

MEASUREMENTS OF ION FLUXES AND SURFACE DEGRADATION IN LOW-DENSITY H₂-PLASMA PRODUCED BY EXTREME UV PULSES AND GAS DISCHARGE TO STUDY ETCH EFFECTS FOR NANOLITHOGRAPHY APPLICATIONS



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1. Introduction

Extreme Ultra-violet radiation (EUV) using a wavelength of 13.5 nm is used in the leading edge nanolithography systems of ASML for high-volume manufacturing of modern integrated circuits with critical dimensions of 10 nm and below. The high-brightness EUV radiation propagates through the system and interacts with the gas environment inside the scanner forming low density plasma and creating a complex gas-plasma environment affecting the performance of structural materials, mirrors, photomasks, fiducials, and sensors within the scanner in a complex way.

It is essential to characterize EUV and plasma effects on materials and optical elements to predict a long term impact on optics lifetime. Experiments can hardly be accomplished in a commercial nanolithography machine due to high operational costs and risks of the system contamination.

Characterization would need an environment similar to the EUV scanner including plasma and gas environments and opportunities to accelerate tests. The metrology to study plasma-material interactions is not always available or produces indirect results.

On another hand, it is difficult to translate findings from a laboratory setup to the scanner due to differences in the EUV beam characteristics (pulse shape, repetition rate, spectrum, plasma composition, dimensions of focused spots, and details of beam-surface interactions).

TNO developed the EBL2 system to comply with the EUV source power roadmap and to support development of components including tests of next generation mirrors and photomasks.

In this report, advanced experimental methods are discussed to understand ion characteristics and mechanisms of ion etching and damage in hydrogen plasma to nanolithography photomasks.

