial components in all kind of systems that receive or transmit RF energy, like communication systems and radar systems. The activities in the Roadmap Components and Circuits are focused on the design and realization of MMICs on GaAs, GaN and SiGe technologies. In particular for the development of the new generation of Active Electronic Scanning Area radars (AESA radars, also referred to as phased-array radars). MMIC technology has a major impact on cost, functionality and performance of these systems. Our ambition is to act as the number one fabless design house for advanced highly integrated MMIC circuits.

3.1.4 Program and results 2015 for the Roadmap Security and the Roadmap Components and Circuits

Three types of activities are carried out in 2015:

- Sponsored contracts with Dutch defence industry and SMEs.
- Contracts of the European Defence Agency carried out together with Dutch defence industry and other EU defence industries and knowledge institutes.
- Contracts within the scope of national funded programs (FES) and regional funded programs (EFRO) carried out with national industry, national universities and SMEs.
- Contracts within the European Joint Undertaking EXCEL and the European EUREKA program CATRENE.

TNO has in the context of D-RACE a very close cooperation with Thales Netherlands. D-RACE steers actively on the implementation and progress in the Roadmap Radar and Integrated Sensor Suites that is detailed until 2016. In the ecosystem that is emerging around D-RACE we see as increasingly important parties NXP, the Centre or Array Technology (CAT) of the University of Twente and Delft University of Technology. Running sponsored programs include the development of GaN amplifiers with the world's highest reported output power (GaNS) and the development of advanced GaAs HEMT transistor layouts to reduce the size of MMIC circuits while maintaining its performance STRICT). For protection, integrated limiters with receivers were developed that show unprecedented protection levels, up to very high power levels within a 1x1 mm2 integrated circuit. The technology base was chosen to be SiGe BiCMOS for reasons of receiver robustness and linearity SiLC. Progress is made to establish a robust SiGe supply

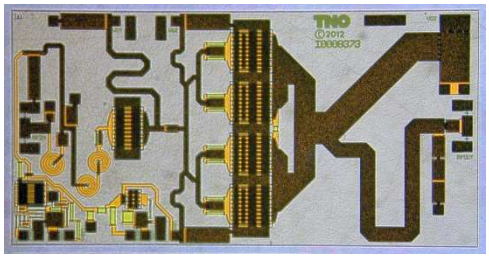


Figure 1: a GaN power amplifier from the GaNS project.

chain and to make the SiLC technology worldwide available through a licensing agreement with semiconductor industry.

Within the framework of STARS, a running FES project, we cooperate with Thales Nederland, NXP, RECOR, TU Delft and the University Twente. STARS is aimed at reconfigurable sensors for national security. Reconfigurable sensors are a trend that we picked up in The Netherlands about 6 years ago and which is only just recently addressed by a DARPA program in the US. STARS is a good example of the innovative nature of this Roadmap and its spin-off to other economic and social sectors. Examples are: beamforming and filter techniques for telecom and multi-core and network-on-chip technology for space. Within STARS fully integrated SiGe receivers are developed and manufactured. STARS boosted across a broad front the knowledge building by a highly multidisciplinary approach. A STARS event was organized on March 31st, 2015 in "De Munt" in Utrecht, and included next to presentations about 70 posters and demonstrations of the various research topics.

Figure 2: a Concept Development and Assessment Game played in STARS for optimal sensor planning, resource allocation and QoS in a harbor scenario.

In the context of DAISY, another great national project funded in this Roadmap by regional structural funds, we worked together with NXP, Thales Netherlands, various technical universities and SMEs. DAISY focuses on the next generation miniaturized but also affordable sensor modules. DAISY is a good example of the social relevance of this VP. The knowledge becomes through the participating of SMEs also available in other sectors on the market. Within DAISY integrated SiGe transceivers are developed and manufactured. DAISY ended in 2014, but activities are carried out in 2015 to define a follow-on program from 2016 onwards.

As a result of both STARS and DAISY we see an increasingly more important role of national industries and universities: NXP is the only Dutch manufacturer of high-frequency integrated circuits and is an increasingly important player as a developer of unique and thereby crucial and strategic technology. We work together with all 3 Technical Universities. Mostly is the cooperation in the Roadmap in the form of regular STW projects, or through the special STW HTSM calls. The relevant chairs of these universities are seen from the perspective of the Roadmap as a provider of long-term scientific knowledge and to address new promising developments in an early stage.

In the framework of the European Defence Agency we partner with almost all major European defence companies and RF semiconductor manufacturers such as UMS, OHMIC, Thales, SAGEM, SELEX, SAAB, AIRBUS etc. and with research companies like FOI in Sweden, Fraunhofer in Germany, II-V labs in France etc.
A long running activity on the development of a European infrastructure on technology and products in the field of high-efficiency high-power GaN amplifiers (MAGNUS) is completed in 2015.
In the field of enabling technologies for active electronically scanned arrays we partner in the project SWAP-C. SWAP-C on the development of new transmitter architectures that enable significant cost reduction of transmit/receive modules for future phased array radars. In the field of early detection of small airborne targets, which are considered as an upcoming terroristic threat, we are a partner in the ACACIA project. ACACIA is a 3-year project starting in 2014 that will focus on emerging waveforms, signal processing and feature-based classification

techniques. ACACIA provides research applications of micro-Doppler and compression sensing for detection, identification and classification of small airborne targets.

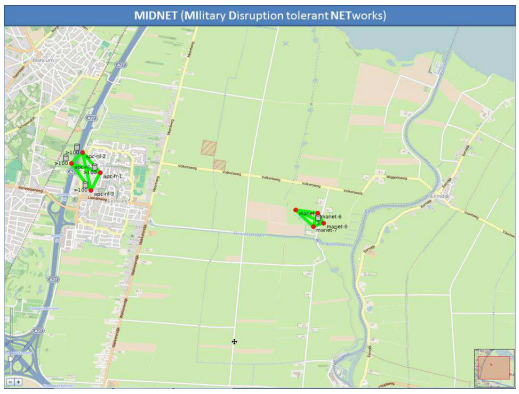


Figure 3: various (military) vehicles that form ad-hoc networks. By different circumstances the vehicles apart and yet form another ad-hoc network.

In the field of military disruption tolerant radio networks we are partner in MIDNET, MIDNET is on robust routing-concepts for distribution of data/information on military radio networks, in a mobile, wireless disruptive environment to improve network performance.
Above activities are fully aligned with the Strategic Research Agendas of the European Defence Agency (EDA), in particular in the fields of radar (EDA CapTech Radio-Frequency Sensors Technologies), miniaturized electronics (EDA CapTech Components) and Electro-optical systems (EDA CapTech Electro-Optical Sensors Technologies). These Strategic Research Agendas of the EDA are partly initiated and set up from above mentioned Roadmaps.
Within the scope of EXCEL and CATRENE we partnered in 2 contracts in 2015: EXIST and EAST. EXIST is an EXCEL contract on research into new technologies for CMOS image sensors that are needed in the next generation of the various applications. EAST is a CATRENE contract on defining, researching and demonstrating signal generation and distribution in array antennas.

3.1.5 Overview cooperations

The various cooperations in this VP are mentioned in detail in the chapter above.

A start is made in 2015 with the definition of a 3-year TKI program. The goal of this program is to enable high-power transmitters, including driver chains and phase control, for future radar sensors. Expected partners are Thales Nederland BV, NXP and UMS in France. The program aims at researching the integration of all relevant factors in a power line-up, including the passive combination technologies, the design of the power-generating microwave chips with world class extreme power levels, the driver components and the thermal issues.

4 VP Automotive Mobility Systems

4.1 Roadmap Automotive

4.1.1 Introductie

Binnen TNO Thema Leefomgeving is het VP AMS (Automotive Mobility Systems) gericht op het versterken van de concurrentiepositie van de Nederlandse Automotive- en Mobiliteitsindustrie met het Ministerie van Economische Zaken (EZ) als regievoerder. Het VP AMS sluit daarmee rechtstreeks aan op de Roadmap van de TKI HTSM Automotive.
Het VP AMS richt zich vooral op het ontwikkelen van innovatieve oplossingen voor het verbeteren van de voertuigveiligheid, zuiniger en schoner maken van voertuigen en verbeteren van de duurzaamheid, efficiëntie en betrouwbaarheid van het verkeer.
Hierbij wordt intensief samengewerkt met de Nederlandse en de internationale automotive industrie.

4.1.2 Programma 2015

Het VP AMS is onderverdeeld in een aantal samenhangende deelprogramma's:

- *Automated Driving*: ontwikkeling van oplossingen voor voertuigautomatisering t.b.v. veiliger, schoner en meer efficiënt verkeer.
- *Cooperative Mobility*: ontwikkeling van oplossingen voor verbeterde veiligheid en efficiency van het verkeer d.m.v. V2X communicatie.
- *Low Carbon HD Transport*: ontwikkeling van oplossingen voor reductie van CO2 uitstoot van commerciële voertuigen in het verkeerssysteem.

Binnen deze deelprogramma's wordt gefocust op oplossingen voor specifieke klanten en markten in zgn. PMCs. Door expliciet een koppeling met een beoogde toepassing en markt te maken wordt meer focus verkregen in de kennis en technologie ontwikkeling. Bedrijven en andere stakeholder uit de markt worden zo vroeg mogelijk in de ontwikkeling van de oplossing betrokken.

Het Vraagsturingsproces is vooral ingericht door actieve participatie in het roadmapteam van de TKI HTSM Roadmap Automotive.
Dit roadmapteam, onder voorzitterschap van AutomotiveNL, is samengesteld uit vertegenwoordigers van de bedrijven en kennisinstellingen die samenwerken in het Automotive TKI programma van HTSM. Het roadmapteam is verantwoordelijk voor opstelling en actualisatie van de TKI HTSM Automotive Roadmap en borgen dat deze gedragen wordt door haar stakeholders. Het roadmapteam initieert eventueel initiatieven voor TKI grondslag of –toeslag projecten en beoordeelt of projectvoorstellen passen op de TKI Roadmap en adviseert daarover aan de roadmaptrekker.
In 2015 is de TKI HTSM Automotive Roadmap geactualiseerd onder regie van AutomotiveNL (http://www.hollandhightech.nl/nationaal/innovatie/roadmaps/automotive).
TNO heeft actief bijgedragen aan deze actualisatie. Het programma in het VP AMS sluit naadloos aan op de focus gebieden Green en Smart Mobility in deze Roadmap.

4.1.3 Resultaten

Het onderzoek binnen het VP AMS is gefocusseerd op de ontwikkeling van oplossingen ten behoeve van specifieke product markt combinaties (PMCs). Met deze focus sluit het VP onderzoek aan op de concrete behoefte van haar

(industriële) stakeholders. De resultaten van het programma in 2015 worden hieronder samengevat per PMC/Product line.

Automated Driving

Next Generation AGV (Automatic Guided Vehicle)

Ontwikkeling en implementatie van slimmere AGVs. Deze AGVs zijn ondersteund door V2X communicatie en worden bestuurd vanuit een gedistribueerd control concept. Er wordt gewerkt aan een stapsgewijze transitie naar een grid-loze operatie van AGVs.

- Strategische samenwerking met een grote industriële partner (AGV fabrikant).
- Het Europese project CargoANTs bevind zich in een afrondende fase richting demonstratie (medio 2016). TNO's innovatieve besturingssoftware is getest op een TNO test platform (auto) omdat een AGV helaas nog niet beschikbaar was.
- Een AGV wereld model is verder ontwikkeld geïntegreerd in het TNO iVSP test platform.

Car technology

Ontwikkeling van efficiënte test methodologie, validatie en certificering ondersteund door een real-life scenario database. Daarnaast wordt gewerkt aan adaptieve automatische voertuigfuncties (incl. bestuurderstoestand en bestuurdersprofiel schatting en voertuig toestandschatting).

- Strategische samenwerking met industriële partijen o.g.v. real-life safety assessment.
- In EU project AdaptIVe zijn voorbereidingen gemaakt voor in-traffic evaluatie van automatische voertuigen functies.
- In EU project EMC^2 is het TNO iVSP platform uitgebreid met een real-time sensor laag, een fietser tracker en een scenario classificatie voor fietsers.
- In SRE project Pre-automated driving zijn een test methodiek en instrumentatie ontwikkeld. Dit heeft onder ander bijgedragen aan de demonstratie van automatisch rijden aan Koning Willem Alexander.
- Marktstudie naar de state-of-the-art in gebruik van big data en een literatuur studie naar machine learning technieken voor toepassing in automatisch rijden.
- Samen met het TNO Enabeling Research Programma 'Complexity' is geïnvesteerd in het EU project Chrystal. In dit project zij eerste concepten voor ICT infrastructuur, methodieken en algoritmes voor grootschalige data collectie en verwerking naar relevante scenario's voor automated driving ontwikkeld.
- Samen met het TNO Enabeling Research Programma 'Human Enhancement' is onderzoek gedaan naar transition of control en is een eerste rijstijl classificatie algoritme ontwikkeld.

Truck Platooning

Ontwikkeling en commerciële implementatie van 2-truck platooning in Nederland.

- EcoTwin demonstratie op N270 samen met DAF. Zie paragraaf 1.3.1.
- TKI project gestart voor verdere doorontwikkeling van EcoTwin concept samen met DAF, NXP en Ricardo.
- Strategische rol in Europese truck platooning challenge geborgd.
- Een adaptief Safety concept is ontwikkeld.
- Ontwikkeling van een methodiek voor de safety case die demonstratie van automatisch rijden op de openbare weg toelaatbaar moet maken.
- Een nieuw wereldmodel framework voor truck platooning is ontwikkeld en geïmplementeerd.

Public Transport
Uitrol van automatisch rijdende bussen en trams op basis van een gelimiteerde ondersteuning vanuit de infrastructuur.

- Eerste demonstratie van een people mover.

Cooperative mobility
Architecture
Ontwikkeling van een high level architectuur voor cooperative mobility systemen a.d.h.v. een aantal concrete (SpitsLive) use cases.

- Activiteiten zijn gestopt nadat SpitsLive niet door ging.

Wifi-p upscaling
Onderzoek naar zendbereik van antennes in specifieke use cases en problemen en oplossingen voor Wifi-P congestie.

- Onderzoek naar een multi-channel aanpak voor het mitigeren van congestie problemen in zeer drukke scenario's (door creëren van extra kanalen).

Security
Ontwikkeling van een security concept voor diensten die communiceren via in-car systemen, hand held devices en road-side infrastructuur.

- Identificatie van relevante security mechanismen in twee coöperatieve use cases (Groene golf en File schokgolf demping).
- Onderzoek naar security van over-the-air firmware updates voor veiligheid kritische algoritmes.

Standardization
Ontwikkeling van Nederlands voorstel voor standaardisatie van een Wifi-p gebaseerd systeem/netwerk profiel (op basis van ETSI standaard).

- Een eerste concept voor een profile is gerealiseerd en heeft geleid tot een DITCM project om dit verder uit te werken tot een voorstel voor een Nederlandse standaard.
- Monitoring van de activiteiten bij Car2Car consortium m.b.t standaardisatie.

Services
Ontwikkeling van een rijstrook/snelheid advies en een schokgolf demping applicatie.

- Een prioriteiten manager voor de bestuurder is ontwikkeld en in 7 (SpitsLive) use cases getest.
- De rijstrook/snelheid adviseur is verder door ontwikkeld en gekoppeld met NDW en Flitsmeister data. Algorithme is in Android app geïmplementeerd en getest in de omgeving van Delft.
- Benchmarking van vergelijkbare commercieel verkrijgbare applicaties.

Intelligente fiets
Door het coöperatief maken van fietsen wordt verwacht dat er significante verbetering van fietsersveiligheid kan worden bereikt door auto's en infrastructuur beter te laten anticiperen op het gedrag van fietsers en fietsers beter te informeren.

- Testen met een achteruitkijk assistent zijn succesvol afgerond.
- Een vooruitkijk assistent bleek niet geschikt voor het detecteren van obstakels, dit concept zal worden aangepast.

Low Carbon HD Transport
Real World Performance

Oplossingen en tools voor het verbeteren van real-world brandstofverbruik en emissies van heavy duty voertuigen.

- In TKI project 'Next Generation Aftertreatment' is de validatie van de TNO aftertreatment modellen op een prototype van DAF uitgevoerd. Verder is er overeenstemming met de partners over de inhoud van het laatste werkpakket.
- Een door TNO gesponsorde AIO is aan de TU/e gepromoveerd op het onderwerp Autocalibratie toegepast op een Waste Heat Recovery systeem. Deze AIO is bij TNO in dienst gekomen.
- Validatie van het DYNAMO+ multipulse verbrandingsmodel is gedeeltelijk uitgevoerd. Het zal in 2016 worden afgerond o.b.v. gemeten data uit het TKI advanced combustion project.
- Voor de virtuele NOx schatter is een nieuwe aanpak geïmplementeerd in Matlab/Simuling met een kleinere memory footprint.
- Voor Integrated Emission Management is een uitbreiding van bestaande (2 dimensionale) optimalisatie concept naar n-dimensionaal concept gerealiseerd waardoor naast VGT en EGR ook bijvoorbeeld injectie tijd en –druk meegenomen kunnen worden in de optimalisatie. De algoritmes zijn gevalideerd tegen verschillende real-world cycli. Validatie in de Hoogte Klimaatkamer is niet uitgevoerd vanwege beschikbaarheidsproblemen.
- In het project Dosing Controls 2.0 is onderzoek gedaan naar HC vergiftiging. Het DOC model is uitgebreid met bijbehorende reactie kinetiek en een fit procedure is ontwikkeld. De SCR dosing control is uitgebreid met een algoritme voor correctie van kruisgevoeligheid tussen NOx sensor op NH3.

