First light on EBL2

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ABSTRACT

TNO is building EBL2 as a publicly accessible test facility for EUV lithography related development of photomasks, pellicles, optics, and other components requiring EUV exposure. EBL2 consists of a EUV Beam Line, a XPS system, and sample handling infrastructure. Recently we finished installation of the source, exposure chamber, handlers and XPS system. This paper describes the integration process and first light of the EUV source.EBL2 accepts a wide range of sample sizes, including EUV masks with or without pellicles. All types of samples will be loaded using a standard dual pod interface. EUV masks returned from EBL2 will retain their NXE compatibility to facilitate wafer printing on scanners after exposure in EBL2. The Beam Line provides high intensity EUV irradiation from a Sn-fueled EUV source from Ushio. EUV intensity, spectrum, and repetition rate are all adjustable. The XPS system is now operational and accepts samples up to reticle size.

Keywords: EUV exposure, mask, pellicle, XPS analysis, metrology, handling, contamination control

1. INTRODUCTION

EUV is approaching its insertion point for high volume manufacturing as EUV sources and EUV lithography tools become increasingly mature products[1] . While the NXE source power roadmap has grown up to powers of 500 W or even beyond this, there is a need to investigate the effects of these kind of powers on optics, reticles and pellicles. With the maturing of the EUV technology there is also an increased need to develop a reticle and pellicle infra structure. Many issues remain to be addressed in these fields, and testing will play an indispensable part in resolving these issues.

TNO International Centre for Contamination Control (ICCC) is dedicated to developing the highest standards and practices in contamination control, for preventing and eliminating both particle contamination and molecular contamination in space and semiconductor applications. In 2005, TNO and Carl Zeiss SMT GmbH jointly established the unique EBL test facility to further the development of EUV technology. EBL contains an EUV Beam Line, in which samples can be exposed to EUV irradiation in a controlled environment. Attached to the Beam Line is an XPS system, which can be reached via an in-vacuum sample transfer system. This enables surface analysis of exposed samples without breaking vacuum. The compound instrument is used to develop and validate optics lifetime strategies for ASML EUV scanners[2].

As EBL is no longer capable of keeping up with the power roadmap and is also not capable of handling larger samples like reticles and a new system was designed, called EBL2. The concept study was described in Ref.[3]. The main parts of the system are a Sn fueled EUV source, collimating grazing incidence optics, an exposure chamber, vacuum and atmospheric handlers and a XPS system for surface analysis hooked up to the vacuum handler. The latter enables moving the samples from exposure chamber to XPS without breaking vacuum. In the near future it is foreseen to extend the system with an EUV reflectometer to measure the reflectivity of the samples with 13.5 nm wavelength EUV light.
The system was realized in close collaboration with our technology partners Ushio Inc for the Sn fueled DPP EUV source and ASYS Automatic Systems GmbH & Co. KG for both the vacuum and atmospheric handler.

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EBL2 will be able to expose a diversity of samples up to full reticles (including pellicles) at several locations on the sample. The power on the sample is compliant with the roadmap up to at least 250 W IF for scanners and the gas environment in the exposure chamber can mimic scanner and source conditions. A summary of the performance of EBL2 is listed in Table 1.

Table 1: comprehensive overview of EBL2 performance

Power	>1 W in 2% BW @ 13.5 nm @ 3 kHz (“IB”) (~10 W 10-20 nm OoB)
Power density	>1 W/mm^2 IB in focus
Spot size	1 – 30 mm diameter (power density scales)
Rep rate	1 Hz – 10 kHz (standard 3 kHz)
Sample size	Max 152x152x20 mm (EUV mask + pellicle possible)
Dose control	<20 % in free running experiment
Uninterrupted exposure time	>100 hours

2. SYSTEM LAYOUT

A full system description can be found in ref [4] and [5], in this part a short summary of EBL2 system will be given. In Figure 1 a schematic overview is shown. EBL2 consists of a) Ushio EUV source mounted on a track for easy maintenance access, b) collector module consisting of two elliptical grazing incidence mirrors with intermediate focus, c) exposure chamber with in-situ diagnostics, d) sample handler with vacuum and atmospheric handler, dual pod opener, storage capability and cleaning chamber, and e) XPS system capable of handling reticles for surface analysis of EBL2 and other samples.

