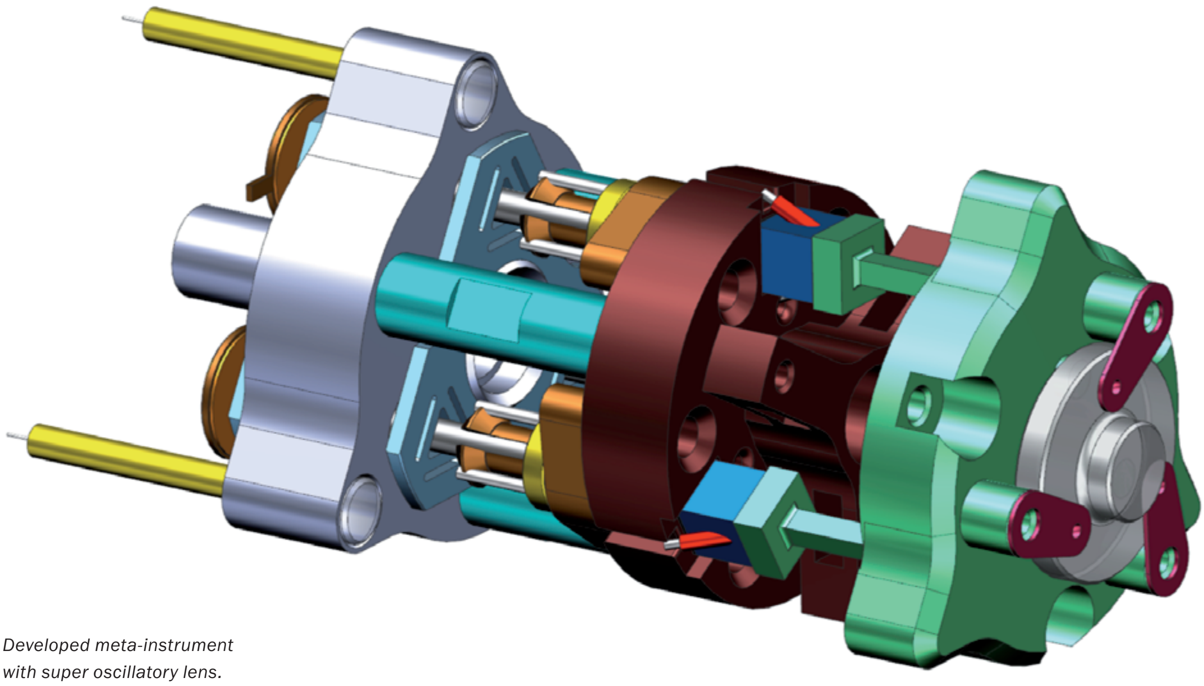
REPORT ON THE ENABLING TECHNOLOGY PROGRAMME OPTOMECHATRONICS



Developed meta-instrument with super oscillatory lens.