Flex Fuel Controls

Controls oplossingen voor reductie van brandstofverbruik (door verhoging van het verbrandingsrendement) en voor verdere verlaging van CO2 uitstoot (door toepassing van low-carbon fuels).

- Een nieuw XCCI model is ontwikkeld dat aangepast kan worden voor elk toekomstig verbrandingsconcept. Het model is gekoppeld aan het DYNAMO motormodel en is compatible met SIMULINK. Validatie van het model is nog niet afgerond.
- Bovenstaand model is gebruikt voor ontwikkeling van een multivariabele controller voor RCCI en geïmplementeerd en getest op de motor.
- De virtuele cilinderdruksensor is verder ontwikkeld zodat het met standaard productie motoren kan omgaan (60 i.p.v. 720 pulsen per omwenteling. Het algoritme is geïmplementeerd en getest in een real-time FPGA rapid prototype omgeving.
- Het TKI project Advaced Combustion is gestart (samenwerking met DAF en Sensata). Het motor ontwikkelplatform is gespecificeerd, gerealiseerd en geïnstrumenteerd. Er is een control architectuur ontwikkeld. De bestaande TNO NOx schatter is verder ontwikkeld richting embedded code.
- Twee verkennende studies zijn uitgevoerd. Eén naar de mogelijkheid om een standaard klop sensor te gebruiken voor closed-loop combustion control (i.p.v. cilinderdruksensor) en één naar concepten voor hoge efficiëntie methaan conversie ter voorkoming van methaanslip.

Predictive Powertrain Controls

Controls oplossingen voor optimaliseren van energiemanagement in het voertuig door toepassing van voorspellende informatie over route, verkeer, bestuurder, etc.

- In het EU project ConVENienT is het testen van de DAF motor in de Klimaatkamer uitgesteld naar 2016.

- In het EU project Transformers is een structuur om simulaties uit te voeren aan complexe voertuigcombinaties ontwikkeld en zijn eerste simulaties uitgevoerd (samen met ViF). TNO heeft een aangepaste communicatie naar de trailer geïmplementeerd in een DAF truck. TNO heet de rol van Daimler in het project overgenomen en heeft hiervoor een testplan opgeleverd. Het project wordt verlengd en activiteiten voor traffic simulaties zijn uitgesteld.
- In het EU project EcoDriver is een algoritme ontwikkeld dat motorvermogen en schakelen van de transmissie automatiseert op basis van de EcoDriving profielen en rijgedrag van de bestuurder met als doel de minimaal brandstofverbruik te realiseren binnen de acceptatiegrenzen van de bestuurder.
- In het EU project Amber zijn batterij testen van het voertuigje afgerond in het nieuwe TNO klimaat kabinet.
- Een TNO senior scientist werkt één dag per week aan de TU/e als assistent professor waar hij onderzoek doet naar batterij gedrag en energie management van elektrische aandrijving.
- In het TKI project E3Bus werkt TNO samen met VDL bus&coach en Heavac aan energiemanagement van elektrische bussen.
- Een Markov stochastisch predictive methode voor cycle prediction is ontwikkeld en in Simulink geïmplementeerd. Het algoritme is gebenchmarkt tegen niet-predictive methodes. Een predictive energiemanagement dat dit algoritme gebruikt is ontwikkeld en ontworpen voor de hybride DAF-LF en voor een elektrische bus. Evaluatie van de energiereductie door toepassing van deze algoritmes is gedaan via een model-in-de-loop simulatie.

4.1.4 Overzicht samenwerking

Samenwerking binnen de Topsectoren

Het VP AMS focusseert zich volledig op een onderzoeksprogramma dat past binnen de ambitie van het TKI HTSM Automotive. De drie deelprogramma's sluiten op de volgende wijze aan op de Roadmap van het TKI:

Automated Driving

Dit deelprogramma sluit aan bij de trend in de automotive sector dat steeds meer voertuigfuncties geautomatiseerd worden en dat voertuigen tijdelijk of in de toekomst zelfs voor langere tijd geautomatiseerd kunnen rijden. TNO richt zich in dit programma vooral op technologie en randvoorwaarden die (coöperatief) automatisch rijden mogelijk maakt en op wat dit betekent voor de bestuurder en voor andere (kwetsbare) weggebruikers.
In 2015 is een eerste concept voor truck platooning gedemonstreerd. Hiervoor is intensief samengewerkt met DAF en RDW. De focus in het TNO programma ligt op (hoog)dynamisch maneuvreren en volgen, veiligheid van kwetsbare verkeersdeelnemers, effecten op de bestuurder van (automatisch) ingrijpen, robuuste controls met als doel het versnellen van de implementatie van automatisch rijden.

Cooperative Mobility

Coöperatieve Mobiliteit is al langer een speerpunt van TNO. Samen met 3TU is TNO verantwoordelijk voor de uitvoering van het DITCM programma. TNO richt zich in het automotive programma vooral op toepassingen van communicatie die direct de voertuigveiligheid en doorstroming verbetert. Dit zijn vaak tijd kritische toepassingen die direct ingrijpen in veiligheidssystemen in het voertuig.
In 2015 zijn een aantal projecten uitgevoerd die aansloten op de ambitie voor de PPS SpitsLive dat helaas niet is doorgegaan. De onderwerpen zijn echter nog

steeds zeer relevant en zullen direct worden toegepast in andere projecten binnen Beter Benutten, Connecting Mobility en in samenwerking met provincies.

Low Carbon HD Transport
Nederland heeft een sterke transport sector met belangrijke OEMs en toeleveranciers in trucks, bussen en speciale zware voertuigen en een sterke logistieke sector. Dit deelprogramma richt zicht op reductie van de CO2 uitstoot in het (integrale) transport systeem.
In 2015 is een belangrijke mijlpaal bereikt in de demonstratie van de haalbaarheid van het dual fuel (diesel-gas) RCCI concept en wordt er in TKI verband samengewerkt aan energiemanagement voor elektrische bussen en geavanceerde verbrandingstechnologie voor HD dieselmotoren.

Samenwerking met Nederlandse universiteiten
De bestaande samenwerkingsverbanden van TNO met diverse Nederlandse universiteiten is in 2015 voortgezet. Belangrijkste initiatieven zijn:

- DITCM: samenwerking TNO met 3TU o.g.v. coöperatieve mobiliteit.
- DAVI: samenwerking met TUD en ander partijen o.g.v. automatisch rijden.
- ASD PDeng opleiding: 4 eindopdrachten van trainees en een in-house project.
- Afstudeerders en promovendi: TNO blijft ruimhartig opdrachten verzorgen. Dit jaar is een door TNO gesponsorde AIO gepromoveerd.
- UHD's en deeltijd hoogleraren: samenwerking wordt uitgebreid. Doel is om in elk deelprogramma een verankering bij een universiteit te borgen. Op 1 januari 2016 is TNO senior scientist Frank Willems benoemd als deeltijd hoogleraar Integrated Powertrain Control aan de TU/e.
  https://www.tue.nl/universiteit/faculteiten/werktuigbouwkunde/nieuws/06-01-2016-frank-willems-benoemd-tot-deeltijd-hoogleraar/

Nationale samenwerkingsverbanden

- TKI HTSM Automotive: in 2015 door TNO opnieuw een significante grondslag gegenereerd, vooral in contractonderzoek vanuit de internationale automotive industrie. Tevens zijn is 2015 twee nieuwe TKI projecten gestart: Advanced Combustion met partners DAF en Sensata en EcoTwin II met partners DAF, NXP en Ricardo. Ook zijn er 3 nieuwe TKI projecten in voorbereiding die in 2016 zullen starten.
- AutomotiveNL is de sectororganisatie voor de Nederlandse automotive industrie met als doelstelling het bevorderen van een bloeiend en groeiend automotive netwerk in Nederland door realisatie van een internationale automotive hotspot voor Smart Mobility en Future Powertrain. AutomotiveNL heeft een innovatieprogramma dat de inhoud van de Roadmap TKI HTSM Automotive afdekt. AutomotiveNL is belangrijke partner voor TNO in de realisatie van projecten binnen de TKI.
- DITCM Innovations is een partnership van leidende Nederlandse bedrijven, overheden en instellingen op het gebied van coöperatieve mobiliteit. Binnen DITCM Innovations wordt gewerkt aan een gezamenlijk innovatieprogramma.

Internationale samenwerkingsverbanden

- ERTRAC, the European Technology Platform for Road Transport. ERTRAC werkt aan een gemeenschappelijke Strategic Research Agenda, waaraan TNO ook haar bijdrage levert. Andere NL partners zijn DVS en SWOV.
- iMobility (vroeger genaamd eSafety) forum. Deze groep werkt aan een gemeenschappelijke Strategic Research Agenda op het gebied van mobiliteit.

- EARPA, vereniging van Road Transport R&D Providers. Vanuit TNO wordt secretariaat ingevuld en heeft de programma directeur mobiliteit en logistiek zitting in de board. Focus ligt op automotive RenD. TNO is trekker en heeft key posities in de meeste Task Forces. Verder vindt hier consortiumvorming voor EU-projecten plaats.
- EGVIA, the European Green Vehicles Initiative Association is het samenwerkingsverband van Europese bedrijven en kennisinstellingen op het gebied van schone voertuigtechnologie. TNO participeert actief in EGVIA in het voorbereiden (en uitvoeren) van pre-competitief Europese onderzoek.
- ERTICO ITS Europe is een multi-sector, Public Private Partnership die zich richt op de ontwikkeling en implementatie van Intelligente Transport Systemen. TNO is lid van dit partnership. Met ERTICO worden regelmatig projectvoorstellen in het EU Kaderprogramma geschreven.

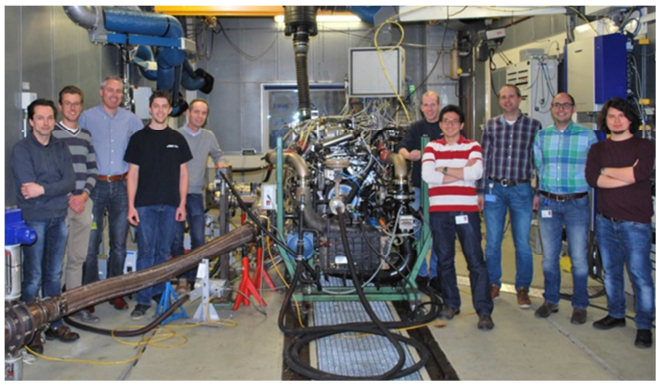
In 2015 participeerde TNO binnen VP AMS in een 22 Europese projecten binnen het Europese onderzoeksprogramma. In deze projecten wordt samengewerkt met een groot aantal internationale partners.

Topsector HTSM Roadmaps Automotive
Het VP AMS is nauw aangesloten bij de Automotive Roadmap binnen HTSM.
TKI HTSM Automotive: In 2015 is ruim 10 M€ grondslag gegenereerd door TNO vooral in contractonderzoek vanuit de internationale automotive industrie bij TNO. Tevens zijn is 2015 twee nieuwe TKI projecten gestart: Advanced Combustion met partners DAF en Sensata en EcoTwin II met partners DAF, NXP en Ricardo. Ook zijn er 3 nieuwe TKI projecten in voorbereiding die in 2016 zullen starten.

Hoogtepunten 2015
EcoTwin
DAF en TNO zijn een samenwerking aangegaan om, binnen 5 jaar, het concept van 2-truck platooning technisch mogelijk te maken en om toestemming te verkrijgen om hiermee te rijden op het Nederlandse wegennet. Dit doel zal stapsgewijs worden bereikt door jaarlijks meer functionaliteit aan het concept toe te voegen en het in steeds complexere situaties toe te passen. Er zal worden samen gewerkt met belangrijke technologie partners op het gebied van ontwikkeling en testen van de nieuwste technologie en partners worden betrokken voor niet-technische uitdagingen.
In 2015 is het zogenaamde Follow-Me EcoTwin2 ontwikkeld en gedemonstreerd. Het project heeft als doelstelling om automatisch rijden op SAE level 3 te demonstreren. De activiteiten concentreren zich op de benodigde sensoren, stabiele regel algoritmes voor aandrijving en sturen van het voertuig en functies voor automatisch volgen. Bijzondere aandacht gaat uit naar het betrouwbaar, veilig en foutbestendig en fail-safe maken van de technologie en de hiervoor benodigde methoden, modellen en tool development.

http://www.daf.com/en/news-and-media/articles/global/2015/q1/27-03-2015-daf-and-tno-demonstrate-ecotwin#

Flex Fuel
Het Flex Fuel Control team werkt aan geavanceerde verbrandingsconcepten die een dieselmotor in een zeer efficiënte en schone verbrandingsmodus op een mengsel van twee brandstoffen laat lopen: Reactivity Controlled Compression Ignition (RCCI). Hierbij wordt met een klein beetje diesel (<10% totale energie) een mengsel van aardgas ontstoken. Dit concept is gebaseerd op gecontroleerde zelfontsteking en is uiterst gevoelig voor bedrijfscondities zoals temperatuur en kan met meerdere brandstoftypen (inclusief biobrandstoffen) overweg.
De ontwikkelde verbrandingsconcepten en modellen van de afgelopen 3 jaar zijn geïmplementeerd op een motor. In een strategisch samenwerking met een grote fabrikant van vrachtwagens zijn deze verder geoptimaliseerd. Met de motor demonstratie van het RCCI concept is een belangrijke milestone behaald. We hebben hiermee aangetoond dat de technologie onder reële omstandigheden goed functioneert en de uitstoot van CO2 met maar liefst 20 procent afneemt. Hierbij is geen NOx uitlaatgasnabehandeling meer nodig is.
Als een cruciale stap richting introductie op de weg gaan we komende jaar laten zien dat het concept ook in extremere omstandigheden werkt. Hierbij spelen recente ontwikkelingen een belangrijke rol: TNO's innovatieve cilinderdruk gebaseerde regeling bepaalt per verbrandingscyclus de optimale brandstofmix. Deze regeling maakt gebruikt van real-time model informatie: zgn. virtual sensors.



Energiemanagement voor elektrische bussen
In een TKI project is het beheersen van het binnenklimaat van een elektrische bus een geïntegreerd onderdeel gemaakt van het energiemanagement van de bus. Omdat geen restwarmte van een verbrandingsmotor beschikbaar is voor

verwarming van het bus interieur, moet bij een elektrisch bus elektrische energie van de batterij worden gebruikt worden voor verwarming (of air conditioning). De belasting op de batterij voor klimaatbeheersing kan hierbij oplopen tot meer dan 50% van de beschikbare elektrische energie.
Door het slim managen van de energiestromen voor binnenklimaat en door het anders aanbieden van warmte aan de passagiers kan meer dan 20% energie (en daarmee batterijcapaciteit) worden bespaard.
TNO werkt in een TKI project samen met VDL bus en coach en Heavac aan dit innovatieve concept.

5 VP Human Health

5.1 Roadmap Nanotechnology

5.1.1 Introduction

Large expectations surround the potential for manufactured nanomaterials to be key elements in the development of innovative materials, products and applications. Manufactured nanomaterials are already produced in large amounts and it is expected that in the next decades numerous new nanoproducts will enter the market every year. For companies it is important to produce sustainable products and comply with the Regulations. However, there is still a great uncertainty to perform a proper risk assessment of manufactured nanomaterials and nanomaterial-enabled products due to the small sizes of the materials. The current exposure limits of conventional materials cannot be easily translated to manufactured nanomaterials and the continuous development of new nanomaterials asks for suitable models that are able to assess the risks of nanomaterials over the complete life cycle.

5.1.2 Program 2015

To assess the risks of the nanomaterials currently on the market, as well as the next generation of nanomaterials, TNO focused their research on the following topics:

1) User friendly tools for industry and SMEs to help companies to support safe innovation and compliance with the regulations.
2) Quantitative models for risk assessment. To reach this goal, there should become available sufficient data for nanomaterials gathered in a harmonized way.
3) An approach to assess the risks over the complete life cycle in various stages of the development process.

By knowing the risks of MN over the whole life cycle and having user friendly tools, the human health of the worker, consumer and generic population can be adequately assessed. This will be an enabler for safe innovation.

The activities of VP Human Health RM Nano consisted of various EU projects and 1 National Project.

Table 1: EU projects of VP Human Health Risks Nano

EU project	Period	Website
NANoREG 1	Apr 2013 - Mar 2017	http://nanoreg.eu/
NanoReg2	Sep 2015 - Aug 2018	Under preparation
GUIDEnano	Nov 2013 - April 2017	http://www.guidenano.eu/
SUN	Nov 2013 - Oct 2017	http://www.sun-fp7.eu/
Marina	Nov 2011 - Oct 2015	http://www.marina-fp7.eu/
FutureNanoNeeds	Jan 2014 - Dec 2018	http://www.futurenanoneeds.eu/
NanoSolutions	Apr 2013 - Mar 2017	http://nanosolutionsfp7.com/
Nanofase	Sep 2015 - Aug 2019	http://www.nanofase.eu/
NanoNextNL	Jan 2011 - Dec 2016	http://www.nanonextnl.nl/

5.1.3 Results

In view of briefness the highlights are described for a selected number of projects.