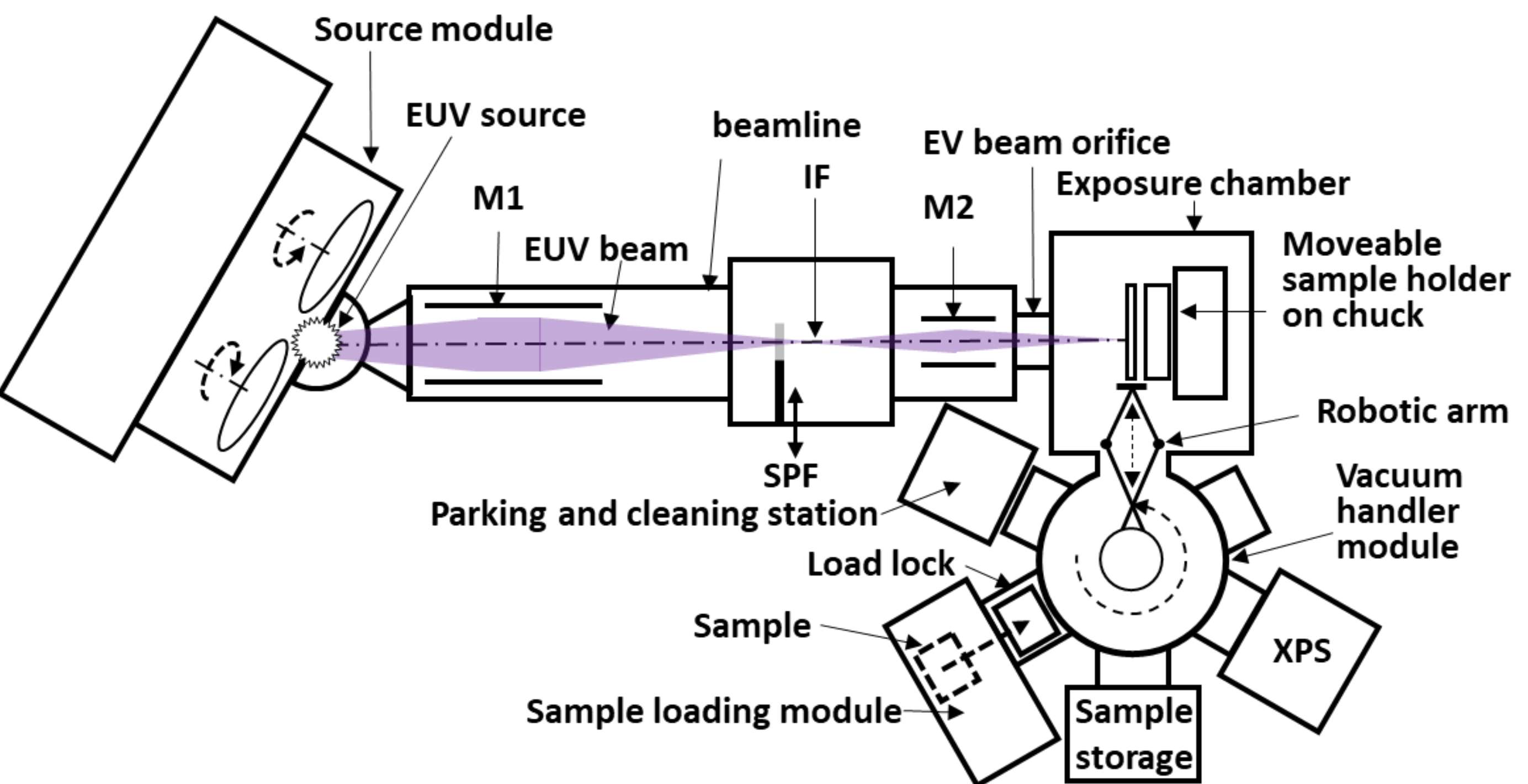


Fig. 1 The EBL-2 research facility overview featuring the main components: the EUV source with the EUV beamline and the exposure chamber.

2. Transparent RFEA concept

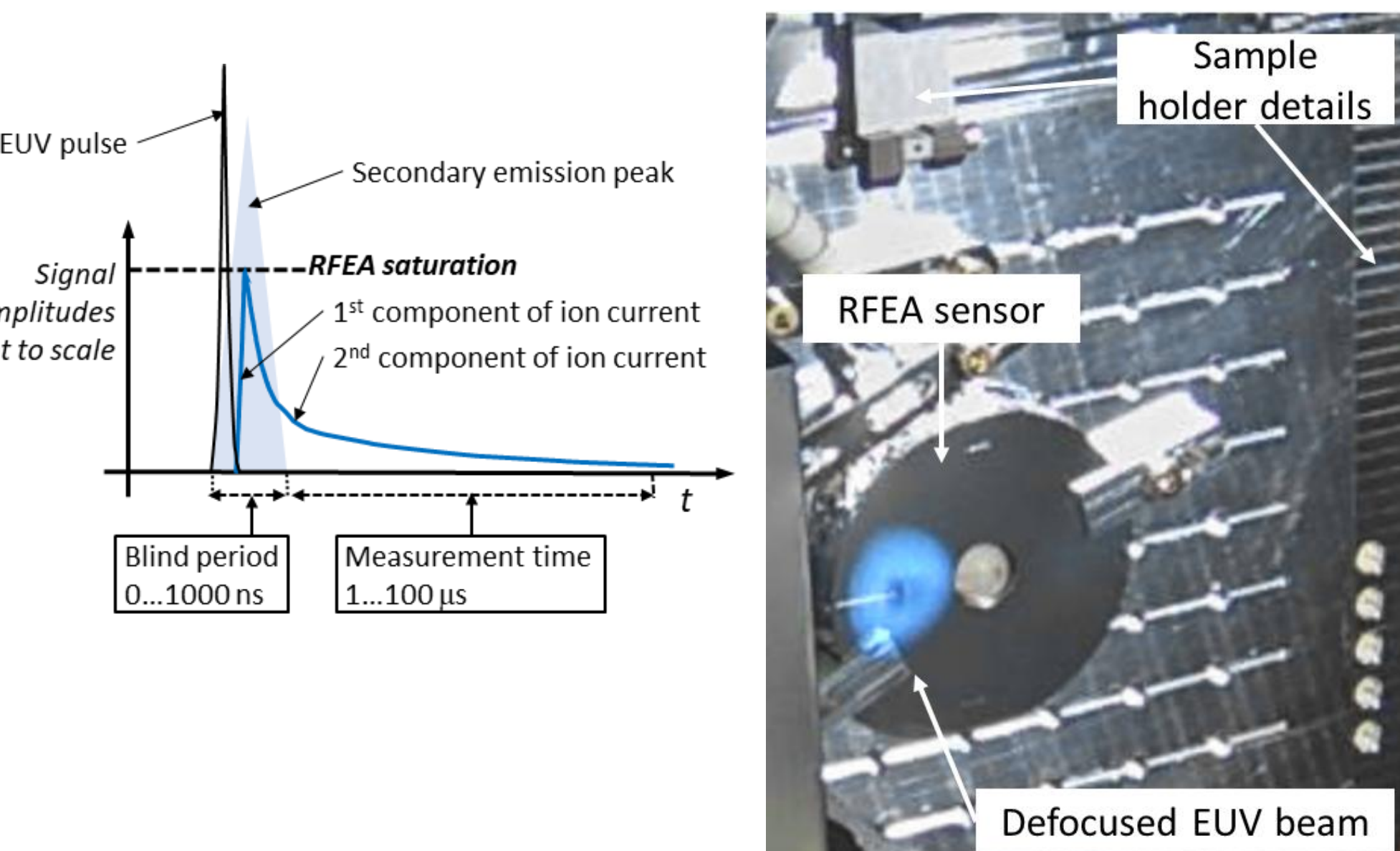


Fig. 2 a) Qualitative representation of ion current appearing after the EUV peak in many experiments with characteristic times; b) position of the RFEA and the EUV induced plasma in the test chamber.