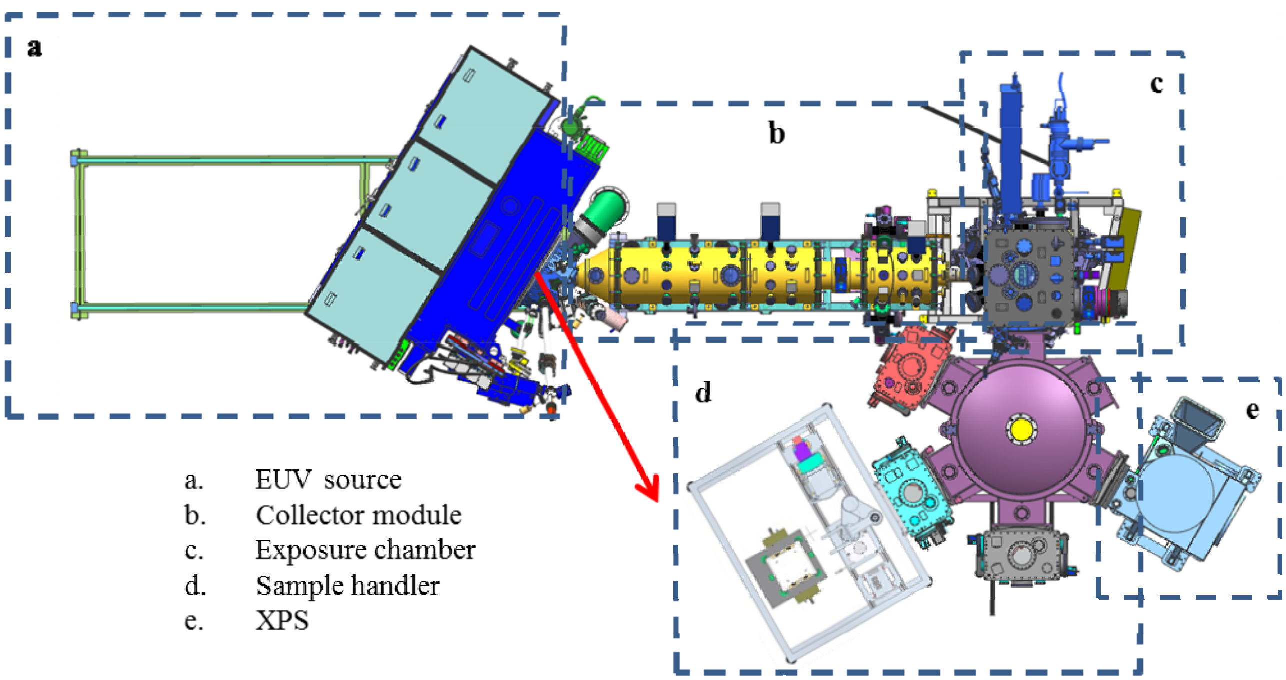

Figure 1: EBL2 system lay out. The red arrow indicates an additional port on the EUV source which can be used for metrology experiments or other type of experiments needing low power and intensity

The Ushio EUV source[6] has a mechanical debris shield to mitigate any Sn debris originating from the source towards the collector optics. This shield is based on the proven technology as used in the ASML AD tools, which have been in use for a number of years at CNSE (Albany, USA) and Imec (Leuven, Be). The source has an increased NA to be able to collect more light in the collector optics. The collector optics are Ru coated grazing incidence elliptical mirrors. The main collector (M1) collects the light from the source and focusses this in the intermediate focus (IF), located approximately at 2/3 distance away from the source. The second mirror (M2) then focusses the light on the sample in the exposure chamber. The IF interface is also used as a pumping aperture to suppress any gasses flowing from the source to the exposure chamber and vice versa. In the collector module it is possible to insert apertures and filters to modify the beam with respect to spectrum and profile. Defocusing of the light on the sample to create a larger spot is established by moving collector module and source on the track to the left. The connection between collector and exposure chamber is a long flexible bellow to accommodate moving while under vacuum.

The exposure chamber has in-situ diagnostics with an imaging ellipsometer. This ellipsometer is also used to find markers on the samples and use those for navigation on the sample. Moving the sample is accomplished by a hexapod stage system mounted to the bottom part of the EC. This hexapod is mounted on the atmospheric side of the system and vacuum connection is established by a very large bellow. By doing so all the motors, encoders and manipulators are not in vacuum and easily accessible for maintenance. This hexapod drive system is delivered by Symetrie (Fr).