User friendly models and tools for industry

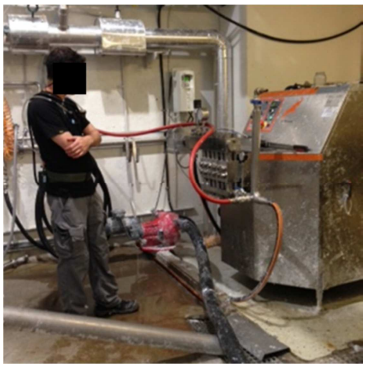
As follow up of the LICARA project in 2014, TNO developed in collaboration with Empa a web-based tool to assess the benefits and risks of nanomaterials over the life cycle, i.e. LICARA nanoSCAN (https://diamonds.tno.nl/licara). This qualitative/semi-quantitative tool is unique because it is scanning both the benefits and risks over the nanoproducts life cycle in comparison to a reference product with a similar functionality in order to enable the development of sustainable and competitive nanoproducts. The LICARA nanoSCAN is incorporated as a first tier tool in the SUN Decision Support System tool to assess the benefits and risks of nanoproducts. Within SUN data are generated to give input to a tier 2 of the decision support system tool which will be based on quantitative risk assessment.

Within NanoREG, a database is developed which is searchable for physical/chemical properties, system biologic effects and the toxicity of nanomaterials in a consistent way to predict the safety of existing and future nanomaterials. This database consists of 1387 peer reviewed entries of literature at this moment.

Case studies

Within FutureNanoNeeds, a framework is developed to determine the main release sources with potential for exposure (*i.e.* hot spots or focal points) at the different steps of the nanomaterials value chain for the next generation of nanomaterials. For 6 case studies the focal points are determined in the following value chains (1) perovskites in energy harvesting, (2) boron doped silicon in energy harvesting, (3) silicon nanowires in energy storage, (4) fullerenes and graphene flakes in lubricants, (5) nanocomposities in thermoelectric generators, and (6) quantum dots in display screens. The results of the case studies are for restricted use.

Within GUIDEnano the exposure of workers to nanomaterials was assessed for 8 cases studies. The data will be used for improving current exposure models. For the case studies that includes spraying the likelihood of exposure is in most cases likely. However, it depends on the exposure scenario as for 1 scenario with automatic spraying the exposure likelihood was unlikely. Details about the case studies are described in the report D4.2: interim report on refinement of exposure estimates to be incorporated in GUIDEnano Tool v2 based in generated data and harvested information and are at this moment for restricted use.



A comprehensively-monitored nanoparticle exposure experiment inside a large climate-controlled chamber at Danish Technical University was conducted in a joint experiment in the frame of the NANoREG project in collaboration with the SUN project. Experimental data on spatial and temporal distributions of manufactured nanoparticles have been collected with high resolution under controlled conditions, varying emission patterns, ventilation rates and particle composition. The data will be used to test the quantitative exposure models and so will enable estimation of the accuracy and uncertainty of the predicted concentrations. The level of control and understanding of these experimental scenarios is studied by means of

advanced 3D-CFD simulations that allow extrapolation of experimental sampling data in time, space and particle size distribution.

5.1.4 Overview cooperations

This VP has a lot of interaction with European universities, research institutes and industry via the EU projects. In 2015, 4 new EU projects NanoREG2, Nanofase, NanoSTreeM (started January 1st, 2016), Calibrate (under negotiation, start May 1st, 2016) were granted.

The exposure and release testing methods developed within NanoNextNL are published in 2015 and those are incorporated in CEN standards to support harmonization of the measurements on workplace exposure(WI 137052, WI 137053, WI 137056 and WI 137057-061).

Dutch stakeholders are informed via the Dutch NanoCentre (www.nancentre.nl) and KIR nano about relevant results from the project. In addition, the developed methods are applied in B2B projects.

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Presentation list

(1) Henk Goede et al. Framework to forecast exposure of the next generation of nanomaterials, SENN, 12-15 April 2015, Helsinki, Finland.

(2) Invited speaker, Tom Ligthart, Life Cycle approaches for nanotechnology-based products, SETAC, 3-7 May 2015, Barcelona, Spain. The results of Task 3.6 were presented.
(3) Thies Oosterwijk, The TNO-NANoREG Database for Safe by Design, EuroNanoForum, June 2015, Riga, Letland.
(4) Wouter Fransman (TNO), Eef Voogd, Derk Brouwer, Evaluation of Nano Exposure Models, SUN-SNO-GUIDENANO Sustainable Nanotechnology Conference, 9-11 March 2015, Venice, Italy.

6 VP Space and Scientific Instrumentation

6.1 Roadmap Space

6.1.1 Introduction

Space technology plays a crucial and unique role in our daily life. Navigation, Telecommunication, Earth Observation and Scientific satellites form the backbone of many integrated applications and services. The focus of VP Space is on areas where TNO has a strong heritage (e.g. optical and radar instruments for earth observation and the ESA science program), and on areas in which TNO has license to operate based upon a very strong technical background obtained in different fields (e.g. laser communication). Being active in the space domain for more than 50 years, it is TNO's ambition to remain one of the core institutes in The Netherlands that is committed to the strong Dutch space heritage. We will do so by strategic collaboration with strong (Dutch) partners (academia, institutes and industry) aiming at a strong international position for the Dutch space ecosystem and healthy business in the areas of world-class instrumentation and demand driven downstream applications.

6.1.2 Program 2015

It is our vision that the worldwide space activities will become more commercial instead of mainly institutional. I.e., we will see more small projects/satellites/instruments for new (commercial) organizations apart from institutional, big projects/instruments/satellites. Partnership networks will grow from mainly European to genuinely worldwide. However, the Dutch ecosystem should work even closer together in order to become a strong player in the international highly competitive field.

It is the ambition of TNO to continue to develop instruments and systems that can be manufactured and sold by the national space industry (if possible on a recurrent basis). The choice of instruments we develop should be driven by market needs, which implies that there should be a strong link to the downstream area. For a strong national business case there is the need for robust data processing systems resulting in remote sensing and scientific information produced in a consistent manner on a daily basis, and applied for commercial use by the national remote sensing information industry.

The technology development program is focused at enabling a relevant contribution to specific applications (within the ESA missions, scientific facilities), in cooperation with the major scientific and industrial partners. The results will be presented at conferences, and discussed with candidate end customers and partners; strategic patent portfolios will be built up whenever that is technically possible and beneficial.

6.1.3 Results

Earth Observation

Main topics of the EO program:

- Develop new optical and radar instrument concepts, in cooperation with the relevant external partners.
- Bring key technology of future instruments to a higher Technology Readiness (TRL) level.
- Further improve accuracy and efficiency of calibration.

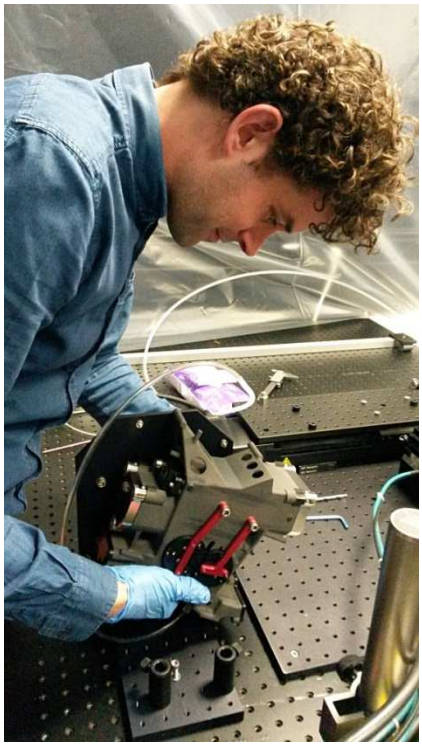
- Use the end-to-end development approach, including the combined TNO expertise: optics, optomechatronics, space systems engineering, calibration, data processing, distribution modelling, radar, control, electronics, materials.

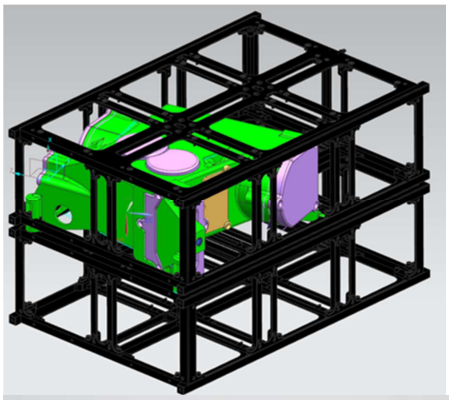
Activities:

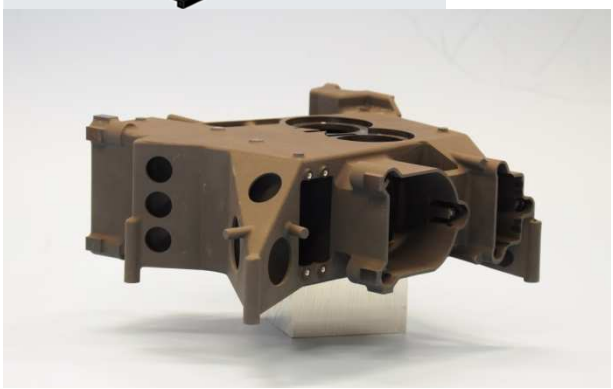
- Development of Optical Instruments; concept design, breadboarding, performance analysis, mission analysis, performance/cost trade-offs, with two tracks: technology development for the new high-performance instruments in future ESA missions for air quality monitoring, and concept design and prototyping of small instruments for small, commercial, satellites.
- Development of Radar Instruments, in preparation for ESA projects.
- Calibration: concepts for (both on ground and on board) calibration of new instruments; technology development for TNO's ARCF facility, and development of Diffusers.
- Space data utilization: development of models, and methods (e.g. OSSE's) for processing data from the new EO instruments, and for optimizing the overall performance of these air quality monitoring missions, specifically for trace gasses and aerosol detection.
- Components: mission critical components for high resolution imaging and propulsion/ignition systems.
- An incubator program enabling Quick Scans for study of technical/commercial feasibility and IP aspects of radically innovative ideas.

Results

The Tropolite instrument concept can provide a successor of the present OMI an TROPOMI instruments. In a joint study with the company ISIS, a successful Dutch nanosat SME, a small-satellite mission has been defined to provide local, region and national governments with NO_2 pollution level data with high spatial resolution. A small-satellite constellation can serve this application more cost-effectively than conventional ground based networks, because the satellite system cost can be shared by multiple regions/countries. The mission proposed here can provide data for almost all major cities on the Northern hemisphere.

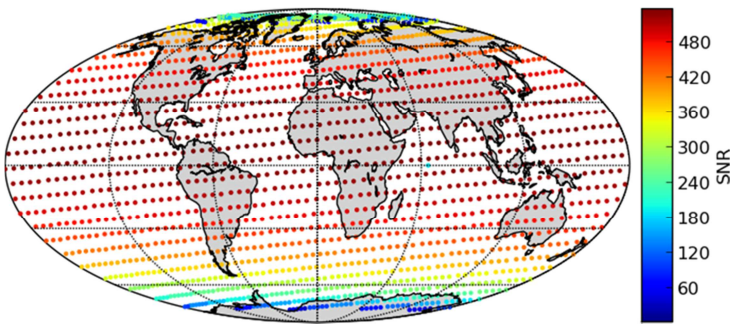






The left picture shows the assembly and test of the Tropolite protype; the tests confirmed the expected performance of the spectrometer. The upper right picture shows that the Tropolite instrument fits in a cubesat structure. The lower right picture shows the Tropolite monolythic structure produced by additive manufacturing (via the “lost-wax” method); this is the first successful demonstration of this technique for complex space structures, putting TNO in the position of forerunner in Europe. In the optical design of Tropolite a combination of freeform mirrors is applied, a unique solution depicted by ESA as an example of innovative optical instrument concepts. These results have been presented at a Smallsat conference and to ESA.

Other new design concepts for small instruments have been designed and analyzed in cooperation with scientific institutes KNMI and SRON, resulting in a superior combination of compact instruments with performance equal to or exceeding present larger instruments. Patents have been applied for most of the concepts. The graph below shows an analysis result of a CO_2 instrument, for which a requirement assessment and concept design have been performed.



For future radar missions the analysis, breadboarding and test of critical components has helped to mitigate developments risks.

The Space Data Utilization activities resulted in the start of development of Observation System Simulation Experiments (OSSEs) for aerosol instruments geared towards fine dust detection, and air quality instruments (Tropolite).
The goal of the so-called green fuel project is to verify, by means of design, production and tests, if a hydrogen peroxide fuel blend can offer a green alternative for hydrazine based space propulsion systems. Some promising fuel blend combinations have been optimized and tested.

Optical Satellite Communication
A promising possibility for Dutch industry to extend Space activities to commercial markets is to enter the market of optical/laser communication. Since optomechanical sub-systems are the core of the optical communication systems, this will enable Dutch industry to enter a market that needs optomechanical systems on recurring and commercial bases, which is attractive due to its recurring character, broad market segmentation and its growth rate.
The Dutch heritage in optomechatronical systems is judged by ESA and the European primes (e.g., Airbus Defence and Space, Thales Alenia Space, RUAG, TESAT) as state of the art for realizing high performance (e.g., highly accurate, compact/light weighted, cost effective) optical communication systems.
A first step in the area of laser communication is taken by running a joint ESA project with RUAG, Nedinsco and Meopta. In the coming years TNO will aim at increasing the Dutch contribution in this Space submarket.
In the near future there will be a need for technology for Ground terminal Downlink systems from Low Earth Orbit (LEO) as well as for VHDR (Very High Data Rate) Uplink systems. The next generation Inter-satellite Communication offers new possibilities to extend the position of TNO and industrial partners in this field.
The foreseen role for TNO is to develop the needed optomechanical systems. The foreseen role for Dutch industry, e.g. Nedinsco, is to manufacture these systems in series.

Results
The optical and optomechanical design of compact ultra-stable systems, with low straylight levels, and extreme pointing stability.

6.1.4 Overview cooperations

The space activities of TNO are undertaken in alignment with the HTSM Roadmap Space and several Roadmaps under responsibility of The Netherlands Space Office (NSO). New developments are discussed with NSO in order to align our activities with other national investments. TNO continues to cooperate with partners: scientific institutes and companies, both national and international, driven by the value chain for Space activities. The main position of TNO in this chain is to develop scientific knowledge, generated by institutes and universities, into prototypes that can be further industrialized by companies. Starting point in these collaborations is added value: we will only contribute where we can make a difference. Of course our partners should use the way of working in order to have a strong joint competitive position.
In particular, together with our partners we will try to obtain a leading role in the market of small satellites, where The Netherlands has all the knowledge and expertise to offer new business models, built upon innovative instruments, small-sat expertise and state-of-the-art downstream services. This implies that TNO should become less dependent on the institutional (ESA) market of large satellites and instruments, by venturing in the commercial market that is addressed by small satellites and so-called nanosatellites.

Recently TNO has coordinated an EFRO budget application, with partners ISIS, Airbus Defence and Space NL, VDL and S&T, for the development of a compact Remote Sensing instrument for nanosats (TROPOLITE), within the framework of the Dutch Optical Centre. Regarding the scientific aspects collaboration with KNMI has been strengthened.
TNO and TU Delft recently initiated a joint R&D centre, called the Dutch Optical Centre, mentioned above. Its mission is to strengthen Dutch businesses in optics and optomechatronics by increasing high-end production processes, with the ultimate aim to bring the Dutch business in these areas to an internationally competitive level. Collaboration with other knowledge institutes such as University Twente, TU Eindhoven, SRON, and FOM Institute AMOLF will be pursued. DOC facilitates and initiates development of commercial projects, production of (small) series of optomechatronic instruments, start-up support and co-development projects. DOC is a research centre for optics and optomechatronics where top researchers share facilities, PhD-students are educated and businesses contribute to new knowledge development.
An evaluation by ESA showed the increased need for stimulation of crossovers between Space and other HTSM Roadmaps, supported by programmatic choices for the Dutch contribution to optional ESA programs; TNO is in a very good position to support and coordinate this.

Of the three PPS projects financed and approved by the Roadmap Space of the Topstector HTSM progress is given below.

TKI Advanced Micropropulsion
The goal of this project is to develop a unique high performance propulsion system for high-end cubesats, which have e.g. optical instruments on board. This project is executed in cooperation with ISIS and Hyperion (both Dutch SME). In the project a space mission analysis has been performed, this resulted in challenging propulsion system requirements. The mission analysis has been documented in a mission analysis report. Following the mission analysis high level solution directions were compared. The arcjet solution and the advanced resistojet solutions were selected for further development in Excel based models. Based on achievable TRL within the TKI activity and to enable a short time to market, the advanced resistojet solution was chosen for further development. The selected technology potentially enables a highly compact (suitable for cubesats) high performance propulsion system which does not contaminate optical instruments of future Earth Obseravation cubesats (in contrary to other propulsion technologies). Based on the first order Excel model a preliminary design of the advanced resistojet was made in CAD. This CAD design has been transferred into a model that could be imported into Multiphysics. The advanced resistojet has been committed to Multiphysics modelling. The Multiphysics modelling showed two critical items, being the prevention of energy loss through radiation and the high temperatures of all components required to achieve the required ISP. Solutions have been found and have been verified. At the same time manufacturers have been approached and the design has been optimized to make production of all parts feasible. The system requirements push almost all parts towards the limits of manufacturability. Almost all subcomponents have been ordered and are expected to be delivered by the end of February 2016 at which time the resistojet can be assembled and tested. In parallel the test setup to be used for the TNO based evaluation test series has been designed and is now being manufactured.