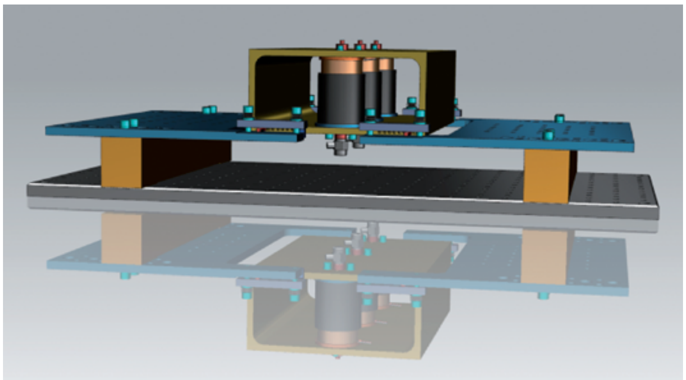
TNO innovation for life

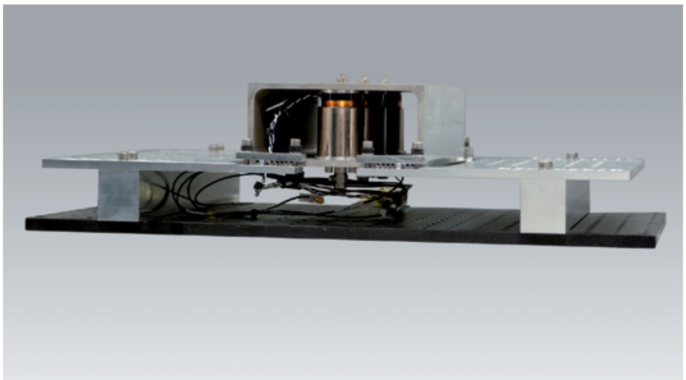
The last four years the research Programme Optomechatronics focused on the development of new key technologies for manufacturing and testing equipment and scientific instrumentation. The challenge is to develop instruments with higher accuracy, less costs and higher throughput than we can achieve today. This is relevant for developing the next generation semiconductor equipment, for space and scientific instruments and for improving manufacturing equipment.
Four research lines were conducted contributing to capabilities beyond conventional instruments and equipment.

MASTERING THE BEHAVIOUR OF COMPLEX DYNAMICAL SYSTEMS

Today, realisation of high-precision opto-mechanical and opto-mechatronic systems largely builds upon the classical design principles, such as 'light and stiff' and 'static determinacy'. These principles essentially try to avoid dynamics in the system by pushing the first eigenfrequency as high as possible. However, as the requirements on such systems are becoming more stringent, this approach is likely to soon hit the wall, and dynamics will become decisive in the overall performance. However, accurate predictions of the dynamic behaviour of complex systems is far from trivial. Hence, development of reliable dynamics analysis techniques is needed, in order to increase understanding of dynamics and pave the way for designs in which dynamics are used instead of avoided.

In order to master such dynamic challenges, TNO has started both internal research and a close cooperation with Eindhoven University of Technology. In the former, multiple cases of existing equipment in which dynamic behaviour turned out to be performance-limiting have been re-analysed and thoroughly investigated. This resulted in the development of new dynamics analysis tools, with which root causes of dynamical issues have been successfully identified. Application of these tools to an ongoing design case has led to the hypothesis of new design rules, in which a dynamic subsystem is made insensitive to its surrounding dynamics via suspension of this subsystem on specific dynamically determined points. These rules have been further investigated via the design, realisation and measurement of a dedicated test setup to arrive at unsurpassed dynamic performance, matching the predictions.





Design and realisation of the Dynamic Design Demonstrator (DDD), a setup in which the first design principle has been validated. Optimal input-output dynamics can be achieved by tuning both the suspension points and the force distribution.

RESULTS

Overall, in this research TNO has taken important steps towards advanced insight in dynamics and new design principles. A patent is pending and two scientific papers on this subject are published.

In its continuation, the developed analysis tools will be elaborated, and the lessons learned will be brought into practice in future system designs. One of these lessons is to explicitly take dynamics analyses into account in every design process, and to explicitly make use of the dynamics in order to meet the increasing performance requirements. Along the way this will also lead to the discovery of more dynamic design principles.

MINIATURISED OPTO-MECHATRONICS

Conventional opto-mechanics technology based on classical optics and continuum mechanics theory cannot fulfil the requirements for future production and inspection, since they are at the fundamental limit of their performance. An example is optical metrology and lithography that suffer from lack of sufficient resolution for features with nanometre dimensions. Nanomechanics based technologies such as near field methods or probe based techniques show sufficient resolution and performance at nano-scale. This research line aimed at developing technologies based on nanomechanics for future instrument development.

Scanning probe microscopy (SPM) is emerging as an essential nanoinstrument in many applications where nanometre resolution imaging and characterisation are required. The ability to accurately measure critical dimensions in nanometre scale, has made it an important instrument in several industrial applications such as semiconductor, solar and data storage.

Examples of applications are surface roughness, channel height and width measurement, defect inspection in wafers, masks and flat panel displays. In most of these applications, the target area is very large, and, therefore, the throughput of the measurement plays an important role in the final production cost.

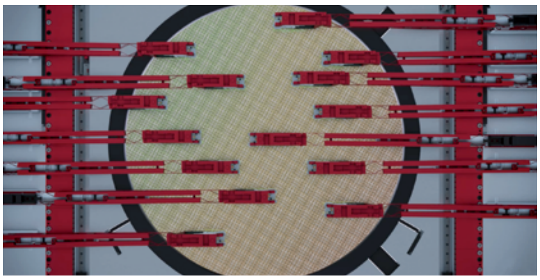
Single SPM has never been able to compete with other inspection systems in throughput, thus has not fulfilled the industry needs in throughput and cost. Further increase of the speed of the single SPM helps, but it still is far from the required throughput and, therefore, insufficient for high-volume manufacturing.

