Electron beam generated hydrogen plasma for material testing and cleaning

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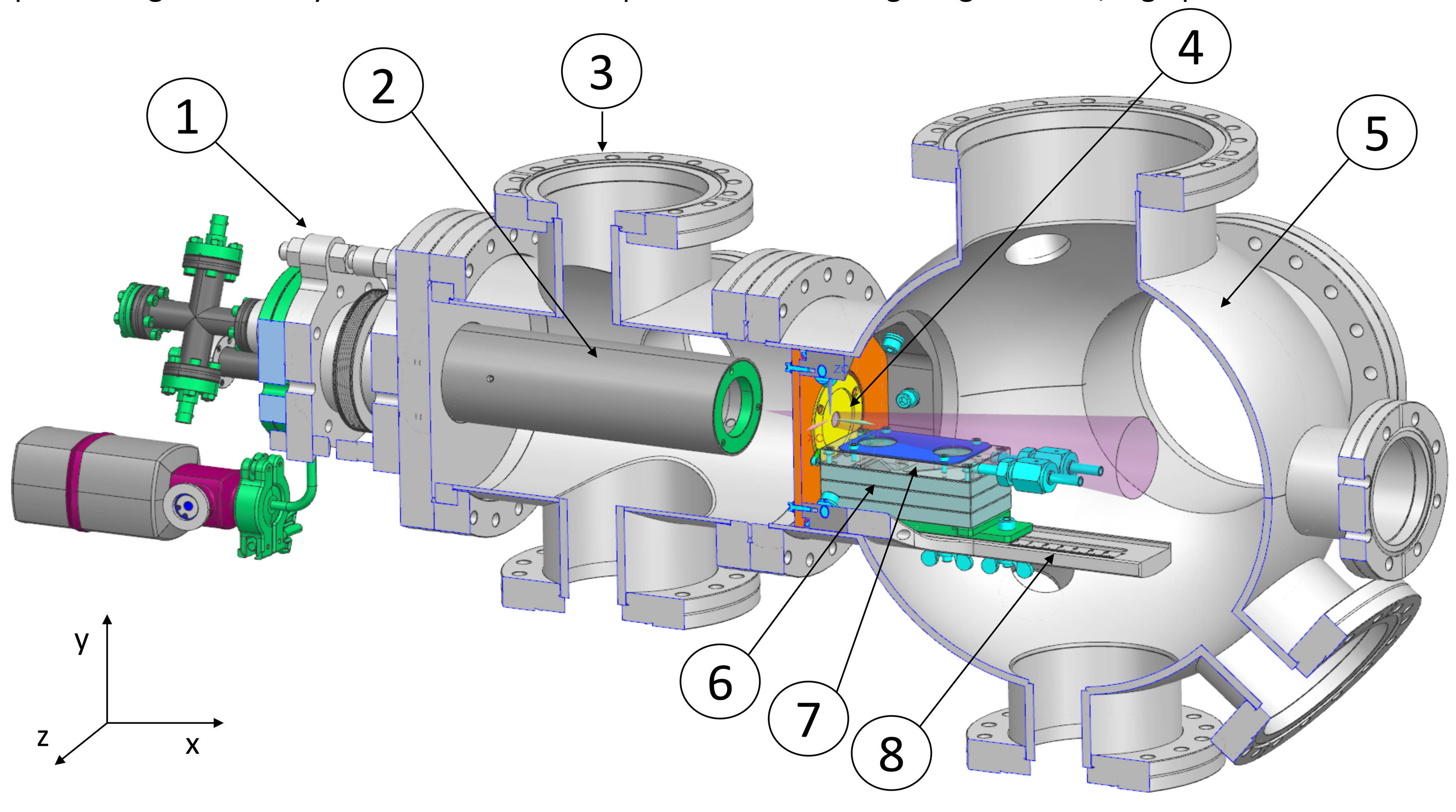
Motivation:

Inside extreme ultraviolet (EUV) lithography machines a hydrogen plasma is generated due to ionization of the background gas with EUV photons. The interaction of scanner components with hydrogen plasma is tested in laboratory setups, where the properties of EUV-generated plasma are mimicked. Here we present a novel experimental setup at TNO, where a low temperature hydrogen plasma is generated by means of electron impact ionization using a high current, high pressure electron beam (e-beam) gun.



a

b

Figure 1: a) Overview of the Electron Beam Rig (EBR) 1. Port aligner 2. High pressure electron gun 3. Vacuum vessel 4. 10 mm orifice 5. Sample Chamber 6. Sample height spacers 7. Cooled sample holder 8. Sample holder rail. b) Inside the setup with hydrogen plasma.

Electron Beam Research (EBR) setup:

The Plasma setup consist of in 3 main parts: the e-gun, e-gun chamber and exposure chamber. The e-gun has a small ECR plasma, which is a source of electrons that are pulled out and formed into a beam with a charged orifice. The e-gun chamber is differentially pumped from the main chamber to ensure the optimal pressure for the e-gun (up to 5 Pa). In the experimental chamber a water cooled sample stage is a manually controlled system that can be moved along the x-axis on the rail, and the filling plates (fig.1a #6) can be removed to change the height of the stage incrementally. Between both chambers a 10 mmm orifice is installed to ensure differential pumping. The opening of the orifice is large enough to ensure > 90% transmission of electron beam.