The chamber itself is fully metal sealed, electropolished and cleaned to a high degree of cleanliness. Actuation inside the chamber for gripping and flipping of the sample is done by pneumatically actuated bellows. This ensures cleanliness of the system as no motors or lubricants are used in vacuum. The chamber has a differentially pumped RGA to check cleanliness of the background and control the gasses admitted for partial pressures and composition. The stage is equipped with calibrated photodiodes to measure intensity and power of the EUV beam. In combination with a scintillator disk and a CCD camera spot size and intensity profiles can be measured. Both photodiodes and scintillator can be used to find the center of the EUV spot and relate this to stage coordinates.

Both handlers and other modules are ASML NXE compatible with respect to reticle backside cleanliness. This enables exposures of reticles on EBL2 and afterwards wafer printing of the reticles on a ASML NXE scanner to verify the effect of high doses of EUV radiation on reticle performance. All samples are loaded using the dual pod EUV reticle storage interface. For samples other than reticles customized sample holders are available, see Figure 2 for possible configurations.

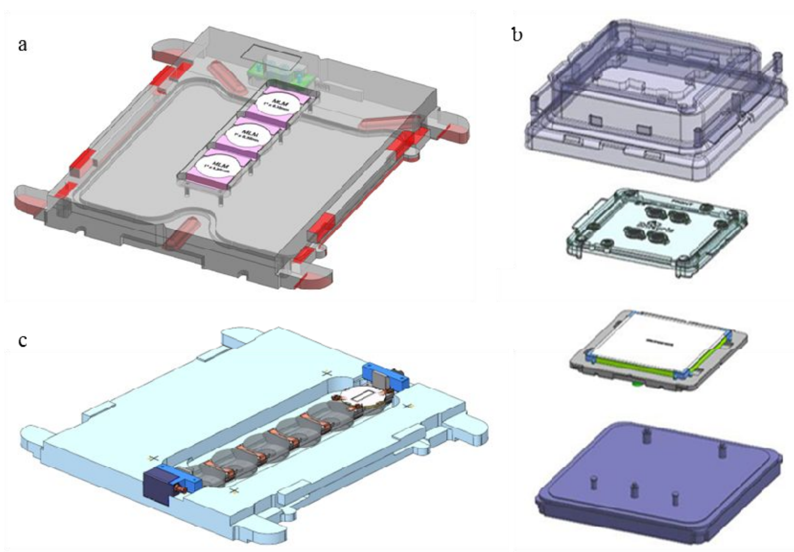

Figure 2: Types of sample holders used in EBL2. a) custom sample holder for exposure of small samples, b) EUV mask in dual pod, and c) XPS sample holder for small samples with rotating for angle resolved measurements (courtesy of Kratos).

The XPS system is a modified Kratos (UK) Nova system. This system has been modified to accept full size reticles and automatic sample loading/unloading by our vacuum handler. For smaller samples it is possible to do angle resolved measurements using the sample holder depicted in Figure **2**c.

3. INTEGRATION

In early 2016 the construction of the dedicated cleanroom for EBL2 began. This cleanroom is placed in the Van Leeuwenhoek Laboratory (VLL) in Delft and is part of the facilities of TNO for ICCC for contamination control research for space and semiconductor applications. This laboratory is shared with the Technical University Delft (TUD) for semiconductor device manufacturing and quantum computing research. Part of the work of QuTech[7], a TUD initiative to develop a quantum computer in which TNO is responsible for the systems engineering and device development, is taking place in the VLL. The cleanroom is an ISO class 8 cleanroom with a raised floor for cable and piping conduits below this floor. At the location of the load port a ISO class 4 area is created and in the atmospheric handler an ISO class 1area is established. A flow bench will be installed for manual handling of samples in a dedicated clean area. A separate grey room for technical installations like air conditioning and another grey room for roughing pumps, chillers and electronic cabinets is available. The clean room is in a separate area of the VLL with no access by outside parties to ensure client confidentiality on the dedicated samples EBL2 is going to handle.

Starting from April 2016 parts and modules started arriving and assembly of EBL2 modules began in separate laboratory areas. From June 2016 the cleanroom was accessible for TNO employees and integration of EBL2 began. First parts to enter the cleanroom are the exposure chamber and beamline frame elements. Next the vacuum handler arrived and was connected to the exposure chamber. In the meantime Factory Acceptance Testing (FAT) of the XPS and EUV source was under way and in October and November these modules arrived at TNO and were moved to the clean room for integration. Figure 3 gives an impression of the several stages of assembly.