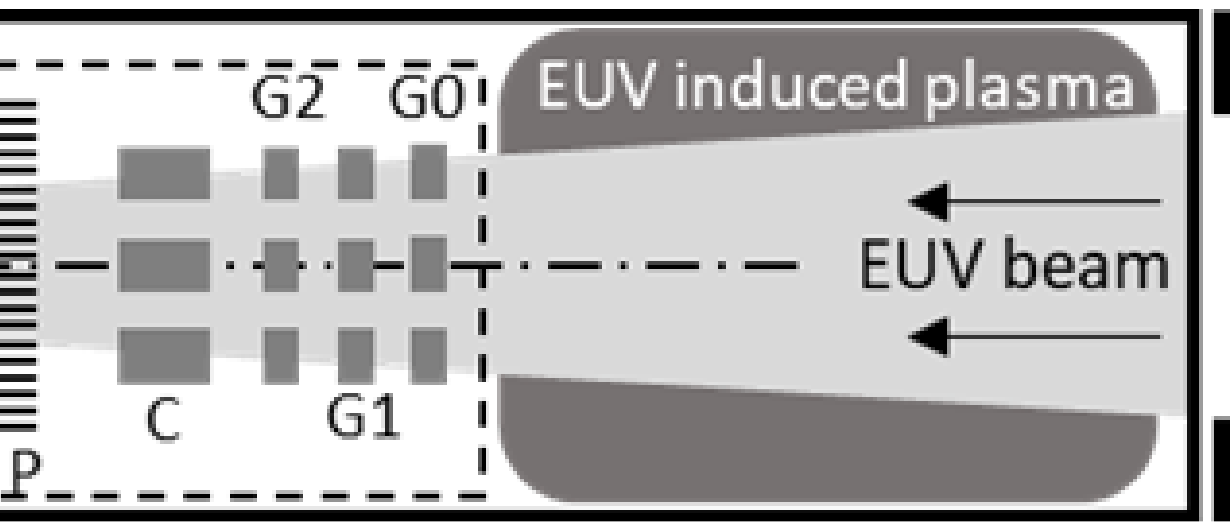


Fig. 3 Scheme of "Transparent RFEA" used in plasma experiments, G0-G2 RFEA grids, C - ion collector P - biased plate absorbing EUV.