A close cooperation with Delft University of Technology via two PhD projects financed by this programme, ensured investigation of more fundamental challenges and risks. The aim of these two PhD programme was to develop a massive parallel SPM system.

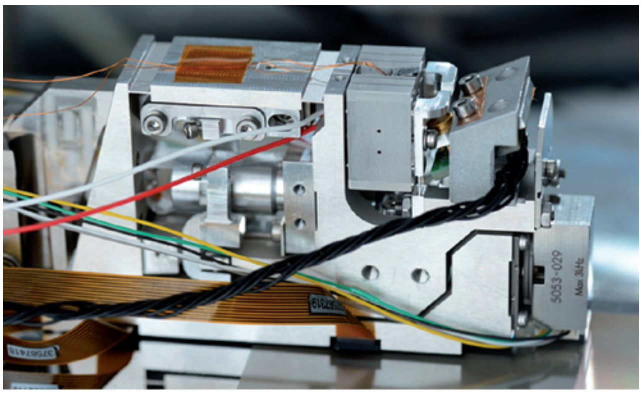
RESULTS

Over the past three years at ETP Opto-mechatronics, a revolutionary concept for a multiple miniaturised SPM heads system has been developed, which can inspect and measure many sites in parallel. The very high speed of miniaturised SPM heads allow the user to scan many area, each with the size of tens of micrometres, in few seconds. Our recent experimental results have convinced us that the time for a parallel SPM has arrived.

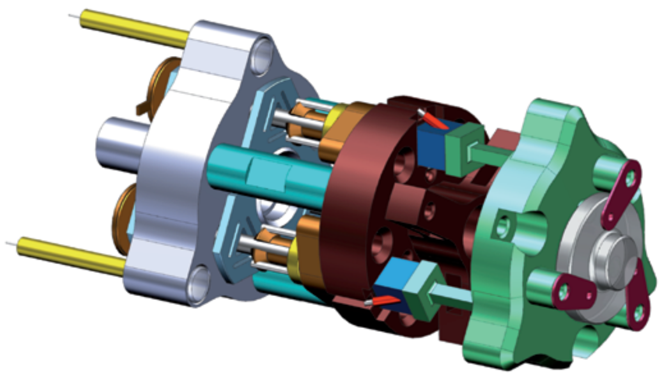
These research line has led to over 10 internationally granted patents and 5 scientific publications in journals and on conferences. One of them was awarded as second best paper of the conference.



Schematic illustration of parallel SPM to image several locations on a wafer or mask. Multiple positioning arms on two sides of the wafer stage, each capable of moving a miniaturised SPM scan head on to a large sample. Many parallel miniaturised SPM heads enable full area coverage at high throughput.



Picture of one of the demonstration heads.



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META-INSTRUMENTS

In order to sustain the current capabilities and momentum in the technology roadmaps for 3D nanomanufacturing, enhancing yields and reducing the time-to-market are essential. This has to be done while simultaneously maintaining reliable manufacturing. Yields are enhanced by getting faster and higher-quality data. The process geometries and device dimensions are shrinking to the level that the conventional technologies currently used for production, quality control and inspection are approaching physical boundaries.

The aim of this programme is to realise concepts which rely on combining photonic metamaterials, which allow light localisation and imaging at sub-wavelength scales, with nanomechanical functionality. Mechanically compliant metamaterials – consisting of arrays of tailored plasmonic nano-antennas or waveguides on mechanical nanobeams – constitute nano-optomechanical systems, in which optical fields and mechanical motion are mutually coupled. This meta-material-based platform provides two functionalities. On the one hand, metamaterials will be developed, which the localised optical fields close to the surface, so-called ‘hot spots’, are strongly affected by nanoscale displacements.