The M2 collector is manufactured by Rigaku (Cz). The full M1 collector will be manufactured by TNO by means of diamond turning of Aluminum substrates with additional nickel plating. Ru coating of the M1 segments will be performed by Optixfab (Ger). In the early stage of EBL2 we will work with only a small single segment M1 mirror providing limited power at sample level. In the mid of 2017 the single element M1 mirror will be replaced with a full size M1 collector and full power and intensity should then be available for users of EBL2.

Figure 3: EBL2 in stages of assembly. On the left side the exposure chamber and vacuum handler. On the right side the XPS is arrived on site (right side of photo), in the front the source frame is visible and the rails for moving source and collector module.

At the end of 2016 most essential parts of EBL2 were installed and alignment of collector optics and source could commence. In Figure 4 a full overview of the system is visible. From left to right the source mounted on the frame is visible, next the beamline elements are shown ending with the exposure chamber. The right shows the vacuum handler and the XPS system. In this picture the atmospheric handler is not present yet.

Figure 4: Full view of EBL2, from left to right: EUV source, collector module, exposure chamber, vacuum handler with load lock, storage, and XPS. The atmospheric handler with pod opener is not yet present.

4. FIRST LIGHT

In December 2016 the EBL2 beam line system consisting of source, collector and exposure chamber was connected. First rough alignment was done using visible light and lasers. When alignment was finished the system was evacuated and the source was heated for the first test runs.

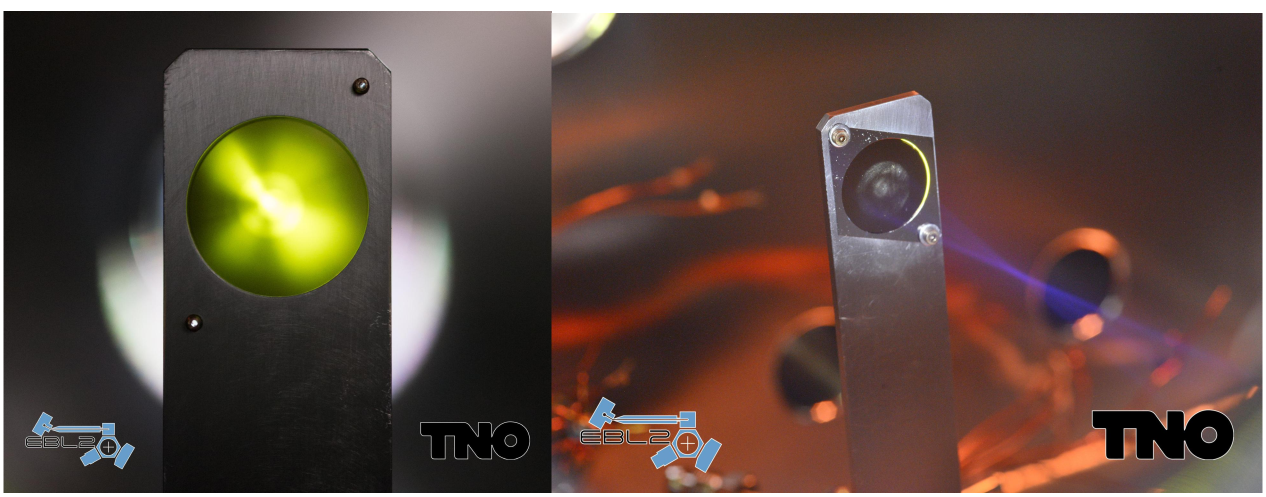

Figure 5: Left picture: First light on scintillator disk on sample position in the exposure chamber. Right picture: EUV induced plasma on the front side of the scintillator disk.

The team managed to get light through the complete optical column within one day after evacuating. In Figure 5 the results of the first light are shown. From the scintillator image on the left side it can be seen that there is side lobe on the spot. This is caused by the pumping aperture in the IF cone which is too small for the optical beam. Because the aperture is not a simple hole, but a cone tightly fitting around the optical beam it is possible to have EUV reflections as the EUV beam hits the surface at grazing incidence. The scintillator was placed behind the focus of the spot to prevent overheating. This can be seen in the right picture of figure 4 where a focal spot can be observed in the plasma glow caused by the EUV radiation in a high pressure gas environment. This spot is approximately 6 cm in front of the scintillator disk. In the same picture the doughnut shape of the beam when out of focus can be seen on the scintillator disk. The plasma was created using Argon as a process gas with a pressure of about 1 Pa.