TKI Innovative Propellant Production Technology
This project is performed in cooperation with Aerospace Propulsion Products (APP, Dutch SME) and focuses on three new propellant production technologies i.e.:

Resonance Acoustic Mixing (RAM), EXTRUSION and Additive Manufacturing (AM). The results so far are summarized in the following text:

- RAM: a current state-of-the-art propellant, as being used in the Ariane5 turbo pump starters, was manufactured by means of the RAM process. The propellant mixing time was reduced from 12 hours to only 12 minutes. Currently the performance of the RAM produced propellant is evaluated and compared to the classically produced propellant. In potential the RAM production technology is a very strong cost saver for propellant production.
- EXTRUSION: the extrusion activities are just started. By means of continuous mixing/production it is investigated if with a relatively small extruder large quantities of propellant can be produced without significant variation in the propellant during production. The challenge is to design the extrusion process such that the highly energetic propellant safely passes the extrusion screw. Heat development or crushing of energetic propellant components may result in ignition of the propellant during production. Extrusion may be a significant cost saving production method for industry to produce large propellant items with only a small production plant.
- ADDITIVE MANUFACTURING: within the TKI it is investigated if current state-of-the-art Additive Manufacturing (AM) technology is a viable production technology for energetic materials, especially rocket propellants e.g. for launchers. With the use of the Stereo Lithography technology a complex Gun powder geometry was successfully printed. A drawback of the Stereo Lithography method is that the viscosity of the 'ink' (liquid propellant) is relatively low. This results in the fact that the amount of solid additives to the propellant mixture is too low for a viable propellant. Currently a different AM technology is studied (deposition Layer Printing) which allows very thick propellant to print. TNO modified the propellant composition to make use of UV light to quickly cure the propellant after a layer is printed. This method is very promising and innovative. Parameters that affect the end product will be investigated as part of the study.

TKI Novel calibration approach Space Borne Spectrometers

Within the TKI "Novel calibration approach Space Borne Spectrometers" 4 research topics have been identified:

1. Diffuser calibration.
2. Use of a pulsed tunable laser light source instead of a continuous monochromator white light source for spectral calibration of the instrument.
3. Use of preflight hardware (electronics) for concurrent calibration (regression method).
4. Generation of standardized instrument characterization data.

In the last year the research for topics 2 and 4 was completed. Topic 1 was started but requires some continued work in 2016 and topic 3 was postponed due to the unavailability of the required MSI-VSN flight instrument.

Topic 1: diffuser calibration.

The alternative diffuser calibration method was tested and analyzed in detail. Based on the analysis results we can conclude that for most spectral ranges the predicted accuracy can be achieved. For the spectral range between 2000 nm and 2500 nm an unexpected effect was found. In that spectral range the lower reflectivity of the integrating sphere material results in a lower integrating sphere homogeneity, which influenced the accuracy of the measurement.

Initial investigations into this effect show that the accuracy can be increased for this wavelength by increasing the distance between the Sphere and the diffuser.

During 2016 this updated measurement approach will be tested.
For the wavelength range between 400 nm and 2000 nm the approach has already been shown to be successful.

Topic 2: use of a pulsed tunable laser light source instead of a continuous monochromator white light source for spectral calibration of the instrument.
The research in the use of the pulsed laser was successful. We were able to demonstrate that the pulsed nature of the laser source did not have any negative effect of the spectral measurements and that we therefore could make use of all the advantages of the laser (such as higher power output, better homogeneity and large opening and field of view of the laser). This meant for the instrument under test that we could measure the entire field of view instantaneous and within ~12 hours, saving roughly a week in measurement time with respect to the continuous monochromator source.
During the test we also measured the spectral characteristic of a separate filter in order to estimate the absolute accuracy of the measurement. Here we found that the spectral shape of the filter could be measured with an accuracy of 0.2 to 0.3%.
Based on these results we are currently proposing this method also in the frame work of the 3MI space instrument calibration.

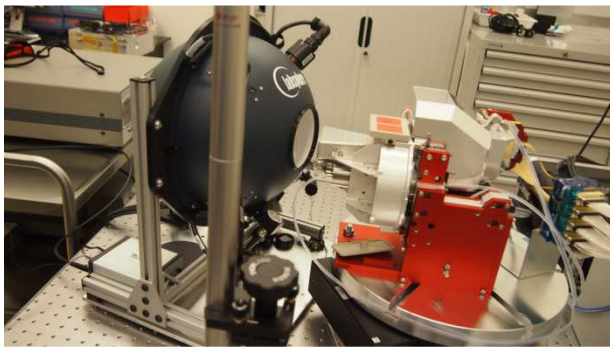


Figure 1: instrument (right) in front of the integrating sphere.

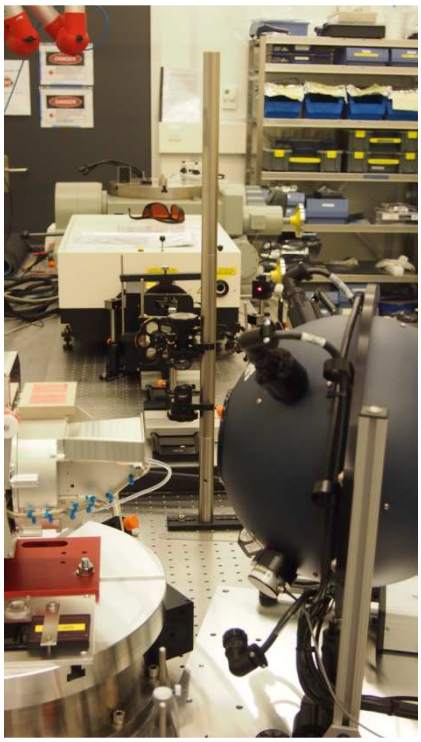


Figure 2: instrument with sphere (foreground) and Laser (background).

Topic 4: generation of standardized instrument characterization data.
Within the framework of the EarthCARE program TNO and SSTL defined a Characterisation/Calibration Database (CCDB). Based on this definition also the CCDB approach for S5 and 3MI (proposal) were set up.

6.2 Roadmap Advanced Instrumentation

6.2.1 Introduction

In this program we address the development activities for the ground based astronomy instrumentation and developments for Big Science. Big Science contains the development and upgrade activities for the large European Science facilities, like CERN, ITER, ESRF, and KM3net. It should be mentioned that there is strong synergy with activities outlined in the HTSM Roadmap Space.

Fully in line with the HTSM Roadmap Advanced Instrumentation TNO underlines the ambition to promote the Dutch ecosystem by strengthening the collaboration between companies, universities and institutes with the aim to increase the return-on-investments in three ways:

- Improved *economic* return-on-investment by supporting Dutch (SME) companies in the development of world-class instruments.
- Improved *scientific* return-on-investment by stimulating that Dutch (SME) companies are highly involved in science projects enabling quicker, more robust and more effective instrumentation.
- Improved *societal* return-on-investment by stimulating that the developed technology know-how is used by (Dutch) SMEs and mass production firms to develop and market instruments that help solving societal issues regarding health, ageing, mobility, energy and safety, etc.

Therefore it is crucial for TNO to cooperate with a network of scientific organizations and industry. Scientific institutes (like Astron, NOVA, DIFFER and NIKHEF) and universities are involved in providing the scientific rationale for the big facilities, in defining the instrumentation needed and in applying the instrumentation for world-class research. The industry has the skills and development capabilities to build high-end equipment, while TNO has experience in designing and prototyping instrumentation for space and science.

6.2.2 Program 2015

- Earth Based Astronomy requires optomechatronics design and analysis of subsystems for large telescopes: adaptive optics and segmented mirrors, e.g. E-ELT-M1 Support technology.
  In optical systems all sorts of disturbances can introduce aberrations that reduce the optical performance. With deformable mirror technology these aberrations can be compensated and the optical performance can be increased.
  In order to build up the expertise required for a fully operating deformable mirror system ,the following Adaptive Optics technology development is foreseen:
  - Deformable mirrors
  - Control, mitigation of turbulence-induced aberrations
  - Artificial guide stars
  - Active large telescope mirror
- Big Science: organization of Het Huygens Huis (HHH), and technical evaluation of the many candidate tenders for instrumentation for the Big Science facilities; The scientific role of The Netherlands in Big Science, with facilities such as CERN-LHC and CLIC, ITER, ESRF, ESS, KM3Net, ESO-VLT and ELT, is substantial. However the role of Dutch technology and industry must be improved, and this is the goal of Het Huygens Huis initiative. Strengthening the role of technology and industry from the Netherlands by:
  - Establishing a platform of cooperating organizations: scientific institutes, TNO, and industry
  - Increase the Return on Investment of The Netherlands in Big Science
  - Create unique technology developments for Big Science, with significant spin-off for industrial applications
- Demonstrator hydrophone for KM3net; For the neutrino detection within KM3net we are working on the development of Fiber Optic Hydrophones to detect the acoustic signal of the neutrinos. The current developed hydrophones are based on FBG sensor technology and are mostly detecting lower frequencies than required. To detect the acoustic signal of the neutrinos a sensing system has to be developed with an extreme sensitivity over a large frequency band. State-of-the-art fiber optic sensors do not have the required sensitivity and do not operate at the high frequencies.

6.2.3 Results

E-ELT support structure

The first mirror of the E-ELT will consists of 798 hexagonal 1,4 meter mirror segments. The M1 Support Segment will give support to each of these segments. Extremely challenging is the requirement to keep the maximum Surface Form Error during operation within 25 nm, while keeping the system low cost and easy to assemble and maintain. This research has resulted in the design and analyses of the support structure that meets these extreme requirements, and leads to new

knowledge to design highly accurate but low cost and easy to maintain structures. The preliminary 3D CAD model has been developed and analyzed, and it successfully passed the review. Critical subsystems, such as wharping harness and strain gauges have been breadboarded (see picture below) and tested.

Adaptive optics

The development of an innovative type of low cost actuators for deformable mirrors (DM): a miniature reluctance actuator (picture to the left). This resulted in creating an overview of different adaptive optics cases and related deformable mirror requirements, addressing the main technical challenges by subsystem development and breadboarding (actuator, electronics, face-sheet), optimizing manufacturing, assembly, and integration aspects, analysis of redundancy, fitness for environment, open-loop stability and closed-loop bandwidth.

6.2.4 Overview cooperations

TNO cooperates with the company VDL-ETG, and astronomy organizations ASTRON and NOVA in the development of the E-ELT support structure; VDL will later take the lead in the manufacturing of hundreds of these structures.
In the field of Adaptive Optics cooperation has been established with ESO, NOVA, SRON, Leiden University, OKO, VDL, Technolution, MI Partners, JPE, ESA, TU Delft, TU Eindhoven, and ICAM Engineering School (France).
TNO initiated plans for a future partnership with two partners: NWO, and high-tech industry. This cooperation is named “Het Huygens Huis” (HHH), with the objectives to increase industrial return, create spin-off, build a network of high-tech partners, strengthen the role of NL-scientists, and trigger extra investments in the knowledge

base. These activities are all in line with recommendations from Topsectors and the Kenniscoalitie. The scope of spin-off projects for industry is found to be a factor of 2-3 larger than the turnover for Big Science and/or Space projects, making this a very effective path for innovation and economic growth. A governing body, consisting of representatives of industry, NWO and TNO, will formalize the involvement of the main HHH partner groups. This should lead to a prominent position of Dutch industry, in focused areas of the worldwide field of high-end instrumentation, in combination with a prominent position for Dutch scientists.

7 VP High-Tech Semicon

7.1 Roadmap Semiconductor Equipment

7.1.1 Introductie

Een wereld zonder elektronica is niet meer voor te stellen. Bij bijna alles wat we doen, spelen geavanceerde integrated circuits (chips) een grote rol. Hun snelle ontwikkeling maakt de rol van deze microchips in de samenleving in de toekomst alleen nog maar groter. Nederland is met een marktaandeel van meer dan 20% een grote speler op de wereldmarkt voor halfgeleiders. Bijna alle chips ter wereld bevatten een Nederlands onderdeel of zijn met Nederlandse tools gemaakt.

Nog steeds verdubbelt het aantal componenten op een chip elke 1,5 tot 2 jaar (de wet van Moore). Dit komt door drie mechanismen, die ook de drijvende krachten zijn achter deze Roadmap voor de komende 15 jaar:

- Miniaturisering van componenten, zowel met nieuwe als met bestaande functionaliteiten. Hiervoor zijn innovaties in apparatuur en (nieuwe) materialen onontbeerlijk.
- Vergroting van chips en substraten. Om in 2018 over te kunnen gaan naar substraten met een diameter van 450mm, zijn intensivering van R&D-activiteiten en Europese samenwerking essentieel.
- Verbetering en vernieuwing in fabricagetechnieken. De introductie van nieuwe materialen en device concepts zorgt voor de ontwikkeling van nieuwe fabricageprocessen. Innovaties in die processen verleggen de grenzen van wat maakbaar is.

Apparatuurfabrikanten zoeken voortdurend naar manieren om chips kleiner en krachtiger te maken en naar de schoonste en meest kostenefficiënte wijze om deze te produceren. TNO ondersteunt de halfgeleiderapparatuurindustrie op de volgende inhoudelijke gebieden:

- Vervuilingsbeheersing
- Positionering en stabiliteitscontrole
- Material interface control
- Lithografische patroonvorming

De doelstelling van het programma Semiconductor Manufacturing Equipment is om de Nederlandse marktpositie en competenties te versterken en te behouden in het Semiconductor Equipment domein. Dit zal worden bereikt met verkenning van nieuwe technologie en procesgebieden, die raken aan de huidige expertise van TNO, maar waar nog geen domein specifieke kennis is opgebouwd.

7.1.2 Programma 2015

Computational Imaging

Bij “computational imaging” vormt de computer een integraal deel van het beeldopnamesysteem. Hierdoor kunnen de prestaties van het opnamesysteem worden verbeterd, of de prijs van het systeem worden gereduceerd. Het onderzoeksdoel is aan de hand van een literatuur onderzoek en eigen berekeningen bepalen van de voor en nadelen van de verschillende “computational imaging” technieken voor toepassing in industriële inspectie. Met als use case 3D topologie metingen tijdens roll-to-roll productie met micrometer resolutie, en een hoogtebereik van minimaal 10 mm.

Fiber interferometrie
In dit project zijn een aantal potentiële knelpunten bekeken rondom een TNO fiber interferometer. Deze TNO interferometer onderscheidt zich van commerciële fiber interferometers doordat ze op relatief eenvoudige wijze aangepast kan worden voor specifieke meettoepassingen (met name de minimale mechanische afmeting is een voordeel bij weinig ruimte). De interferometer zal mogelijk gebruikt gaan worden in verschillende projecten binnen TNO en zal hierbij gebruikt worden als afstand sensor. Een beoogde toepassing is in 'Small Devices' waarbij de verplaatsing en positionering van bijvoorbeeld een AFM tip gemeten moet worden.

Optical Coherence Tomografie (OCT) voor het scannen van de achterzijde van een EUV masker

Aantonen dat de theoretisch haalbare specificaties gerealiseerd kunnen worden met geselecteerde bestaand hardware. Theoretisch is het mogelijk om een heel reticle op hoogte te scannen in 2 minuten, met een xy resolutie van 5 µm en hoogte meting van een particle met een resolutie van 0,5 µm bij een range van 35 µm.

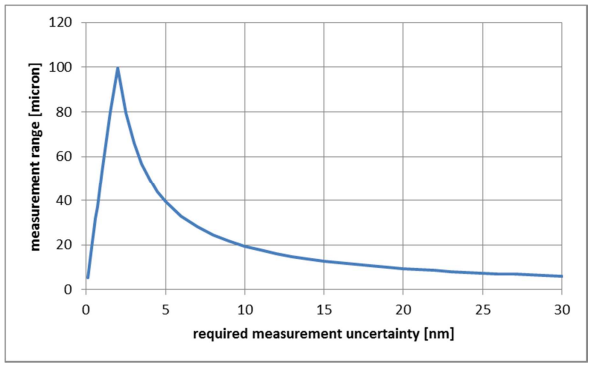
Rapid Nano 4 development

Doel voor 2015 is de realisatie van een concept en detail ontwerp van een particle scanner, welke deeltjes tussen 20nm en 1000nm kan detecteren op een silicium reticle blank. Deze particle scanner zal aan de reticle handler worden gebouwd.

7.1.3 Resultaten

Computational Imaging
Er is uitgebreid in de literatuur gekeken naar de zeer recente ontwikkeling van de "Fourier Ptychografie". Hier zijn Matlab simulaties mee gedaan om inzicht te krijgen in de schaalbaarheid. Vanwege de constatering dat het hoogte meetbereik beperkt is tot de helft van de golflengte van het licht, is er vervolgens gezocht naar alternatieve meetmethodes die een meetbereik hebben van minimaal enkele millimeters. De belangrijkste conclusies zijn:

1. Het meten van de fase van het aan een voorwerp gereflecteerde licht, om de topologie te meten kan beter gedaan worden met een directe meetmethode zoals een interferometer, dan met een iteratieve methode zoals Fourier Ptychografie.
2. Voor industriële inspectie maakt de ambiguïteit van de golflengte van het licht het meetbereik onpraktisch klein, als er met één enkele golflengte wordt gemeten.
3. Door met twee verschillende golflengtes te meten kan het meetbereik worden vergroot (zie figuur 1), maar alleen als de golflengte van de lichtbron extreem goed bekend is en dan nog over een bereik van veel minder dan 1 millimeter. Het toevoegen van een 3e golflengte zorgt voor een verdere vergroting, maar het is praktischer om dan meteen breedbandig licht te gebruiken en de coherentielengte van het licht als meetlat te gebruiken (zoals in een wit licht interferometer).