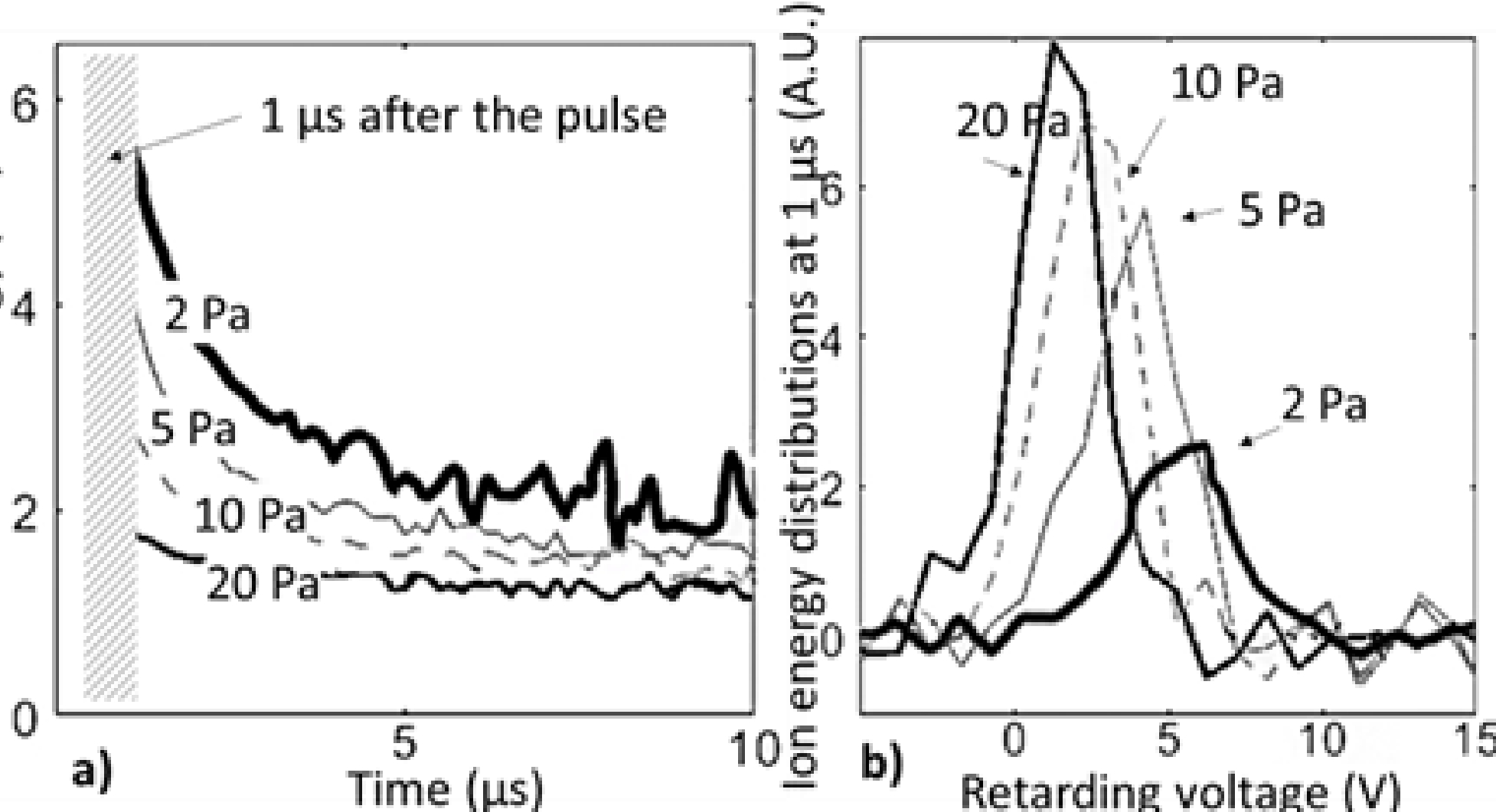


Fig. 4 Typical RFEA measurements: a) Peak ion energies as functions of time after the EUV pulse; b) ion energy distributions for several pressures at 1 μs after the pulse.