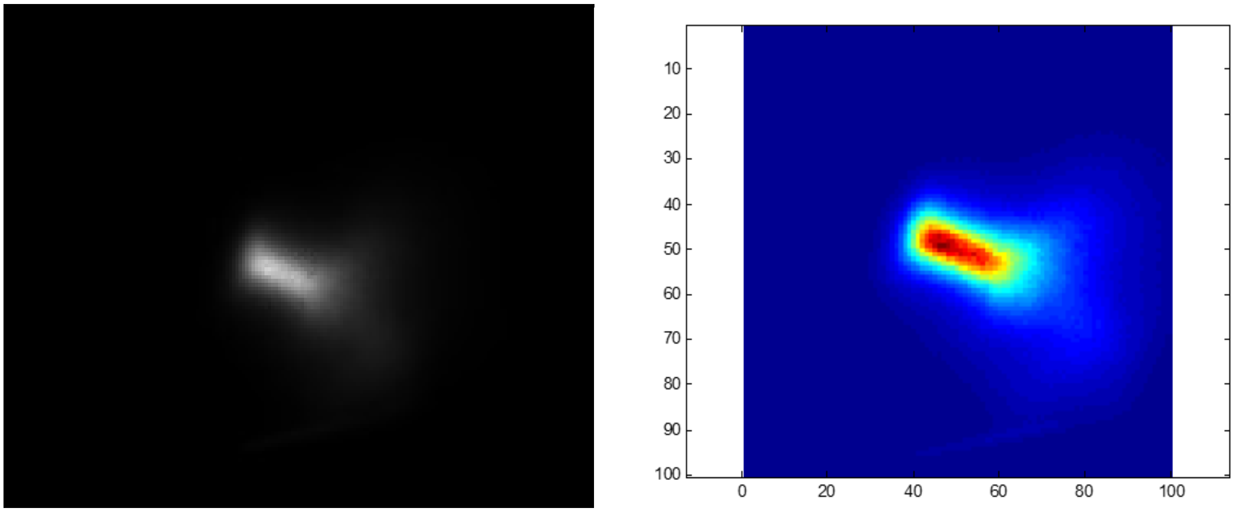

Figure 6: Left picture: EUV plasma in source at 13.5 nm wavelength. Right picture: size of the plasma in and intensity in arbitrary units

In Figure 6 the plasma inside the source is shown. In the left photo the plasma in the EUV spectrum is shown. As this plasma is not yet optimized for performance a part of the EUV light is not collected by the first mirror. The left side of the plasma is the origin of the pulse where the high voltage rotating wheel of the source is. The right side of the plasma becomes oblique as the plasma fades away to the second, grounded wheel. The size and intensity of the plasma can be seen in the right picture, which is data processed image of the left picture

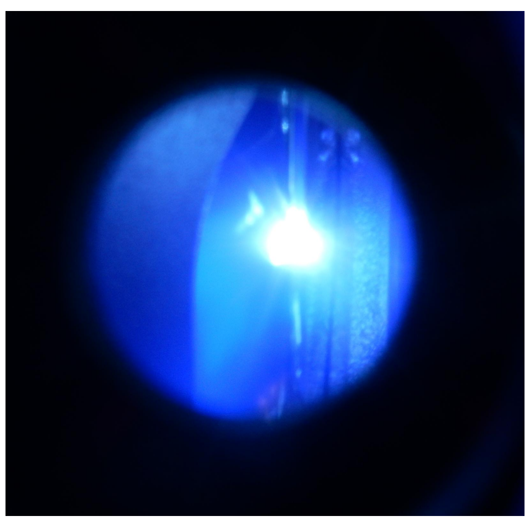
Figure 7: visible light picture of the EUV plasma in the source

The picture in Figure **7** is the visible plasma from the source. The right side of the picture shows one of the rotating wheels covered with liquid Sn. The plasma is established between the two rotating wheels and ignited by means of laser pulsing, thus evaporating a small amount of Sn and creating a high voltage discharge.

5. CONCLUSION

The construction of EBL2 is going according to schedule and first light was achieved in December 2016. Ongoing activities on the system include installation and calibration of diagnostics like ellipsometer, photodiodes and RGA system. The XPS system is fully operational and can accept samples up to reticles from customers via automatic loading with the vacuum and atmospheric handlers using the dual pod interface. A major upgrade of the collector mirrors is expected to take place in May 2017 and then full EUV power and density is available on sample level. After the upgrade a full qualification program and first test runs on reticles will take place. The facility will be open for customers mid of 2017. Additional funding for an extension of EBL2 with an EUV reflectometer has been submitted and in April 2017 is expected to hear if this funding has been granted. This will be a very valuable extension of the EBL2 system.

6. ACKNOWLEDGEMENTS

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