Figuur 1: meetbereik op basis van de fasemetingen met twee golflengtes, als functie van de vereiste meetnauwkeurigheid. Zelfs als men niet op de nanometer nauwkeurig hoeft te meten, heeft dat geen groter meetbereik tot gevolg. De grafiek is berekend op basis van een golflengte welke met 10 pm (absolute nauwkeurigheid) bekend is.

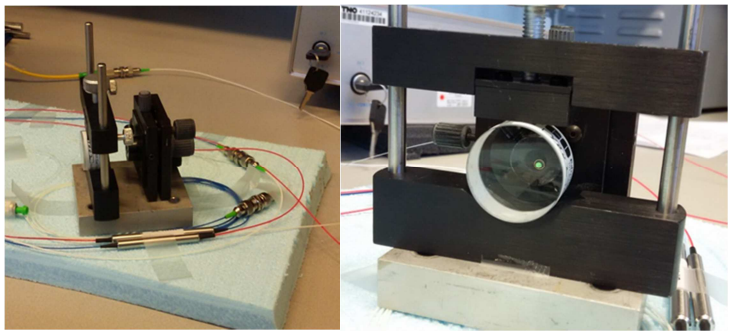
Fiber interferometrie

De volgende situaties zijn geanalyseerd:

1. ‘Displacement drift’ ten gevolge van temperatuur variaties.
2. Haalbaarheid van het optisch ontwerp van een fiber interferometer waarmee een gefocusseerde spot van ~15µm verkregen kan worden. Dit is nodig voor metingen aan een AFM tip met typische dimensies van 10-20µm.
3. Simulatie van een gekromd golffront op de locatie van een referentie vlak in de interferometer. In standaard configuraties wordt gebruik gemaakt van vlakke golffronten ter plekke van de referentie en meet spiegel/target. In het huidige ontwerp is dit echter een gekromd golffront, wat mogelijk verplaatsing meetfouten kan introduceren.
4. Simulatie van meetfout ten gevolge van een focusseerde spot op het te meten target.
5. Simulatie van de meetfout ten gevolge van ruwheid van het gebruikte target.

Resultaten

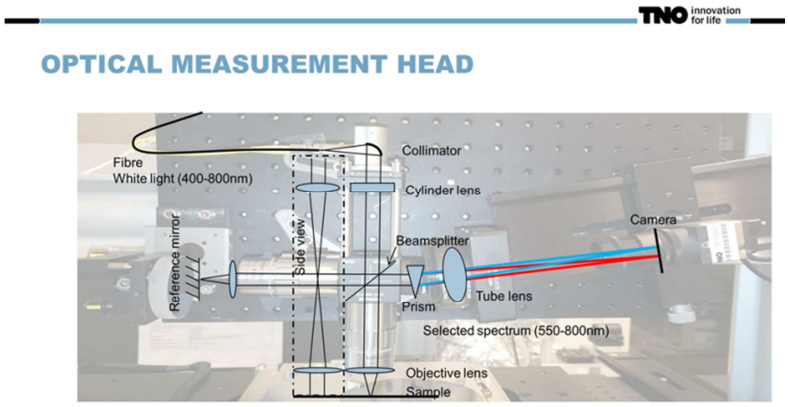
1. Testen zijn uitgevoerd om de thermische gevoeligheid van de fiber interferometer te bepalen. Met de gemeten thermische gevoeligheid kan voor verschillende toepassingen eisen worden gesteld aan de isolatie van de fiber interferometer en/of de thermische stabiliteit van de omgeving.
2. Door leverancier van ‘fiber coupled GRIN’ lenzen is een ontwerp gemaakt waarmee het mogelijk om een spot te genereren met 15µm diameter. Dit optisch ontwerp is gecontroleerd met behulp van ZEMAX waarmee aangetoond is dat dit haalbaar is.
3. In de simulatie resultaten is te vinden dat doordat gebruik gemaakt van een gekromd golffront een fout gemaakt wordt in de afstand uitlezen.
4. Simulatie resultaten geven aan dat doordat het target zich in de beam waist van een gefocusseerde meetbundel bevindt er een meetfout gemaakt wordt in de afstandsbepaling. De verwachte afwijking is enkele nanometers bij een verplaatsing van 1µm.
5. Simulatie resultaten geven aan dat oppervlakte ruwheden een meetfout introduceren in de te meten verplaatsing. Deze effecten zijn echter vele malen kleiner in vergelijking met het gekromde golffront en de gefocusseerde meetbundel.



De gebouwde opstelling met de GRIN lens.

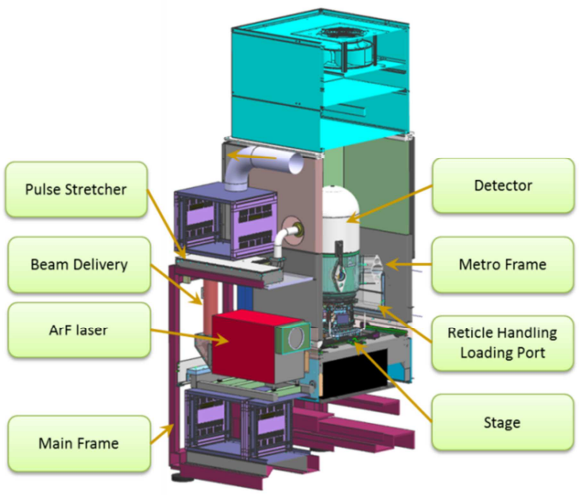
Optical Coherence Tomografie (OCT) voor het scannen van de achterzijde van een EUV masker

Er is een werkende test opstelling gerealiseerd die in de clean room van het Van Leeuwenhoek Lab staat. Resultaten die bewijs leveren dat beloofde specificaties van een snelle scan haalbaar zijn.



RapidNano 4 Particle Scanner

Het concept ontwerp is gerealiseerd. Ook het detail ontwerp is nagenoeg klaar. Inmiddels is reeds begonnen met de aanschaf van onderdelen. Ook de elektronica is ontworpen en deels al gerealiseerd.



Het gerealiseerde resultaat is een detail 3D ontwerp van de particle scanner.

7.1.4 Overzicht samenwerking

Het overgrote deel van het budget is ondergebracht in mixed-funding projecten in Europees en nationaal verband. Deze mixed-funding projecten volgen de bijbehorende projectplannen en doelstellingen en staan beschreven in de rapportages van de desbetreffende projecten. Het zijn allen meerjarige onderzoeksprojecten met een gemiddelde looptijd van 4 jaar. Het betreffen de volgende groep projecten.

Projecten in EU verband:

- Eniac EEM450PR
- Eniac Silver
- Eniac 450 EDL
- Eniac Sea4Ket
- Eniac E450LMDAP
- ECSEL SeNaTe

Projecten in nationaal verband:

- STW HIM
- STW UPON
- TKI Low-density plasma fundamentals

Daarnaast wordt met het hoogleraarschap van TNO researcher Giampiero Gerini aan de Technische Universiteit Eindhoven een link gelegd naar het fundamentele toegepaste onderzoek. Dit wordt gezamenlijk gefinancierd met het early research program 3D Nanomanufacturing Instruments. De focus van het onderzoek ligt in “Artificially Engineered Electromagnetic Materials”.

7.2 Roadmap Nanotechnology (QuTech)

7.2.1 Introduction

Quantum science has entered a transformational phase from university based research to engineering driven technologies. Seemingly fundamental limitations of quantum systems have recently been overcome. Although significant challenges remain available to create further scientific breakthroughs, we have also reached the point where quantum science is ready for engineering.

The Netherlands has an innovative ecosystem in the high-tech industry supply chain. In The Netherlands a well-trained and talented human capital pool is already present and can be further expanded towards this future technology. The very first quantum technology startups and SMEs addressing these markets are already sprouting.

Quantum research in Delft is at the forefront of new developments with seminal discoveries in superconductor- and semiconductor-based qubits, the discovery of the Majorana fermion, and the recent demonstration of teleportation between two chips separated by 3 meters. In order to enable the existing and future European high-tech industry to gain a sizeable portion of the future quantum sector, TU Delft and TNO have established joint a center of know-how with Industrial partners.

The envisioned developments cover many TRL’s, multiple disciplines, and thereby about 15 years. This will result in a different approach during the subsequent phases of the development. The first phase (2014 – 2017; Proof of Principle) will be dominated by solving the current bottlenecks to accelerate the research, and by

making the transition towards the mission-based way of working. The latter includes, amongst others, a better defined goal of the project, working out the project plan, system architectural considerations, and involving third parties.

The second phase (2018 – 2022; Proof of Concept) will be used to demonstrate progress on key technologies (critical milestones), benchmarking, defining the requirements and system architecture, and updating the project plan including contributions by third parties and potential spin-off. Also a relevant and mathematical challenge shall be selected for the demonstration. This challenge shall be mapped to the electronic hardware.

During the third phase of the project (2023 – 2029; working demonstrator) all technologies shall be developed to the level of a working demonstrator. A convincing demonstration shall be executed. Positioning the Dutch industry (by knowledge transfer) is critical during this phase.

7.2.2 Program 2015

QuTech works according to Roadmaps. The most critical enabling technologies that will be developed during the coming years are incorporated in the most relevant Roadmap. The state-of-the-art, knowledge gaps, and planned developments will be described per Roadmap. (Beyond 2018 Roadmaps will likely be organized according to components and modules of the quantum computer or setups for secure quantum internet.).

Roadmap A: topologically protected quantum computing

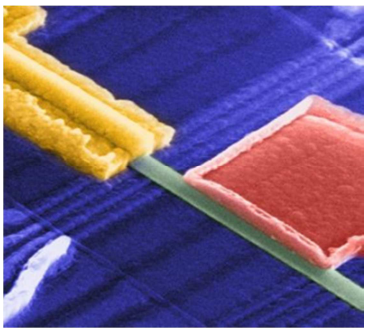
So called zero state- or Majorana qubits have the potential of very long coherence times. The most convincing experiments on the demonstration of the appearance of Majorana quasi-particles have been performed by the TU Delft in 2012/2013. This was done on devices based on InSb nanowires in which superconductivity is induced by a connected superconductor. A qubit based on Majorana quasi-particles actually requires braiding of those Majorana particles which in turn requires the integration of a few nanowire crosses (instead of nanowires) in combination with a few Josephson Junctions.

The research in this Roadmap is focused first on improvements in materials, device technology, and measurement techniques. Improvements in materials are needed to reach higher electron mobility in the nanowires/nanocrosses. A new process flow shall lead to better control/prevention of contamination, and in-vacuum growth of superconductor and semiconductor material shall lead to ultimately well-defined interfaces. Several properties of the current superconductor material NbTiN, like the quasi-particle density of states within the superconducting gap, are unknown. This material will therefore be characterized better by means of tunneling studies.

The interface between the semiconductor and superconductor materials is the most critical and very sensitive to imperfections like oxidation, dangling bonds, chemical residues, or non-homogeneous coverage. To improve this interface we will investigate etch recipes which are more gentle than the current Ar sputtering (needed to remove native oxides that show up due to transport of the nanowires from the growth chamber at TU/e to the deposition chamber at TU Delft). High-resolution electron microscopy will be used to investigate the precise interface coverage. Deposition of the superconductor material by means of sputtering maybe replaced by other techniques or materials. A new deposition tool will be installed and a new process flow will be develop to ultimately execute all material growth and deposition steps in one system without breaking vacuum. The device is grown on

top of an insulating Si substrate with gate pattern. This ‘gate chip’ will be improved by better planarization (even CMP seems to result in too rough surfaces), and selection of a dielectric material which is both high quality (no charge noise on timescales of days at low temperatures) and enables a non-reactive and hydrophobic surface to avoid reactivity in ambient conditions.

TNO will work on most of the challenges mentioned above: TNO’s experience with nano-fabrication and contamination control will be required. Also the new deposition tool will be installed in the cleanroom of TNO and a specialist in this technology will be hired. Finally TNO will execute simulations on multiscale physics to understand, amongst others, the effects of stress induced in the nanowires by cooling down from room temperature to 15 mK on electron mobility.

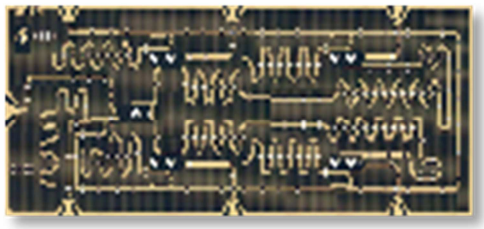


1. SEM image of Majorana device (false colours; TU Delft).

Beyond these developments this Roadmap will focus more on the development of so called Majorana-Cooper pair Boxes (MCPB), superconducting-insulating-superconducting (SIS) junctions, integration into a circuit, and finally the actual braiding of Majorana’s.

Roadmap B: fault- tolerant quantum computing

The transmon qubits are relatively speaking the most mature type of qubits. Circuits with 5 qubits with controlled interaction are currently being studied. The activities over the next few years will be dedicated to the development of a 17-qubit design. This is the smallest set of qubits required to demonstrate surface code protection. This protection against decoherence is based on a set of primary qubits plus ancillary qubits. The latter will be used to probe decoherence at the primary qubits (parity check), followed by repair of the states of the primary qubits.



Important technological developments on which TNO will work include the development of electronics architectures for circuits with more than 8 qubits, more compact resonator designs (to make devices with more than 17 qubits fit on one chip), and FPGA- and RF technology for fast electronic feedback control.

Spin qubits may intrinsically have longer coherence times. Still surface code protection is required. Current research topics include scaling to circuits of 5 qubits, and integration on the devices of the superconducting transmon qubits.

Important technological developments on which TNO will work include investigation of potential 2D architectures (required for scaling beyond about 5 qubits), a PCB/interposer for connection of about 100 DC-, RF-, and microwave signals to/from the circuit, nano-lithography and contamination control for higher quality devices and miniaturized qubits (to reduce the number of imperfections in the device which limit the coherence times).

Roadmap C: secure Quantum Internet

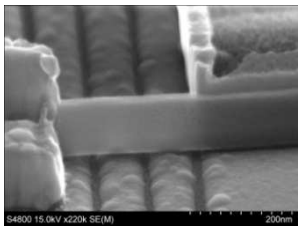
The fourth type of qubit is based on the N-V color centers in diamond. One of the advantages of this type of qubit is the possibility to read the state of this qubit by means of visible photons. This makes this type of qubit attractive for applications in encryption and communication via glass fibers. Entanglement over 3 meters distance has been demonstrated by the TU Delft last year.

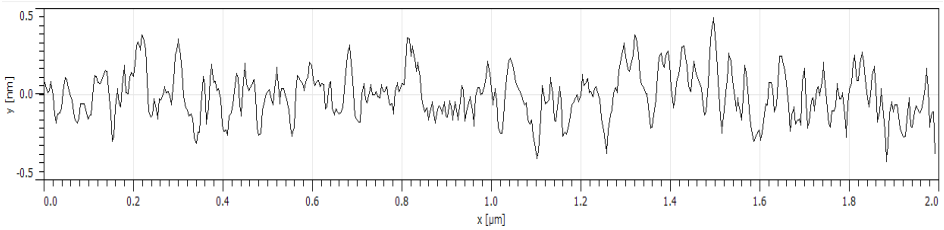
Challenges include the efficiency in coupling light to the fibers, wavelength conversion (from the intrinsic wavelength of N-V centers near 637nm to the wavelengths used for telecommunication, needed to make use of known technologies and reduce the transmission losses in fibers), generation of arrays of color centers in a controlled way.

7.2.3 Results

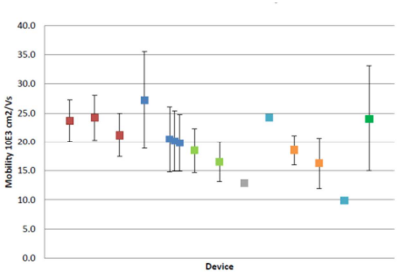
An enormously complex and costly MBE cluster tool (picture left) has been installed in the cleanroom of TNO, which was thoroughly reconfigured for this purpose. This unique tool shall enable growth of high-quality nanowires for Majorana zero state qubits.

The new fabrication process results in perfectly flat gate dielectrics (<0.2 nm RMS, graph right) underneath the nanowires, which is critical for accurate field control inside the nanowire for Majorana zero state research. In 2014 the surface morphology was still significant (picture left).

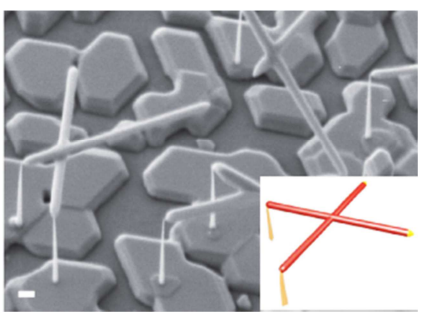


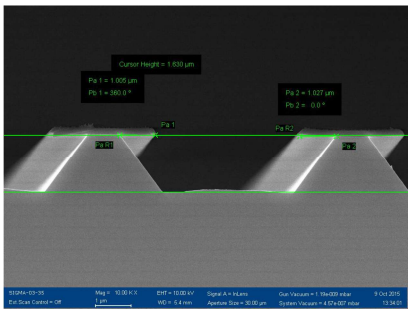


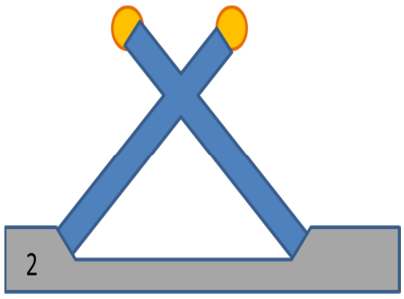
InSb nanowires were systematically characterized to optimize nanowire growth and fabrication procedures. High electron mobility in the nanowire are now achieved routinely.