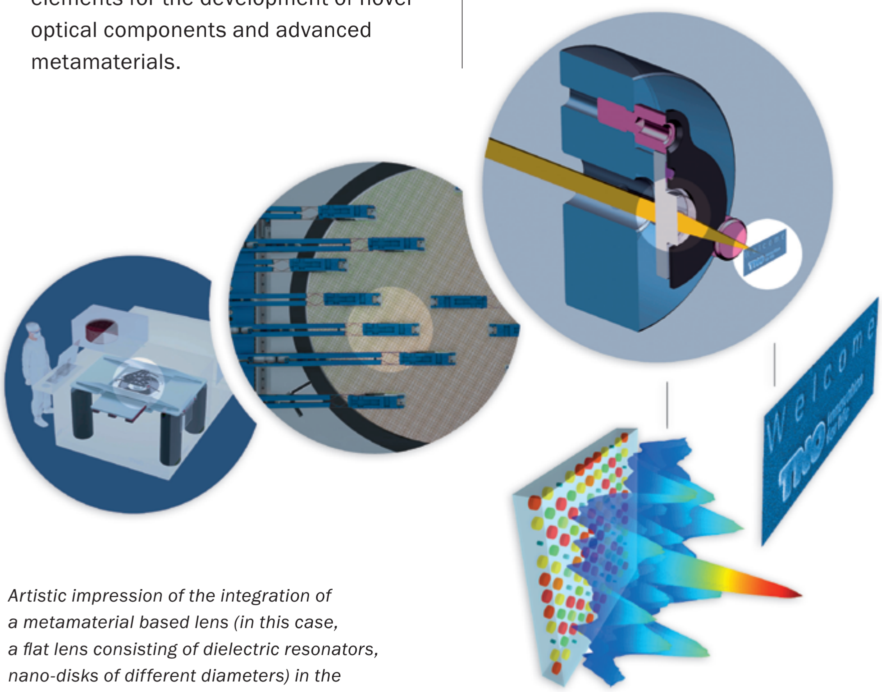
Nanomechanical actuation thus enables agile reconfigurable sensors and imaging systems, in which many nanoscale optical sensing volumes can be scanned over a large surface and detected simultaneously. Moreover, the same optomechanical interaction allows highly sensitive optical readout of nanomechanical motion by monitoring the metamaterial’s far-field response. This enables massively parallel, ultra-sensitive readout of nanomechanical force sensors.

BEYOND CONVENTIONAL OPTICS

The main objective of the ’Beyond Conventional Optics’ research line is the development of novel, non-conventional optical components/sub-systems based on artificially engineered materials, so called metamaterials. Metamaterials are artificially engineered structures obtained by loading standard dielectric substrates with sub-wavelength metallic and/or dielectric scattering particles. This modifies the macroscopic constitutive parameters of the original material, such as permittivity and permeability, thus realising electromagnetic properties otherwise not available in nature, and hence enabling the realisation of revolutionary components and subsystems.

The project addresses the problem from different, but strongly related points of view:

- **Theoretical modelling** – The theoretical formulation of the problem and the development of efficient and accurate analysis and design models are essential elements for the development of novel optical components and advanced metamaterials.
- **Manufacturability** – The manufacturing of these components is very critical given the extremely small dimensions and the extremely high accuracy required. Materials’ characteristics are also very important since their properties change significantly with optical frequency. This requires that in the modelling and design phase all these aspects are carefully considered and taken into account. An ECO system of design – build – test of meta-materials is being established with TNO at its centre.
- **System integration** – The new lens concepts are developed with the final objective to integrate them into optical sub-systems/systems where they add new functionalities and/or bring better performances. This approach strongly influences the design, which has to conjugate optimal electromagnetic performances and full compatibility with the systems.



Artistic impression of the integration of a metamaterial based lens (in this case, a flat lens consisting of dielectric resonators, nano-disks of different diameters) in the meta-instrument concept.

The project has focused on three types of structures: flat lenses, super-oscillatory lenses and hyper lenses.

RESULTS

Theoretical models and tools have been developed to analyse and design these structures. The development of the models happens in close cooperation with TU delft and TU Eindhoven. Several concepts have been assessed in terms of optical performances and manufacturability.
In the continuation of the project, these concepts will be further investigated and developed with the main objective to generate innovative optical sensors for the next generation of metrology and inspection systems.

MORE INFORMATION

More information can be found on TNO's website: TNO.NL/OPTOMECHATRONICA

PUBLICATIONS

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JRV141114-01