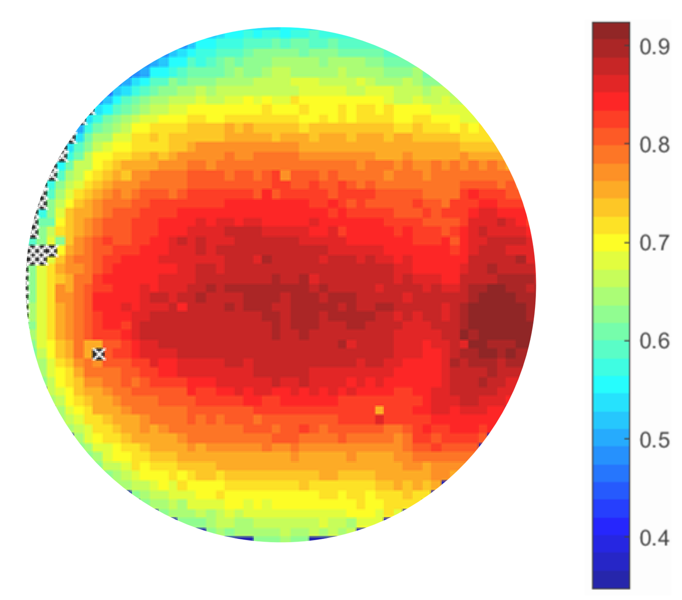


Figure 3: Carbon cleaning rate profile (nm/min). Sample was placed under the beam path

Plasma characterization & application

The plasma generation starts by injecting H_2 gas at few pascals into the mail chamber. Retarding field energy analyzer (RFEA) measurements showed that the produced ion flux and the ion energy are comparable to the scanner conditions. The total ion flux increases with hydrogen pressure and decreases with electron kinetic energy.

Additionally, compared to electron cyclotron resonance (ECR) plasma sources, that are typically used in off-line setups, e-beam generated plasma shows less contaminations due to lack of active elements like antennas in the exposure chamber. Finally, in experiments with carbon coated quartz plates we show that the measured carbon cleaning rates (~0.9 nm/min) are similar to one obtained with hydrogen radical generators (1 nm/min) but unlike the latter the resulting heat load towards the cleaning surface is lower (< 1kW/m²). Hence, the e-beam generated plasma could also be implemented in the EUV machines for cleaning carbon contaminations from scanner elements like sensors on the wafer stage.

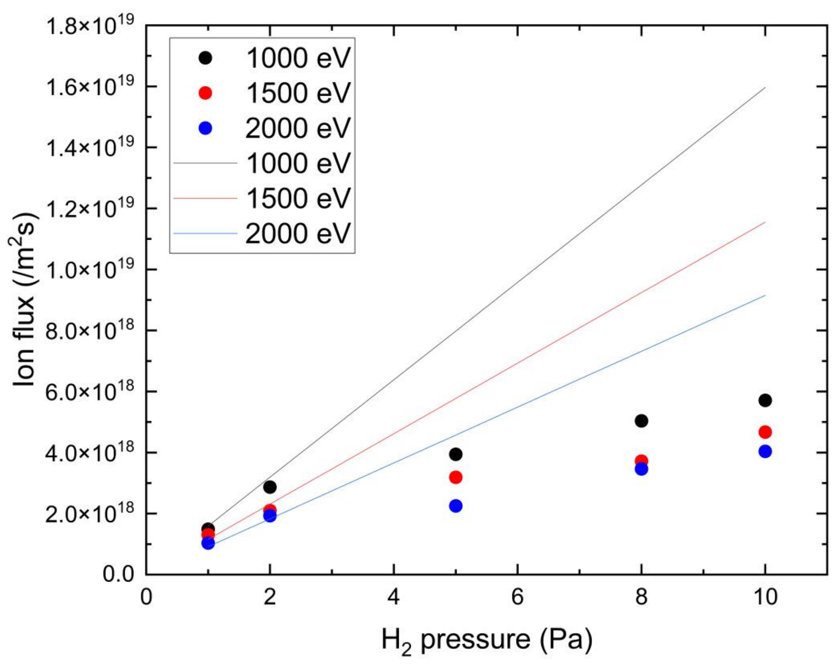


Figure 4: RFEA measurements of the ion flux at different pressures and electron energies. The solid line shows the expected ion flux and the dots are real measurement points. Ion energy is in the order of 2-2.5 eV. Gas recombination with ion/Electron formula is used to calculate the solid line.

$$\Phi_{ion,RFEA} = \frac{I * p_{H_2} * \sigma_{H_2}}{e * k_B * T * 2\pi y}$$

where I is the e-beam current, p_{H_2} is the hydrogen gas pressure, σ_{H_2} is the ionization cross-section area, e is the elementary charge, k_B is the Boltzmann constant, T is the absolute temperature and y is the distance between the beam and the RFEA

System Specifications	
Background pressure	5E-8 mBar
available Gasses	Hydrogen, water
Hydrogen pressure	up to 10 Pa
Water vapor	5E-8 - 5E-3 mbar
Stage movements	X,Y
Sample diameter	1"
Sample thickness	5 mm
Water cooling stage	2 - 80 °C

Electron Beam/Plasma Specs	
Max. ion flux	6E18 ions/m²s
Max. carbon cleaning rate	0.87 nm/min
Ion energy	2-2.5 eV
Electron energy	0.1 - 2 kV
Electron beam current	4 - 30 mA
E-beam beam width (at focus point)	~6 mm
Hydrogen radicals	~4e20 H/m²s

Outlook

- Investigation of different pulse durations (200 ns – 100 µs) and repetition rates (1-100 000 Hz) on plasma build-up and total ion fluxes. The goal is to mimic dynamic of EUV-generated plasma in the scanner. Preliminary results suggests that the process by which the hydrogen plasma is generated (photodissociation vs. electron impact ionization) plays a critical role in plasma build-up and decay.
- Experimental study on the role of secondary electron emission in deep oxidation of construction materials like aluminium and stainless steel. With this work we want to investigate if electrons can be used to mimic EUV photons in EUV induced processes like oxidation or carbon growth.

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