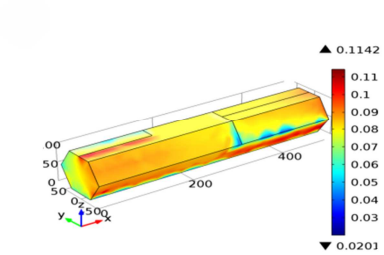
Growth of nanowire crosses is essential to braiding. So far crosses could only be grown by creative processes during growth inside the MBE system, with unacceptably low yields (picture left). In 2015 a 3D patterning process and gold dot deposition on InP substrates was developed (picture center). The geometry of the patterned surface will determine growth directions, which shall enable growth of nanowire crosses by more conventional MBE processes and much higher yields (graphic right). This growth process is currently under investigation (MBE system of Prof. E. Bakkers, TU/e).

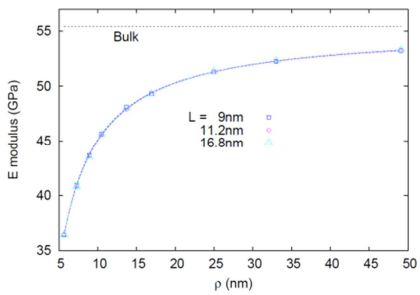




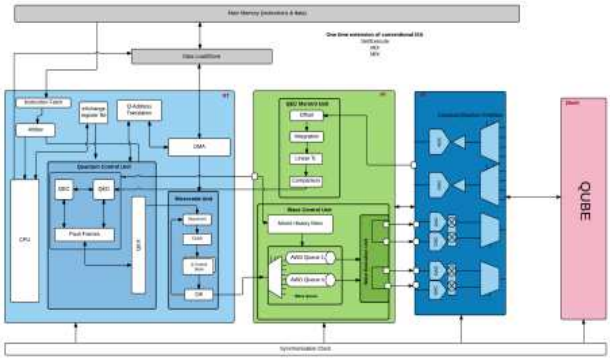


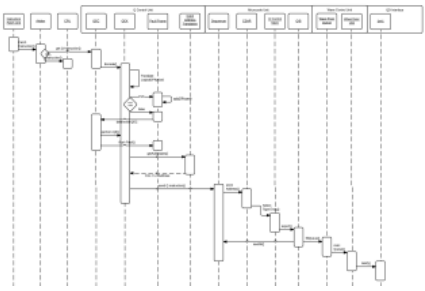
Theoretical and simulation models have been developed further to predict the behaviour of Majorana devices due to operation loading. Results include a model in COMSOL (picture left), implementation of Vashista potentials for atomistic simulations of III-V compounds, theoretical results on size dependent Young's modulus (graph right) and gradients in InSb lattices (the so called skin-effect in nanowires).





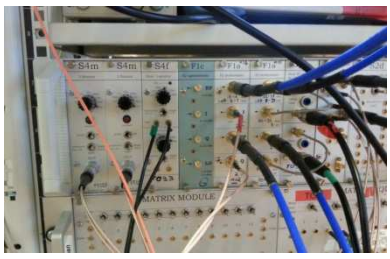
The first systems architecture models for fault-tolerant quantum computing have been developed. These models give the first indications on the milestones in scaling to large numbers of qubits; like the maximum number of qubits that can be controlled by brute force scaling of the number of cables, frequencies, and electronics. Multiple layers of software layers have been defined, with their respective interfaces and degree of dependency on specific physical qubit implementations.



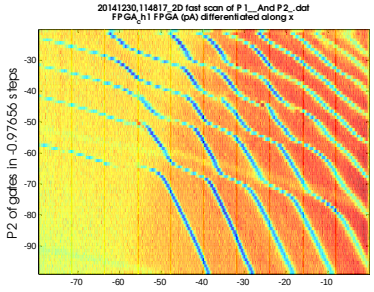


The QuTech Wave Generator (QWG, see picture), a specialized version of the commercial AWG, was designed and assembled. It will allow for flexible low-latency qubit control and measurements, in a scalable manner. Software and firmware developments are still ongoing.

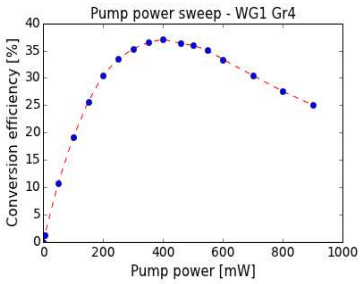
The Vector Switch Matrix for selective broadcasting of RF-signals to multiple qubits, developed in 2014, has been used in real qubit experiments (picture left). This work is published in a paper on arXiv, and iscurrently being reviewed for publication in Nature Quantum Information Processing. A dedicated upconverter (mixing 4-8 GHz RF signals with envelop signals from the AWG/QWG) was developed for qubit control (picture right).



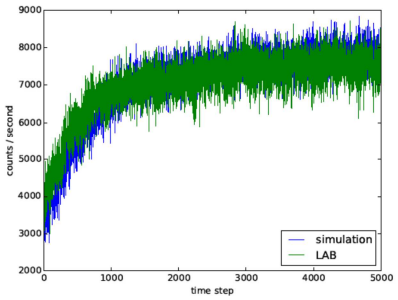
Automated tuning of spin quantum dots has been developed to initiate spin qubits fast. Initiation of a single spin qubits could still be done by hand (couple of hours). But double or triple qubit systems take hours to weeks of work. The algorithm, based on computer vision technologies, is already capable to tune a double spin qubit (see graph). In the coming years we envision further development of this technology to be able to initiate systems with larger numbers of qubits.



Light from N-V centers has to be converted to telecom wavelength in able to develop quantum communication over longer distances. We achieved over 35% conversion efficiency by means of difference frequency generation in PPLN crystals (graph below). This was achieved by better alignments of beams with the crystal, beam overlap, collimation, and temperature of the crystal.



A new algorithm was developed to enhance the collection efficiency on the emission from N-V centers by means of a deformable mirror. This algorithm is used to drive a mirror with 144 actuators and uses only the input from a photon-counting detector. (A wavefront sensor is thus not needed.) The photon collection is increased by a factor or more than two (graph below). Note that two of such setups have to be included in a single quantum communication experiment. This improvement shall thus lead to 2x2 times higher yields.



7.2.4 Overview cooperations

- The ‘partnerconvenant’ was signed by TNO, TUD, departments of EZ and OCW, NWO (incl. FOM, STW), and Topsector HTSM/TKI in June 2015. The agreements add up to about 135 million euro commitments, giving QuTech a firm basis for the first 10 years.
- Only foreseen within a few years from the start of QuTech, a contract with a large commercial partner was closed in September 2015 already. Intel will support research at QuTech with over 50 million dollars plus expertise of Intel in the fields of material sciences, nanofabrication and computer architectures. Both events mentioned above have generated a very extensive media coverage. QuTech and TNO have been mentioned in NOS and RTL4 new bulletins, Volkskrant and other newspapers, New Scientist, Signalement, and others, Radio5, and even the New York Times.
- QuTech has been invited for negotiations with IARPA on its proposal on logical transmon qubit development.
- Ministers Kamp and Bussemaker as well as European Commissioner Oettinger have visited QuTech. QuTech/TNO is well connected to Innovate UK and the

UK department of BIS in our joint effort to generate activities and funding from the European Commission/European Parliament/and H2020.

- QuTech/TNO is still in contact with ASM, ASML, Fox-IT, SURF, KPN, and other companies about potential cooperation and/or joint efforts towards European projects.

8 VP Flexible and Freeform Products

8.1 Roadmap Components and Circuits

8.1.1 Introduction

There is an increasing need for flexible and lightweight electronic systems. Examples are: wearable medical devices such as skin patches, smart garment, flexible displays and large-area (X-ray) imager sensors, seamlessly integrated human machine touch interfaces and wireless nfc playing cards. Holst Centre aims to develop materials, processes and manufacturing platforms that allow such flexible electronic systems to be made economical for mass-production. The multi-year Roadmaps of the relevant Holst Centre programs are also embedded in the HTSM Roadmap Component and circuits.

8.1.2 Program 2015

The two important trends continued in 2015: (i) a stronger focus to bring technologies to a higher TRL level, and (ii) combine the technologies to enable new product categories.

(i) Holst Centre is more frequently asked to make a multitude of its prototypes for field-trials and/or early market studies. To accommodate these requests, Holst Centre is actively working to more reproducible and reliable prototyping realized using standardized baseline processes on pilot lines equipment for flexible thin-film transistors and hybrid printed electronics.

(ii) Whereas initially our technologies were geared towards high-volume, low cost applications, Holst Centre is increasingly asked to direct its activities more towards higher added-value flexible electronic systems. Examples lie in the domain of (bio)medical and automotive.

8.1.3 Results

In 2015 we demonstrated several prototypes of new-form microelectronics. By placing silicon components and thin-film circuits on unusual substrates such as plastics, rubbers, textile and paper, we realized world's first prototypes of stretchable displays in textile, medical skin patches and curved X-ray imagers. Electronic and mechanical design rules were established. The underlying technologies were further developed. For instance, printed metal interconnects were downscaled to 10 micrometer using LIFT. Further downscaling of the transistorR dimensions in combination with a novel, self-aligned structure enabled smaller pixels and faster circuitry, plus the possibility to realize semitransparent electronics. We investigate semiconductor materials and that do not require high vacuum deposition methods, and achieved 3x higher performance using spatial ALD oxide semiconductors. Part of these results were reported at top level conferences, both as invited and contributed talks (Printed Electronics USA, ESREF, ISSCC, SID, IMID, IDW).

8.1.4 Overview cooperations

The program is an integral part of the Shared Research effort of Holst Centre/TNO. As such, the contents are defined by the industrial partners. Current partners for example include Artek Electronics, AU-O, Cartamundi, CPT, DuPont, Evonik, Merck, Philips, dpiX, Henkel, Nordson Asymtek, Orbotech.

In 2015, 4 new European projects started: DiCoMo, Hi-Response, PING, InforMed, and one project proposal was successfully submitted. Holst Centre has an active role in shaping the Roadmaps of international fora such as the Organic Electronics Association (OE-A), Photonics 21 and INEMI. The good relationship between Holst Centre and academia is substantiated by two newly appointed professors (prof. Groen, TU Delft and prof. Gelinck, TU Eindhoven).

8.2 Roadmap Ligthing

8.2.1 Introduction

TNO's activities in the Roadmap Lighting are performed as part of the Public Private Partnership Holst Centre. The vision is to support industry in creating the next generation free-form, robust, customizable lighting technologies based on ultrathin films containing either OLEDs or LEDs (or both). Development of low cost manufacturing processes (<10 €/klm), for high performance devices (>50 lm/W, >10 years shelf lifetime) with novel form factors are the long term goals of the program.

8.2.2 Program 2015

Goals in 2015 were to: 1) transfer fabrication of high performance water barrier for OLEDs from a sheet-to-sheet to a roll-to-roll production process, 2) demonstrate flexible OLEDs with comparable device performance to rigid glass-based devices, 3) fabricate roll-to-roll solution processed flexible OLEDs on new state-of-the-art roll-to-roll coating line and 4) demonstrate added functionality such as flexible, (con)formable, stretchable, addressable and cut-able light sources, and the possibility of integration with other thin film electronics.

8.2.3 Results

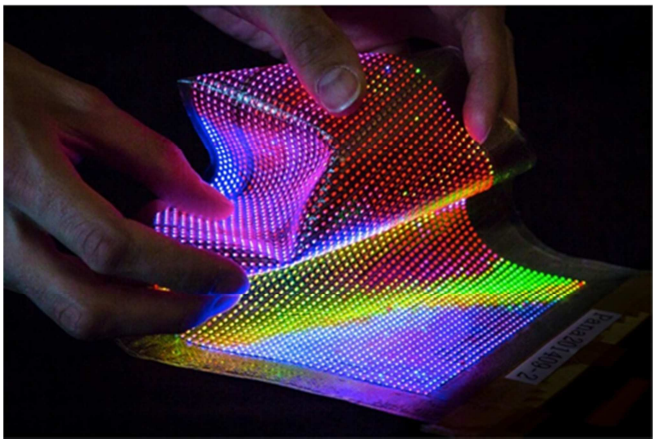
During 2015 a number of key milestones were achieved in the development of flexible OLED production processes at Holst Centre/TNO. Roll-to-roll moisture barrier film can now be produced on length scales of kilometers, and even with only part of the barrier stack in place (single silicon nitride layer) the barrier films now show water vapour transmission rates of less than 2 -5 $x10^{-6}$ g/m^2/day under 20^oC/50% relative humidity conditions. This is better than any commercially available water barrier film, and has already proven to be good enough for water protection of photovoltaic devices, giving >20 years lifetime in a product that is close to commercialization. During 2015 the first trials of depositing the full water barrier stack needed for OLEDs began. Using a hybrid sheet-to-sheet and roll-to-roll process to fabricate the water barrier, the roll-to-roll flexible moisture barrier was used as a base for more than 100 flexible (12 cm x 4 cm) OLED lighting prototype products. In these prototypes, the OLED layers were deposited in an industrial production tool at Philips Lighting. This allowed a simple replacement of glass substrates with flexible ones in Philips' OLED production process, whilst maintaining the high performance moisture barrier properties (>5 years lifetime) as well as the OLED efficiency (>40 lm/W, which is comparable to glass-based devices made in the same run). In these pilot production runs, flexible OLEDs with world-leading brightness's of 10 000 cd/m^2 were also achieved! 2015 also saw the first OLED fabrication runs on the new state-of-the-art, roll-to-roll solution processing line at Holst Centre. 100m of flexible OLED foil could be coated with OLED layers in one run, and devices were produced on both metal and plastic films with more than 80% yield. Development of a specialist tool to allow intermittent slot-die coating at high speed, is starting to make it possible to pattern solution processed (OLED) materials, improving materials utilization and reducing production costs. One of the

attractive features of OLEDs is the possibility of transparency, and in 2015 flexible OLEDs with a state-of-the-art transparency of 80% were demonstrated (typically OLED transparencies are limited to 65%). In the case of LEDs the focus in 2015 was on integration of bare die light sources into products from a wide range of application areas where it had not previously been possible to add a lighting feature (including medical and clothing). Through combination of stretchable meander technology and ultrathin LEDs, it was also possible to create stretchable, addressable LED lighting prototypes with a wide range of possible applications.

8.2.4 Overview cooperations

In 2015 partners of the (O)LED lighting program included: Panasonic, DuPont Teijin Films, Mitsui Mining and Smelting, Rolic, Roth and Rau, Solvay, Sumitomo, and Cambridge Display Technology. There were also a number of product development projects for integration of (O)LEDs into value-added products. EU projects were: Flex-O-Fab, Clean4Yield, SOLEDLight, INREP, LightTouchMatters, and ALABO. The RM lighting (OLED) is also part of NanoNext NL, and involved in STW projects.

Optional pictures:



Stretchable LED-based RGB smart lighting (3 mm pitch). Useful for signage applications but also for mood lighting luminaires.

High brightness (10 000 cd/m^2) evaporated OLEDs on flexible plastic (PEN)/water barrier/anode foils, with shelf lifetimes of >5 years.

8.3 Roadmap Solar

8.3.1 Introduction

The TNO activities under the Roadmap Solar are performed as part of the Public Private Partnership Solliance (the research alliance of TNO, ECN, imec, Holst, FZJ, TU Eindhoven, TU Delft, and UHasselt). Focus is on process and equipment development for production of thin film solar modules, and on integrated application of this type of photovoltaics. Specific focus is on solar modules based on thin film CIGS and Perovskites. Program goal is to improve product quality and lifetime at reduced cost by process/equipment innovation and smart production, and to create added value by application in integrated products.

8.3.2 Program 2015

Goals in 2015 were to establish a sheet to sheet CIGS baseline process for manufacturing of CIGS demonstrator cells on 30x30cm^2 scale of at least 12% efficiency, to make a large area ALD tool and a novel roll-to-roll coating line operational for thin film PV and organic electronics, and to demonstrate feasibility of up-scaled (10x10cm^2) Perovskite solar cells. Availability of several pieces of equipment was delayed by bankruptcy of Dutch equipment partner, but installation goals were achieved and tools were ready for process demonstration by the end of 2015.

8.3.3 Results

The CIGS baseline, based on reduced cost processing, has been made operational and is developed into a stable supply line for demonstrators for process development and module integration; 13% efficiency has been achieved (average efficiency above 10%, single cell record 14,2%). The in house reference line, based on traditional (co-evaporation) technology, achieved levels above 15%. On this line, successful process innovations were demonstrated using alternative, cadmium free buffer layers by atomic layer deposition (+0,5% efficiency), and using nanoscale texturing for improved light capturing (+0,7%). Buffer layer formation by atomic layer deposition was also demonstrated for the first time on 50cm wide roll-to-roll processing of third party substrates. A similar system for processing of 30x30cm rigid glass plates was completed in house by end 2015. First CIGS modules were demonstrated by off line back end interconnection: an in line setup has been completed end 2015 for free form laser scribing, printing and curing, which will eliminate present state-of-the-art alignment problems and enable smart, free form on demand module formation.
Facilities for accelerated life time testing, which were successfully developed with a Dutch start-up, are expanded with the installation of an up-scaled facility for commercial size modules. Specific insights have been developed in life time determining factors in state-of-the-art thin film cells.