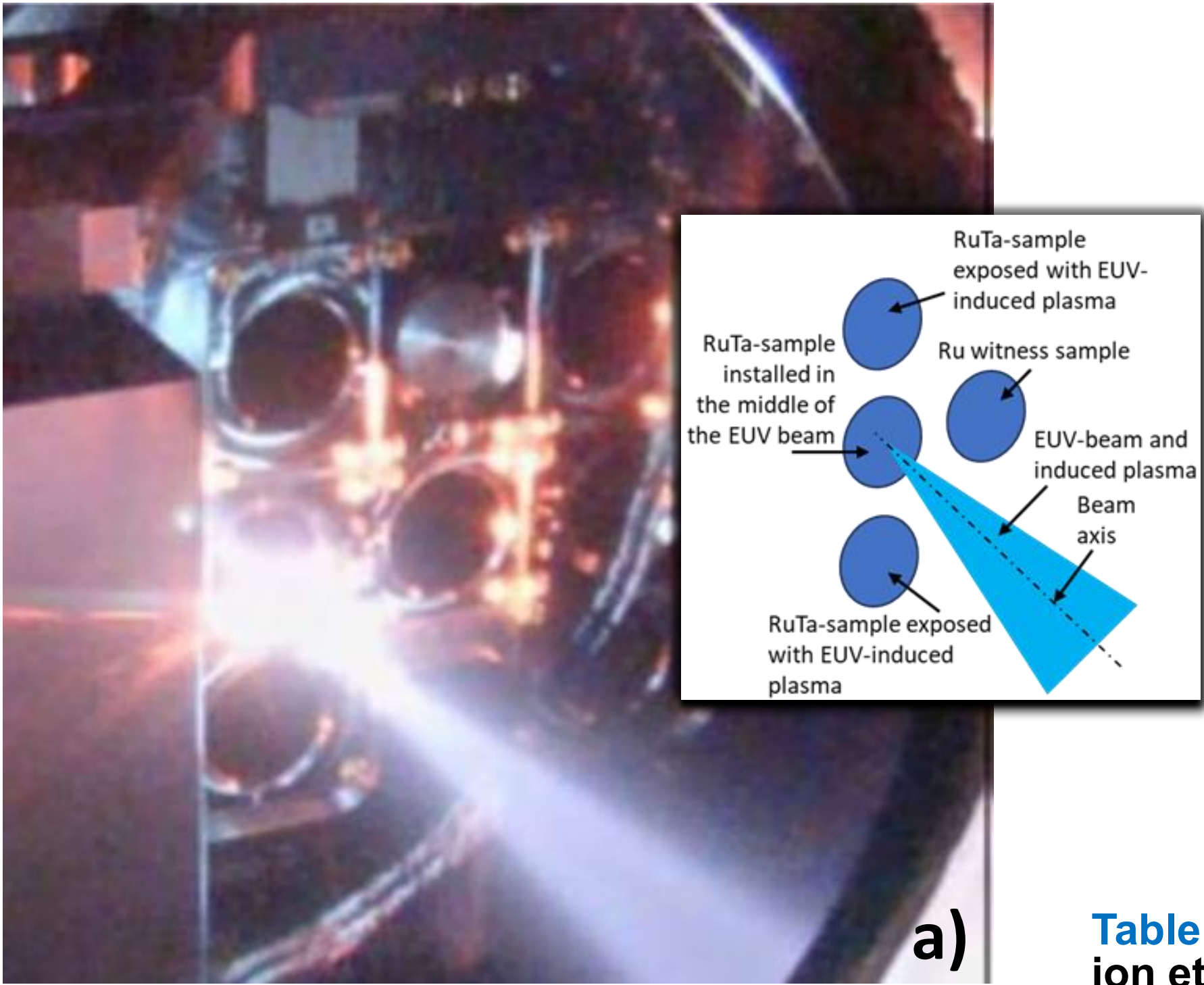


Fig. 2 Details of the photomask exposure: a) integral photo of the EUV test chamber featuring the photomask test samples installed on the way of the EUV beam and EUV-induced plasma generated in hydrogen at 5 Pa; the inset depicts the legend for the samples' details. b) Schematic representation of photomask layers used in model plasma-photomask interaction tests at EBL-2.