Within one year, the Solliance Perovskite based PV activities came at a world class level. Lab-scale produced Perovskite based PV cell performances of above 17% were realized. Lab-scale produced Perovskite based mini-modules of 5x5 cm^2 with 12% were realized. And an up-scaled Perovskite based mini-modules (5x2 cm^2) was demonstrated achieved with an efficiency of 6,7% on 15x15 cm^2 substrates by using up-scale-able sALD, slot die coating and laser interconnection processes. End of 2015, an unique (30cm web width) interconnected roll-to-roll coating facility based on TNO/Holst inventions, and built by a consortium of Dutch equipment builders passed the acceptance tests and was officially opened at an event with 150 attendees from industry and research. It enables the integrated deposition and

curing of multiple layers for thin film photovoltaics or other flexible electronics, it handles polymer or metal foils without touching the coated surface and greatly reduces clean room requirements.

8.3.4 Overview cooperations

In 2015, long term partners of the Solliance research program were DSM, Thyssen Krupp, SmitOvens, Solartek, Dyesol, VDL ETG, and Nano-C. Project based collaboration with 30 companies. EU projects: R2RCIGS, Nanomend, X10D, SWING, CPV4ALL, Mujulima, EFFIC, etc. TKI projects: Fantastic, Desire, CALM, Rolling Suns, HIEFF, Zonnegevel, ACCESS, TRUST, etc.

Optional: illustrations

Equipment for fast Atomic Layer Deposition on large area glass substrates (based on TNO invention for spatial ALD).

Innovative roll-to-roll facility for flexible photovoltaics on polymer or metal foils.

8.4 Roadmap Printing

8.4.1 Introduction

In 2015, TNO initiated the creation of two ecosystems around materials and systems for Additive Manufacturing (AM) to address challenges identified by the industry. The integral approach of TNO is a key selling point and will be secured by a strong interdependency between these ecosystems.

The ‘Materials for AM’ program, positioned at the Brightlands Materials Centre, aims to develop functional polymer-based AM materials, in order to obtain functional products with good mechanical (strength, durability), optical and electrical

performance. The focus of the program is on photo-curable and other thermoset polymers and polymeric composites, in particular materials that are processable by Vat photo-polymerization and large-scale patterned illumination. Target applications include human centric products (such as dental products, medical microfluidic devices, or organs-on-a-chip), automotive and optoelectronic products. The 'Systems for AM' initiative is the strategic collaboration between TNO and the High-Tech Systems Centre of TU/e on the development of new multi-material/multi-technology AM concepts and the integration of these technologies in mass-customization production chains, making AM an integral part of a 'next generation industrialization with emphasis on new functionality and cost-effective manufacturing while Vat photo-polymerization maintaining system flexibility, stability & reliability.

8.4.2 Program 2015

In 2015, 16 PhD projects were defined with TU/e and University of Maastricht in the field of advanced polymers for AM and biomedical applications. Also, a collaboration with HZuyd was established. In addition, good progress was achieved in the field of functional photo-polymeric materials for dental applications. A work plan was defined with industrial partners to further expand the dental applications into printing of multi-color dentures.

The 'Systems for AM' program has a strong representation in EU (involved and leading several EU programs on hybrid manufacturing and multi-technology digital manufacturing and strong involvement in the AM platform) and has positioned the Multi-Material 3D print Fieldlab with 20+ partners in the context of the national Smart Industry action agenda. Within this Fieldlab, a collaboration with ECN on ceramic AM technology and applications is established. The program targets human-centric and high-tech customization applications, including medical, dental, 3D structural electronics and food/pharma, with spin-off to other markets that require personalized, customized, on-demand manufacturing. Within the collaboration, 7 PhD projects were defined, including projects on ceramics, food printing concepts and hybrid integration.

8.4.3 Results

- A full integrated continuous AM technology was showcased at a line speed of 1 m/s, including the printing of 3D parts, the inline metrology, in-line post-processing via selective ablation and product handling.
- Good progress was made in the development of a laser-array technology for in-line SLS (thermal sintering) for mass-customization applications (like footwear, 3D electronics and exoskeletons). The technology will be commercialized via a spin-out company.
- The high-resolution, high speed multi-laser array technology was successfully used for multi-material and ceramics photo-polymerization applications. Ceramics and multi-material parts with a resolution below 50 micron were made.
- The research done on functional materials for dental applications led to the market introduction of 8 biocompatible materials and a dental printer by partners.
- A first step towards the full-integration of electronic components in 3D printed parts was made, showcasing printed conductive tracks, embedding of electronics (LEDs, battery, chip) and multi-material printing of optical elements.

- A model was developed to predict the thermal history during the AM process and the related phase transitions (w.r.t. required strength and ductility).
- A model was developed to predict the heat up of the product during the build.

8.4.4 Overview cooperations

- 'Materials for AM' program, with research partners TNO, HZuijd, TU/e, industrial partners.
- 'Systems for AM' initiative, with research partners TNO, TU/e-HTSC, industrial partners, and 10 EU projects with 80+ partners.
- Smart Industry Fieldlab MultiM3D with 20+ partners.
- PPS on materials for AM, with NLR, M2I, TUD, UTwente, with 8 industrial partners.

8.5 Roadmap Healthcare

8.5.1 Introduction

The Van 't Hoff Program is a Shared Research and Innovation Program in the field of biomedical optics. The program forms an ecosystem where industry, hospitals, research institutes and health foundations collaborate in order to accelerate medical and technological innovations and their implementation in health care. The program aims to improve medical diagnosis and therapy through the development of innovative medical devices based on photonics and biomedical technologies to enable better and faster diagnosis and monitoring of diseases in (a)symptomatic stages; better and/or personalized treatment for patients; and less invasive surgical procedures leading to improved health outcomes, reduced healthcare costs and a sustainable health care system.
The 2015 work focussed on a sensor for *selective ion measurement during dialysis*; *sensor systems to measure neurodegenerative diseases (ND) related biomarkers*; a *sensor for non-invasive glucose measurement* and a *screening instrument for risk assessment of the development of cancer*. Several optical technologies are integrated on our technology platforms (a nano-photonic biosensing platform, a tissue characterisation platform, a fluid characterisation platform, an ophthalmic imaging platform and a fiber optic sensor platform) and are used as underlying technologies for our developments.

8.5.2 Program 2015

We have designed a TRL 5 model of the Laser Induced Breakdown Spectroscopy **(**LIBS) sensor for the *selective ion measurement*. The building and testing was slightly delayed due to a delay in the manufacturing of the spectrometer. We re-designed our *biosensing platform* for accurate multiplex measurements of 4 analytes as planned and started with Amyloid B experiments for the detection of this *ND biomarker*. Furthermore we worked on a 1.0 version of the prospective method for *non-invasive glucose measurements* and started working on the 1.1 version. We've also re-designed the hardware in order to miniaturize the sensor. We designed and tested a sensor concept for a *minimally invasive* glucose measurements. The development of an easy to use *screening instrument for risk assessment* of cancer by a simple measurement of mucosal tissue was executed as planned.

8.5.3 Results

The *LIBS sensor* was redesigned in order to improve performance and to meet the required system goals. This resulted in a system comprising of a new type of spectrometer (patent pending), less (expensive) optical components and less laser pulse energy. The system was tested and partly validated in a relevant environment. We improved thermal interface, sensor cladding and the signal processing (patents pending) of the *ring resonator biosensor*, the latter resulting in the ability to simultaneously read-out 4 ring resonators. We also started a track to detect ND based on *retinal imaging*. Here we identified a set of candidate ND related retinal biomarkers and designed an optical platform to image and facilitate measurement of both the size distribution as well as the retinal localization of biomarkers in vivo and we tested our eye tracker. We extended and analysed the dataset of the measurements with our Raman spectroscopy based sensor prototype in order to develop and improve the method we use for prospective analysis of the glucose data. Furthermore we focused on preparing the technique and method for future adaptation in a hand held device. We investigated the influence of fiber geometry on the sensor signal of the minimally invasive sensor concept. We designed and started to build 3 *screening instruments* (including probe) for *risk assessment of cancer*. The in vivo testing in a clinic has started and protocols for the testing and staining of biopsies were developed.

8.5.4 Overview cooperations

In 2015 new corporations started with 2 health foundations, 6 companies, 2 universities and 1 hospital amounting to a total of 6 health foundations, 9 companies and 5 research organisations and 5 academic hospitals that are part of our ecosystem. The Van ‘t Hoff activities are embedded in the HTSM Roadmap Healthcare that was revised in 2015. As secretary of the Roadmap, the manager of the program has fulfilled an editing role for the 2015 HTSM Healthcare Roadmap revision.

8.6 Roadmap High-Tech Materials

8.6.1 Materials for Extreme Conditions

Introduction

TNO, NLR and a consortium of partners are working on improving the understanding of the performance of materials used in extreme conditions, removing unnecessary barriers of conservatism, and improving processes. The materials considered are: fibre reinforced composite materials; steel and aluminium for structural applications; and coatings for high temperature applications. Serving several knowledge ecosystems, the research is executed in separate JIPs (Joint Industry Project or Public Private Partnership).

Program 2015

The Network “Materials for Extreme Conditions” is established which serves as the platform to exchange information between JIPs and initiate new JIPs. JIPs on composite materials: 1) development of a nondestructive inspection procedure to detect manufacturing flaws and realistic in-service damage in thick, prime carbon aircraft components; 2) development of models to predict the durability and degradation over service life of thick glass composites joints. JIP on metals: development of a low-cost test procedure to measure the near to brittle fracture toughness of steel. Three further JIPs are in the process of initiation on the subjects: 1) variable amplitude fatigue of steel/aluminium; 2) multimode brittle fracture of steel; 3) thermal barrier coating.

Results
Durability of hybrid bonded glass composite joints: 2 PhD studies have started; the model approach to be explored further is selected and materials/structures to validate the model are identified.
Fracture toughness test method for steel: the feasibility to use the AFSuM for higher material toughnesses has been demonstrated and the experimental program has been detailed.

Overview cooperations
Network Material for Extreme Conditions: cooperation with NLR, M2I, TU Delft, 1 SME, 7 industrial companies, 1 Dutch governmental body. It is expected that the Network will grow with 8 parties in 2016.
Closely related projects/initiatives:

- TKI-WoZ: FeLoseFI; Monitor; Microbe
- ERP Structural Integrity
- Offshore wind research program EUROS

8.6.2 Thin Layer Manufacturing Program

Plasma Enhanced Spatial Atomic Layer Deposition

Introduction
In this program TNO is working together with a consortium of industrial and academic partners on optimization, scale-up and applications of new dedicated plasma sources for Spatial Atomic Layer Deposition (SALD). SALD is an emerging technology for fast deposition of high quality thin films and enables 100x faster deposition rates with respect to current time-sequenced ALD. The plasma enhanced version of this technology (PE-SALD) is needed for a variety of thin film applications such as hydrogen doped transparent conductive layers in solar cells, titanium nitride conductors and blocking layers in batteries. In addition the plasma application is necessary for high throughput ALD applications at reduced temperatures. An example is roll-to-roll ALD on temperature sensitive polymer foils, replacing the traditional water co-reactant by oxygen plasma.

Program 2015
A first activity in 2015 (WP1) was to develop and benchmark different electrode materials and geometries for laboratory scale plasma sources. These 30 mm wide sources have been tested in an existing ALD laboratory scale reactor.
The dimensional and chemical stability of 400 mm wide plasma sources based on the same basic concepts have been tested separately in a tube oven facility (WP2).
The plasma source developments have been supported by modelling of gas flows and active plasma species transport including radical recombination losses.
Different from the original plan, the design and development of a 2nd laboratory scale ALD reactor has been added to the program as work package WP3. The second reactor is necessary for better controlled gas and temperature conditioning for deposition of for example high performance barrier coatings, battery materials and for the associated more stringent gas safety measures. Moreover the new ALD reactor head offers the space needed for wider plasma sources and for optical plasma diagnostics directly in the head (WP5).
Plasma ALD process research for new materials (WP4) has been started-up using the existing ALD reactor and will be further extended during 2016 with the availability of the 2nd ALD reactor.

Results
<u>Laboratory and upscaled plasma sources for PE-SALD systems (WP1, WP2)</u>

Problems of particle contamination caused by the laboratory sources have been solved by redesigning gas flow paths in the source and replacing stainless steel electrode materials by Titanium. A structural and elemental analysis (SEM, EDX) shows that Titanium remains stable under various plasma conditions even at high temperature. In addition Raman spectroscopy has been used to show that Ti contamination of dielectric parts of the sources is absent. However, the tests revealed contamination from gas lines. An enamel based scaled-up electrode structure has been tested and proven chemically stable. High resistivity silicon carbide has been tested as dielectric material as well but appeared unsuitable because of too high conductivity in the desired PE-SALD temperature window (room temperature up to 250°C). On the contrary, low resistivity SiC has been shown very promising as chemical stable material suited for homogeneous plasma generation. This use of this material will be further explored. A very significant improvement of plasma homogeneity has been shown as well by using a partial remote and partial direct plasma.
For substrates sensitive for direct plasma or high electromagnetic field (such as substrates comprising parts of electronic devices) a 100% remote plasma source has been developed where plasma species are pushed to the substrate with high gas flow. The patented principle has been shown very effective for a particular device application. As for this type of remote plasma source, high gas consumption may be a concern, it has been proposed to mix gas flows downstream of this remote source. CFD-plasma model calculation show that indeed gas flows can be reduced significantly in this way. The idea has already been implemented in the design of 3rd generation plasma sources to be tested in the course of 2016 on the new (2nd) ALD laboratory reactor.

WP3 New ALD reactor development
The development has passed the phases of detailed specifications, conceptual designs and agreement of partner contributions. First testing is anticipated during the 2nd quarter of 2016, full operation with 3rd generation plasma sources in the 3rd quarter.

WP4 PE-SALD process development
The application of direct plasma sources for highly homogeneous ALD films has been shown for a number of materials such as ZnO, In_2O_3, Al_2O_3, TiO_2, SiO_2. In scaled-up systems, where the distance between the ALD injector head/plasma source and substrates is necessarily much larger. Increasing the gap distance from 0.02 to 0.2 mm not only affects plasma effectiveness (unsaturated layer growth) but also plasma homogeneity. The remote plasma operation mode appears to offer a potential solution here but with the remote source tested so far layer inhomogeneity appears due to insufficient gas flow distribution. The 2nd generation remote plasma has much improved flow conditions and will be tested in the first quarter of 2016. Particular promising results have been obtained by developing a new process for hydrogen doped Indium oxides using hydrogen or water in the direct plasma source. Surface conductivities are already in the range of conventional ITO layers even before systematic parameter optimization. As a summary we gained insight in the applicability of direct and remote plasma sources for different types of substrates and devices, have extended the plasma application from functional oxides to conductive hydrides in 2015 and will further optimize those processes in 2016. In addition, the improved gas flow conditions enabled by the new ALD reactor and 3rd generation plasma sources are expected to enable deposition of metal nitrides.

Overview cooperations
For this program industry participation contracts have been signed in 2015 with Meyer Burger (former Roth and Rau) in Eindhoven and with Xycarb Ceramics in

Helmond defining their financial and in kind contributions to the program. The cooperation with the Eindhoven Technical University is based on two appointments. A Technology Designer in Training (TOIO) started in 2015 to design an in situ ellipsometry system for measuring atomic layer properties during deposition, and an emission spectroscopy system for detection of the active gaseous plasma species. A FOM PhD project proposal has been submitted by prof. dr. F. Roozeboom and prof. dr.ir. W. Kessels (TU/e Plasma Materials and Processing group. It has been approved in December 2015 and the PhD vacancy is available from January 2016. The subject of the PhD research is application of Microscale Diagnostics of Atmospheric Pressure Proximity Plasmas for Spatial Atomic Layer Deposition (HTM call project number 15HTM2013).

8.6.3 Additive Manufacturing

Introduction

TNO is together working with NLR and a consortium of partners on understanding and improving the metal print process.

Program 2015

TNO focuses in this program mainly on modelling and NLR more on the experimental part. 2 types of models are being developed. Models that can help understand and optimize the process and models that can help to make a one-time right build of a product.

Results

Models have been developed to make a detailed prediction of the thermal history of the material during Selective Laser Melting. This is used in combination with an also developed model of the material phase transition of Ti6Al4V. This was used to predict an optimum temperature trajectory to get the required strength and ductility of the material.
Also a thermal model has been developed on a more product scale. This model predicts the heat up of the product during the build. This can cause local overheating and is strongly dependent on the design. The models will in the future be used to take proper actions and optimize the build orientation, support structure and if necessary the design before actually building the object. It will also be coupled with a mechanical model to predict the internal stresses and deformation in a product.

Overview cooperations

PPS Materials (Metals) for Additive Manufacturing cooperation with NLR, M2I, TU Delft, UTwente, TU Eindhoven and industrial partners
EU project Borealis
EU project E450 LMDAP

9 VP ESI

9.1 Roadmap Embedded Systems

9.1.1 Introduction

About embedded systems. Embedded systems are defined as the collection of hardware and software components (computer technology, software, semiconductors, control, actuators, sensors, etc.) that are built into high-tech systems and devices. These are not necessarily recognized as computers, but as intelligent autonomous devices.

Embedded systems are omnipresent in today's computerized world. They are at the heart of all innovative high-tech products and applications and represent one of the fastest growing global markets. To illustrate this, it is estimated that only about 4% of the computer chips that are produced globally will end up in a normal computer - the remaining 96% is used to become part of the hidden computerization in the form of embedded systems.

The Dutch high-tech industry is at the forefront of this development. It is world-class, adding significant value to our national economy, and represents one of the largest and fast-growing industrial sectors[3]. To these companies, the development of latest high-tech products, with enhanced functionality, better cost-performance and flawless integration in the end-user environment, are key attributes for a leading global competitive position. But also emerging manufacturing processes[4], require latest solutions that heavily rely on embedded systems technology.

The advances of embedded systems do not limit themselves to industry. With few exceptions, most societal improvements incorporate embedded applications in one form or another, with the aim to improve quality-of-life, or enhance effectiveness and efficiency of service. Societal sectors that are actively embracing embedded system technology are, among others, health and wellbeing, transport and logistics, safety and security, energy and environment, but many others could be mentioned.

These challenging industrial and societal needs make latest professional capabilities for design and engineering of high-tech and embedded systems a key competitive discriminator. The ever increasing complexity and multidisciplinary characteristics of their products and services, requires a more fundamental basis for embedded systems engineering to ensure lasting effectiveness, efficiency, reliability and security, as well as improve on their quality and costs.

TNO-ESI demand driven program. A common denominator for both the industrial and societal stakeholders is their need for access to distinguishing technology, state-of-the-art development processes and tools, leading capabilities for design and engineering, and a highly qualified workforce. This requires an organization that explores, facilitates and strongly supports these strategic needs through a process of open innovation.

The TNO-ESI research group[5] is organized as a Joint Innovation center (JIC) within the TNO focus area for industry. It addresses the abovementioned needs through a 'demand-driven' innovation program (VP) in a number of different ways: (i) national

[3] Turnover is estimated to be more than B€ 30/year.
[4] These are extensively discussed in "Industry 4.0" and "Actieagenda Smart industry".
[5] ESI is the acronym for "Embedded System Innovation".

and European research programming[6], (ii) an extensive portfolio of joint research projects, (iii) a dedicated program for knowledge consolidation and dissemination, and (iv) a competence development program for training and education of system architects. Please refer to www.esi.nl for details.

HTSM roadmap on Embedded Systems. A large number of application- and technology-based Roadmaps form the heart of the Topsector HTSM, of which the Embedded Systems Roadmap represents an important cross-sectoral building-block. TNO-ESI is a leading member of the HTSM roadmapteam, and editor of the Embedded Systems Roadmap[7]. This guarantees a strong alignment between the HTSM Roadmap for Embedded Systems and the strategic research agenda of TNO-ESI in general. Please refer to www.topsectoren.nl for details.

TNO-ESI Research agenda 2015-2018. The TNO-ESI research projects predominantly focus on multi-disciplinary challenges in system design and engineering. It emphasizes the fact the ever-increasing complexity of high-tech system design cannot be dealt with by the current, mainly mon-disciplinary design methods and tools. To address these emerging knowledge needs, it focuses on four key lines of innovation: (i) system performance, (ii) system quality and reliability, (iii) future-proof systems, and (iv) systems in context, as further elaborated in the HTSM Embedded Systems Roadmap.

9.1.2 Program 2015

TNO-ESI Program 2015. The TNO-ESI research projects are funded by means of a Public Private Partnership, typically based on 50% - 50% with TO2 flex-budget and industrial or European contributions. In 2015 the following projects were part of the TNO-ESI portfolio in this way:

1. **CARM2G.** A joint project with ASML that addresses performance of complex real-time (mechatronic) control systems. The goal of the research project is to develop new model-based methods and techniques to specify and design highly complex real-time multidisciplinary systems. The research focuses on control of advanced mechatronics systems, deploying platform-based hardware and software architectures. A key part of the research focuses on intelligent scheduling strategies to maximize (real-time) system performance, using these computing resources.
2. **TheMa.** A joint project with ASML that addresses model-based testing, user profiling and health monitoring and the coupling between these aspects. The objectives are to (i) improve the overall effectiveness of the testing process by model-based test techniques. (ii) include usage models obtained from customer profiling for dedicated test sequences that apply realistic use cases, and (iii) develop strategies for data collection, processing and analysis that monitor system behavior and interaction in operational use to detect any current or emerging error state.
3. **Integrated Performance.** A joint project with ASML that addresses early verification of system behavior. The objective is to: (i) optimize the product development process by the introduction of an incremental system integration process, (ii) develop integration strategies that support system performance analysis at the earliest product development stage, (iii) develop tools and techniques for optimization of the integration process to a variety of criteria, such as component availability, availability for (partial) test, project risk, lead-time, etc.

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[6] Incorporation both industrial and academic stakeholders.

[7] HTSM Roadmap Embedded Systems 2012, 2015.

4. **Octo+ 2015 (data path).** A joint project with Océ Technologies that addresses model-based techniques for optimization of design trade-offs. The objective is to develop an approach in which physical systems are represented by virtual models in such a way that they can be used to analyze the system's functional and non-functional characteristics at earlies possible design stage. The models can be used to: (i) eliminate the need for costly physical prototypes, (ii) predict the impact of system variations and design alternatives, and (iii) enable (semi-automatic) code and product configurations synthesis.
5. **Octo+ 2015 (system architecting).** A joint project with Océ Technologies that addresses model-based architecting methods for complex multidisciplinary systems. Goal of the research project is to develop, explore and introduce model-based architecting processes, methods and tools. Focus is on advancing an architecting paradigm in which high-tech systems are represented by quantitative (executable) models, thereby allowing system architects to virtually analyze design criteria and system trade-offs before any physical prototype is built.
6. **PROMES.** An ITEA2 project that addresses the development of process models for engineering of embedded systems. The goal of the project is to deliver a flexible industry-wide product innovation process framework. This includes a supporting (model-driven) engineering toolset that: (i) supports cooperative developments across multiple disciplines, (ii) supports product innovation teams on multiple geographic locations, and (iii) incorporates the flexibility to support multiple life-cycle approaches.
7. **Allegio.** A COMMIT project with Philips Healthcare that addresses composability of complex systems. The objective of this research project is to develop advanced model-based software design techniques that formally evaluate the correctness of designs and automate labor-intensive activities. This includes both design models, that are part of the design-flow which ultimately result in code, and analysis models that evaluate certain aspects such as performance, evolvability, and functional correctness.
8. **Crystal.** An Artemis project that addresses the development of a tools chain for safety-critical embedded systems. The overall goal of the research project is to foster Europe's leading position in design, development and deployment of interoperable safety-critical embedded systems, adressing both functional and non-functional design criteria.
9. **Metis.** A COMMIT project with Thales that addresses the development of cooperative systems-of-systems (cyber-physical systems) for situational awareness in public safety and security. The goal for the research project is to provide key enabling technologies for the next generation of situational awareness systems.
10. **Prisma.** An joint project with Philips Lighting that addresses the development techniques for robust control of distributed systems (cyber-physical systems). The goal of the research project is to: (i) develop methods and techniques for system robustness & reliability analysis, (ii) develop the associated concepts and architectural guidelines, and (iii) develop techniques to reduce risk and integration effort for on-site commissioning.
11. **OpenAIS.** A H2020 project that addresses open architectures for intelligent lighting systems. The goal is to develop a leading standard for SSL systems as a fully internet connected system with open interfaces for all components.
12. **EMC2.** An Artemis project that addresses the development of embedded multi-core systems for mixed criticality applications in real-time environments. The focus of the project is on methods and techniques with application for Advanced Driver Assistance Systems (ADAS) in cars and trucks.

9.1.3 Results

For each of these research projects, new methods and techniques have been developed that were tested up to Proof of Concept, using *real* industrial cases. In most cases the respective industrial research partner(s) have adopted, industrialized and integrated these results into their own operational practice. In addition to this, TNO-ESI has paid special attention to further generalization, consolidation and dissemination of the research findings, in order to maximize the knowledge and investment multiplier, both towards industrial and academic stakeholders.

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10 Smart Industry

10.1 Roadmap Mechatronics and Manufacturing

Het TO2 flexbudget voor het Thema Inclusieve Maatschappij is conform de afspraken ingezet in twee onderwerpen, namelijk het Smart Industry programma en het Additive Manufacturing (3D) printing programma.

10.1.1 Smart Industry

TNO heeft in 2015 het TO2 flexbudget besteed aan de strategische ondersteuning (WP2) en de opzet van de volgende Smart Industry Fieldlabs: Flexible Manufacturing, Smart Food (now FreshTe.nl), RoSF (WP1) en de ICT support Smart Dairy Farming en de Digitale Fabriek (WP3). De opstart van het 3D multimaterial (3DMM) Fieldlab valt onder het andere deel van het TO2 flexbudget.

Strategische ondersteuning

Dit betrof vooral de ondersteuning van enkele regionale Smart Industry agenda's, de internationale vergelijking van soortgelijke vierde industriële revolutie programma's in het buitenland en het nog te publiceren onderzoek naar de verwachtte ecosysteem effecten van Fieldlabs. Daarnaast is een deel van het budget ook ingezet in de adviezen aan de Topsector en EZ m.b.t. de optimale financieringsmix van Fieldlabs (nu bekend als de PPS 50/50 discussie). Tenslotte is gewerkt aan de uitwerking van de kennis agenda met support aan de Scientific Roadmap Smart Industry 2015-2025 en de voorbereiding van de NWO/STW call 2016. Al deze onderwerpen zijn op regelmatige basis afgestemd met het Smart Industry Programmabureau. De inzet van TNO in het Smart Industry Programmabureau valt niet onder het TO2 flexbudget, doch komt uit de eigen inzet van TNO.

De resultaten zijn o.a. een bijlage aan de Tweede Kamer brief van september 2015 over de internationale vergelijking en de publicatie van de Scientific Roadmap, alsmede twee regionale agenda's (Oost en Zuid). Andere producten zitten nog in de pijplijn voor het voorjaar 2016 (ecosysteem effect, PPS50/50, STW call tekst). Ook is op basis van bovenstaande strategische ondersteuning mee gewerkt aan Europese voorstellen die in januari 2015 zijn ingediend.

Fieldlabs opzet

De opstart van de Fieldlabs en in het bijzonder de financiering daarvan via o.a. de EFRO is aanmerkelijk lastiger gebleken dan verwacht. Ook het proces om tot goedkeuring te komen duurt aanmerkelijk langer dan verwacht. Voor TNO zijn de condities uitermate ongunstig en daarom is dan ook besloten om in een aantal gevallen zelfstandig met de partijen al aan de slag te gaan via HTSM en extra HTSM middelen. Smart Dairy Farming, Flexible Manufacturing, Digitale Fabriek (en 3DMM) zijn met deze middelen nu gestart. RoSF en SmartFood verwachten hun start rond 1 maart.

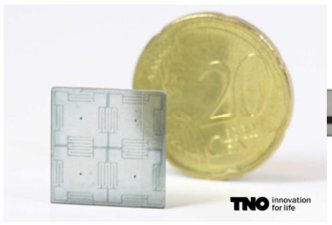
Opgemerkt moet worden dat met de andere 4 Fieldlabs (Smart Bending Factory, CAMpione, Secure Connected Systems Garden, UPPS) uitgebreid is gesproken. Om diverse, afzonderlijke redenen is er (nog) niet sprake van concrete substantiële deelname van TNO of anderszins sprake van forse voorinvestering vanuit het TO2 flexbudget van TNO.

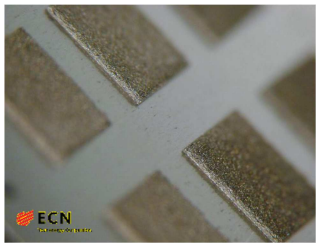
Over het jaar 2015 heeft het Smart Industry Programmabureau een jaaroverzicht http://www.smartindustry.nl/wp-content/uploads/2015/12/SI-jaaroverzicht-los-.pdf gemaakt waarin het totale beeld wordt gegeven.

10.1.2 Additive Manufacturing (3D) Printing Programma

Industriële Additive Manufacturing (AM) wordt beschouwd als een potentiële doorbraak-productietechnologie voor een scala aan toepassingen onder andere in de medische en high-tech sector. Op Europees niveau zijn gezamenlijke AM Roadmaps en AM standaardisatie-activiteiten geformuleerd. De meeste initiatieven beogen het ontwikkelen van mono-materiaal technologie. Multi-materiaal technologie staat nog in de kinderschoenen maar is een van de grote beloften van Additive Manufacturing die het mogelijk maakt complexe producten met uiteenlopende materiaal eigenschappen in een keer te fabriceren.

Zowel binnen TNO, als binnen ECN en NLR wordt gewerkt aan Additive Manufacturing, elk met een focus op andere technieken en materialen. De doelstelling van dit project is de kennis van elkaars expertise te vergroten en te profiteren van de onderlinge synergie. Op deze wijze wordt geprobeerd tot een aantal veelbelovende doorbraken te komen op het gebied van Multi-Material Additive Manufacturing.



De gekozen aanpak is te werken aan een aantal technologische concepten op het gebied van Multi-Material Additive Manufacturing die op de kruispunten van de kennisposities van de deelnemende instituten liggen:

- Metaal
  Hier is gewerkt aan het door middel van lasersintering verwerken van materiaalcombinaties met interessante eigenschappen, (bijvoorbeeld slijtvastheid en taaiheid) en het creëren van overgangen tussen deze materialen. Hierbij is gebruikgemaakt van de uitgebreide kennis op metaalkundig gebied bij NLR en ECN, laser faciliteiten van ECN, een speciaal hiervoor ontwikkelde SLM testmodule van TNO en de selective laser melting faciliteiten van NLR. Tevens is gewerkt aan een alternatieve methode om metaal te kunnen 3D printen door middel Vat foto-polymerisatie gecombineerd met sintertechniek. Hierbij is gebruikt gemaakt van de kennis op het gebied van printen van slurries van ECN.
- Keramiek
  Hier wordt gewerkt aan mogelijkheden om keramische delen te combineren met metalen bijvoorbeeld om geleidende sporen te kunnen realiseren. Hierbij is gebruikt gemaakt van de kennis op het gebied van printen van slurries en de laser faciliteiten van ECN.
- Polymeren
  Het onderzoek hier richt zich op het kunnen combineren van verschillende polymeren en het kunnen realiseren van 3 dimensionale geleidende sporen in kunststof delen door middel van Vat foto-polymerisatie. Hierbij is vooral gebruik

gemaakt van het TNO Lepus Next Gen research platform voor multi-material Vat foto-polymerisatie.

De activiteiten hebben geleid tot nieuwe kennis op het gebied van multi-material Additive Manufacturing en een aantal technologie demonstrators waarmee industriële partners geïnteresseerd kunnen worden in verdere ontwikkeling van de technologie.

Metaal
Voor multi-metaal selective laser melting zijn twee verschillende metaal combinaties onderzocht op printbaarheid en de eigenschappen van de materiaalovergangen. Dat zijn de overgangen tussen RVS (SS316) en nikkel (Inconel 718) geprint met de SLM machine bij NLR, en RVS(SS316L) en koper geprint in een speciaal door TNO ontwikkelde mobiele selective laser melting module op laser systemen van ECN. Naast de hierboven genoemde monsters is een demonstrator geproduceerd door middel van Selective lasersintering vervaardigde warmte wisselaar van RVS (SS316) en Nikkel (Inconel 718) die vervaardigd is in de metaal printer van NLR. ECN heeft analoog aan het keramiek print proces via Vat foto-polymerisatie een alternatief metaal printproces ontwikkeld. In de toekomst zou dit onder andere toepassing kunnen vinden in multi-materiaal keramiek-metaal producten.

Keramiek en Polymeren
Er is gewerkt aan nieuwe concepten voor multi-materiaal Vat foto-polymerisatie waarmee producten gebouwd kunnen worden vanuit verschillende harsen. Dit kunnen twee verschillende polymeren zijn, een polymeer en een geleidend materiaal in een polymeren matrix, maar er kan ook gedacht worden aan het combineren van keramiek-slurry en metaal-slurry, om na een co-sinter-stap een product met 3D geleidende 3D sporen van hoge nauwkeurigheid te krijgen in een product van hoofdzakelijk keramiek. De multi-materiaal Vat foto-polymerisatie technologie biedt bijvoorbeeld mogelijkheden bijvoorbeeld op het gebied van meta-materialen, embedded electronics en koelkanalen. Er is kennis opgedaan in de procesontwikkeling van multi-materiaal Vat foto-polymerisatie en er zijn verschillende multi-polymere demonstrators gerealiseerd.

De ontwikkeling van vervolg trajecten is gedurende het project al ter hand genomen. Een eerste voorbeeld hiervan is het 3D Multi-Material Fieldlab binnen het Smart Industry initiatief waarin TNO en ECN met een aantal industriële partners zullen gaan samenwerken aan de ontwikkeling van large area keramiek printen. Tevens zal tussen TNO en ECN op het gebied van keramiek verder samengewerkt gaan worden in het kader van TKI. Tussen TNO en NLR loopt al een samenwerkingsverband op het gebied van metaal printen voor de aerospace industrie.

11 Ondertekening

Eindhoven, 1 februari 2016 TNO

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