3. Photomask biasing in front of plasma

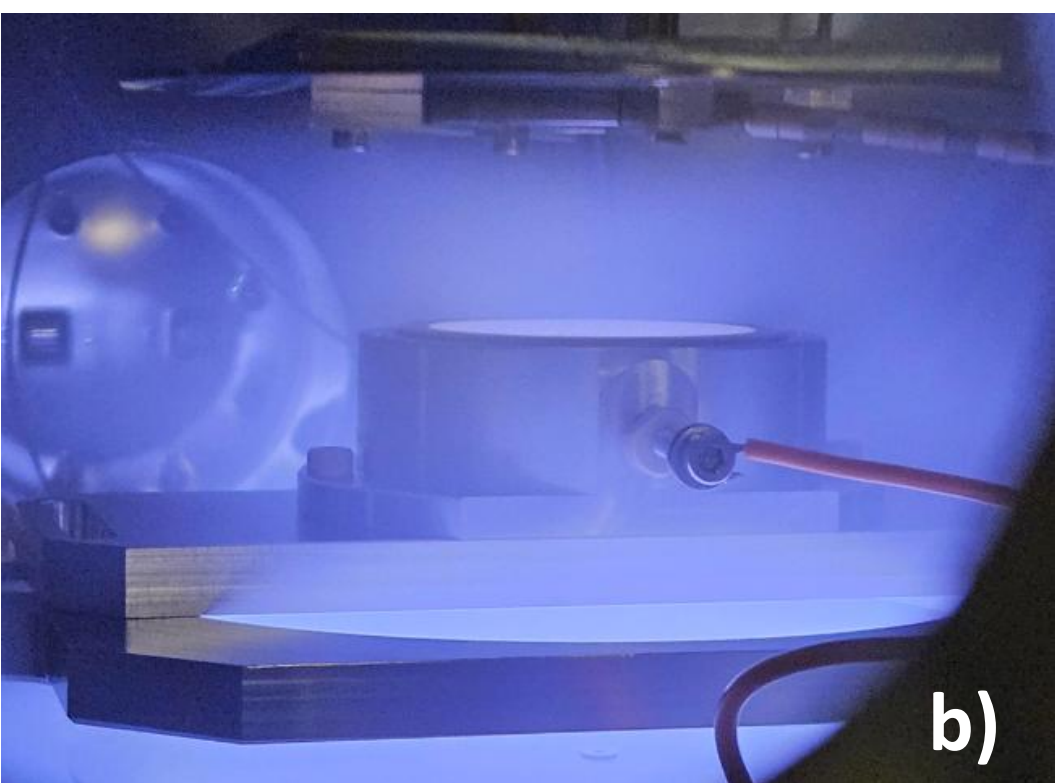
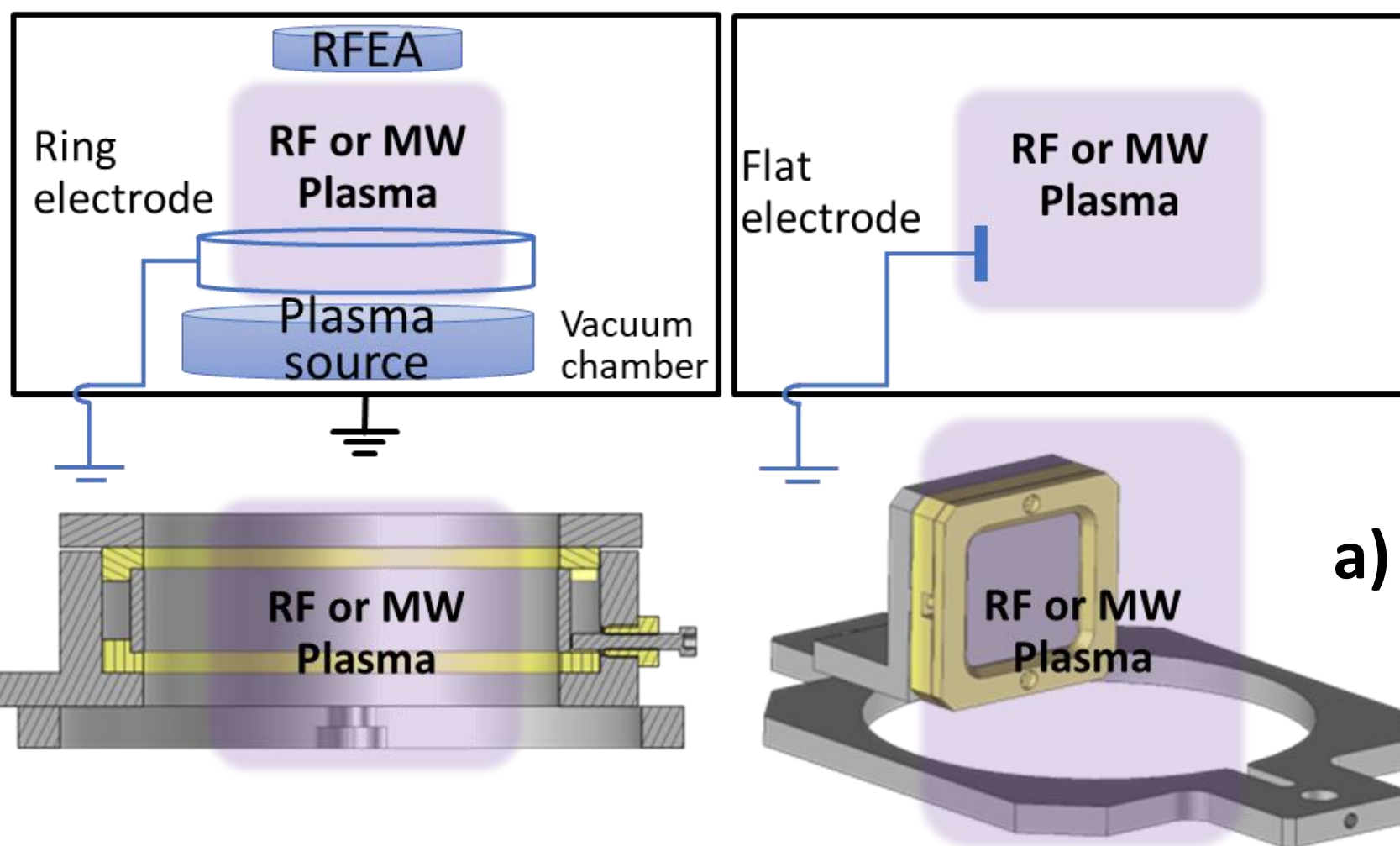


Fig. 5 Test configuration details: a) schematic illustrations of various test configurations: cylindrical biased electrode (left side) and flat biased electrode (right side); b) RFEA sensor with a partially defocused EUV beam spot. The sensor head diameter is 50 mm.

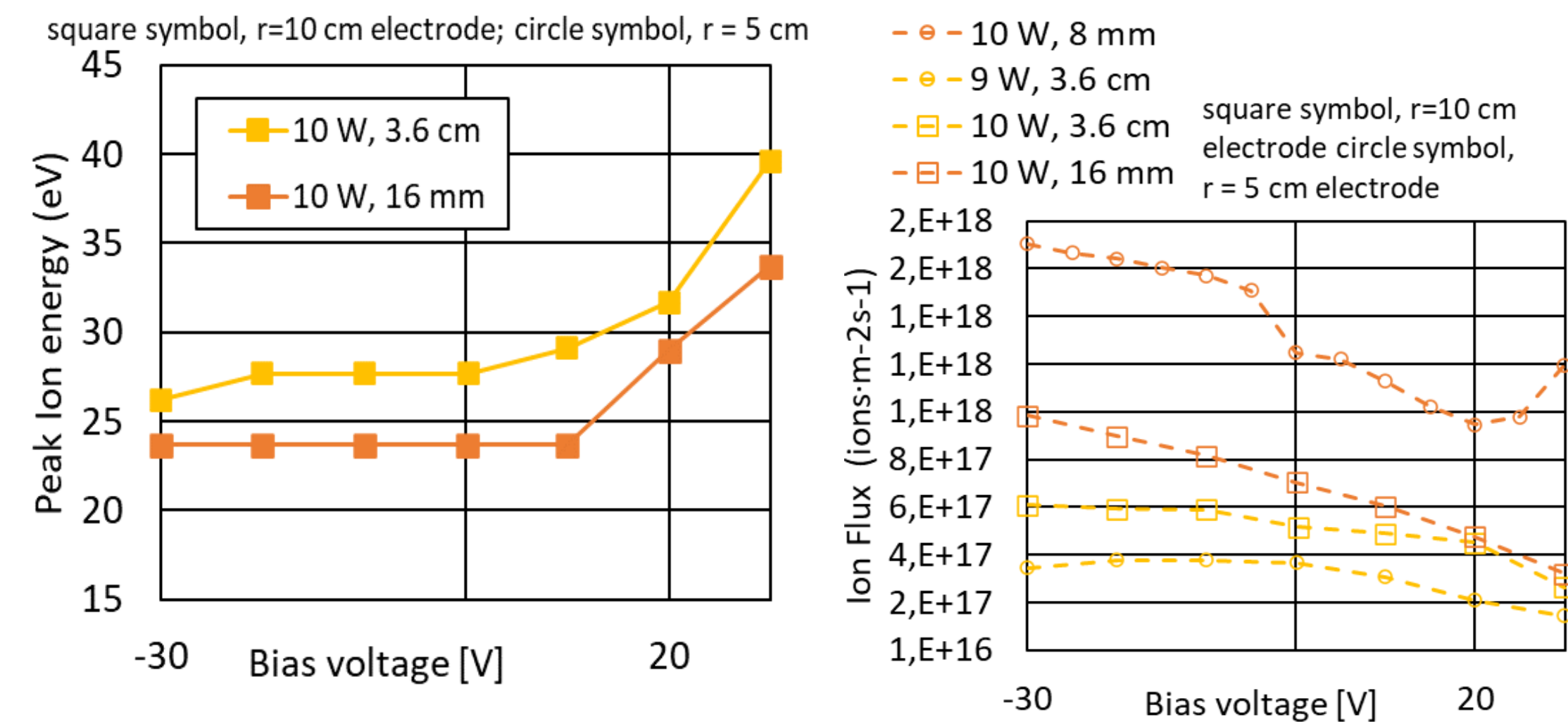


Fig. 6 RFEA measurements in H₂-plasma produced by the RF source at 5 Pa using the configuration with tubular biasing electrode; a) Peak ion energies as functions of the biasing voltage applied to the round electrode for the RF plasma source b) Ion fluxes measured by the RFEA as functions of the biasing voltages (-30 to +30 V).

Acknowledgements

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Photo illustrating the overall view of the EBL-2 research facility at TNO (left side: EUV source, center: beamline; right: sample loading module)

Table 1 Parameters used in the EBL-2 photomask ion etching experiments

Gas	Hydrogen
Operating pressures (Pa)	2-20
Test chamber background pressure (Pa)	2·10 ⁻⁶
Energy in one EUV pulse (J)	4.2
Pulse repetition rate (kHz)	3
Number of pulses per exposure (·10 ⁶)	100-200
EUV peak intensity (mW/mm ²)	20-23
Ion energies (eV)	1-8
Highest ion flux (ions·m ⁻² ·s ⁻¹)	10 ¹⁹
Lowest ion flux at decay (ions·m ⁻² ·s ⁻¹)	(1-2)·10 ¹⁶

4. Damage investigation with AFM

Surface etching is accompanied by other mechanisms of degradation. Using the atomic force microscope (AFM), blistering and surface spatial oxidation are investigated after the exposure to EUV. In case of blistering, hydrogen is accumulated sub-surface, causing tension and finally the formation of large blisters on a multilayer structure of a photomask. Using the contact resonance AFM, early stages of blistering can be found and associated with particular defects or morphological changes on the surface introduced by plasma. Contact resonance AFM is sensitive to stiffness and therefore suitable to detect the earliest potential onsets of blistering. The oxidation is investigated using the potential of IR-AFM to see the initiation or spatial heterogeneity of oxidation due to plasma-surface interactions. It is expected that the onset of oxidation takes place at locally induced damage sites. Subsequent development will involve a study of chemical composition through IR spectroscopy with nanometer scale resolution to understand the oxidation and damage pathways on the surfaces of EUV optics.

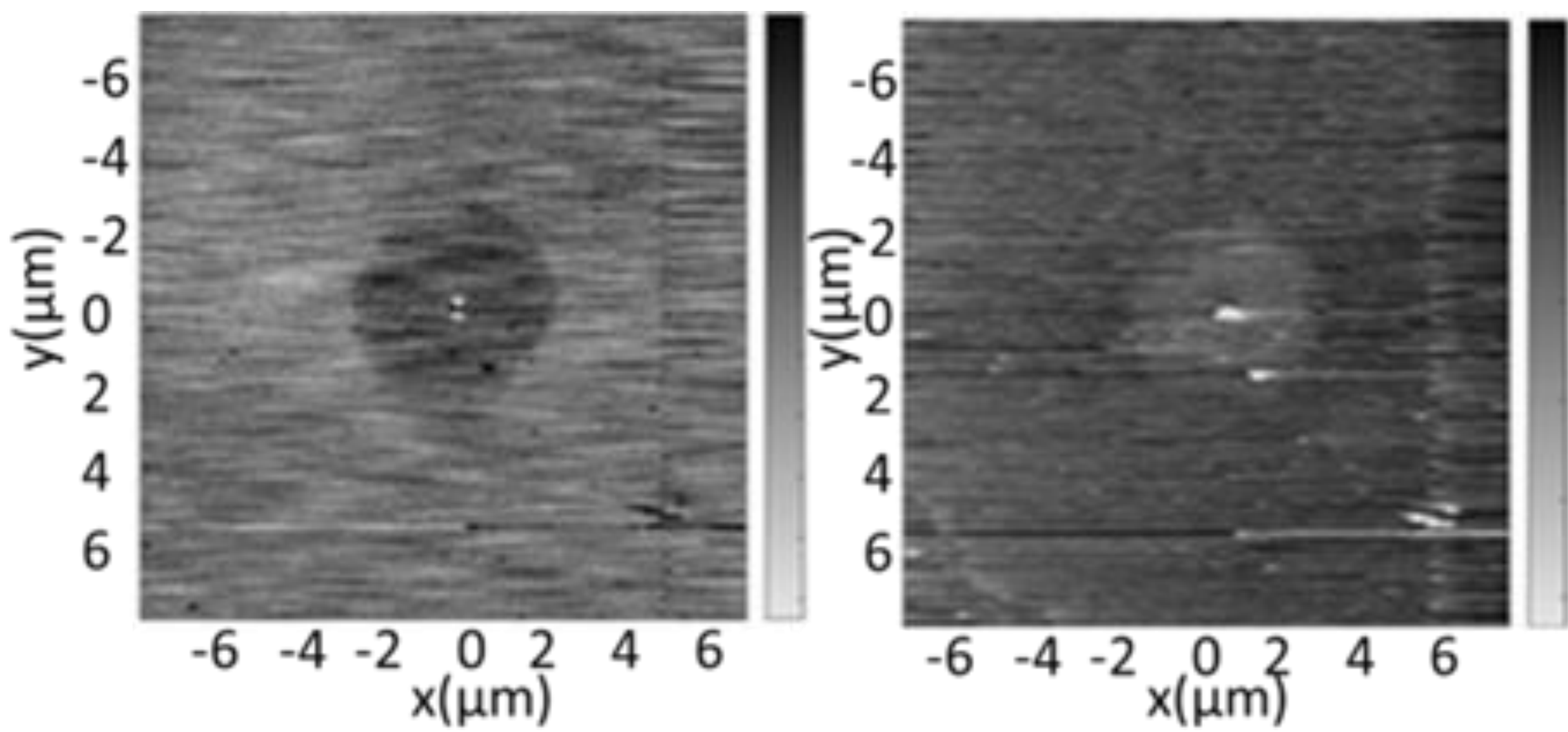


Fig. 6 a) Topography and b) Contact resonance contrast (indicative of stiffness) of a potential early blister measured by AFM on a representative sample on which blistering was evoked.

Summary

Etching and damage of nanolithography photomasks in low-density low-pressure EUV-induced H₂-plasma or in RF plasma are studied with methods to influence ion and particle fluxes to surfaces. A new RFEA design is proposed together with methods of electrical biasing to study ion etching in the range of 10 eV. A method to determine surface blisters in multilayer masks using an atomic force microscope is proposed. New measurement techniques are compatible with the EUV environment and can be used to predict and monitor photomasks etching and damage in modern nanolithography materials' tests.

References

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- [2] J. van Veldhoven, et al., J. Vac. Sci. Technol. B41, 012603 (2023).