Time-resolved measurements of ion energy distribution function in cold low-density plasma induced by nanosecond pulses of extreme ultraviolet radiation

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Extreme ultraviolet lithography (EUVL) is a stage of semiconductor chip manufacturing which is expected to be introduced at technical nodes 22 nm and below [1]. An EUVL tool consists of pulsed light source and mirror optical system operating at a wavelength 13.5 nm. Since such radiation is strongly absorbed by any gases, the EUVL tool is maintained under ultra-high vacuum conditions. However, due to technical characteristics, various background gases, mainly hydrogen and argon, are present in the vacuum vessel of an EUVL tool at low pressures of ones to tens pascal. During operation these gases are ionized by both the high-energy EUV photons and the collisions with the secondary photoelectrons emitted by the mirrors. Thus, the plasma is formed within the EUVL tool.

Such plasma is known to cause various physical and chemical processes at the optical surfaces. These include, for example, etching the carbon contaminations that can accumulate on the mirrors due to hydrocarbon decomposition [2]. Other well-known effect is the delamination of the uppermost layers of the mirror, the so-called blistering [3]. The latter leads to the decrease in mirror reflectivity, which is undesirable for the commercial viability of EUVL tools. In order to reduce the degradation caused by the plasma, methods of controlling such plasma are required. This, in turn, calls for the development of diagnostic methods.

In this paper we present the unique experimental setup which allows to reproduce the experimental conditions close to those of an actual EUVL tool [4]. This consists of the pulsed EUV light source, the collector mirror and the ultra-high vacuum clean chamber. The clean chamber can be pumped for high vacuum and pressurized with various background gases. In this chamber the sample holder is mounted thus imitating the EUV-irradiated surface. We implement a retarding field energy analyzer (RFEA) as a diagnostic technique. This technique allows measuring the ion energy distribution function, a very important quantity since it is

precisely what determines the rates of the surface processes invoked by the plasma. The results of the measurements are presented at the end of the paper.

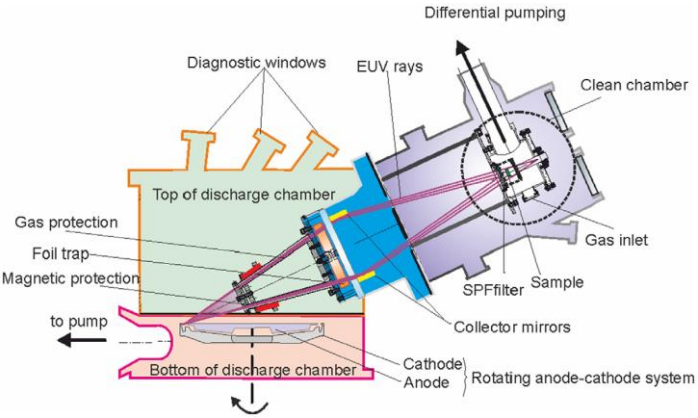

Fig. 1. Schematic view of the experimental setup.

The experimental consists of an EUV source based on the laser-ignited z-pinch discharge in tin vapor. It emits radiation pulses with the repetition rate of 2 kHz. The radiation spectrum in the EUV range has a strong peak at 13.5 nm. The duration of EUV pulse is about 40 ns at half-maximum. The light from the pinch is collected by the grazing incidence collector and then focused into THE clean chamber. To filter out the visible and deep UV radiation the light passes through the spectral purity filter which is a 150 nm thick zirconium foil covering the entrance window of the chamber. The light entering the chamber consists mostly of wavelengths in the range 10-20 nm. In the focal plane of the collector a sample holder for irradiated surface is installed. It is a copper electrode with a mount for 1 inch wafers, which in our experiments we replaced with the RFEA.

The clean chamber can be pressurized with the background gas with the pressures up to 100 Pa. In our measurements we use hydrogen as it is the primary gas present in the EUVL tool. In order to enhance ionization, a negative bias voltage can be applied to the sample. This creates an electric field which accelerates secondary electrons emitted from the surface by photoelectric effect. The bias voltage also varies the energy of ions impinging onto the surface. Opposite to the sample, a grounded cylindrical electrode is mounted. This electrode focuses the field lines and confines the plasma within its volume. The conditions within the clean chamber are close to those of actual EUV lithography tool.

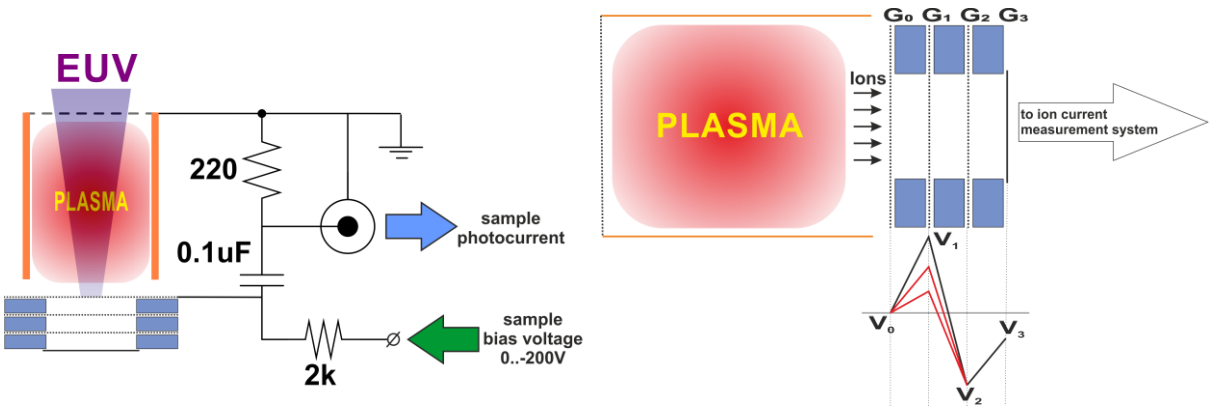

Fig. 2. Schematic view of the clean chamber rig(left), internal structure of the retarding field analyzer (right).

The structure of the retarding field energy analyzer is shown in fig. 2. It consists of three nickel grids G_0, G_1 and G_2 each with the transparency of about 40%, separated by ceramic insulator plates of 0.5 mm thickness. It is terminated with a copper collector plate G_3 which is connected with the current measurement system. The grid G_0 is facing the plasma and EUV radiation and is biased to the desired sample potential of 0 to -200 volt. All the other grids are biased with respect to G_0. The grid G_2 is biased to the potential -60 volt to repel secondary electrons, the collector plate G_3 has a potential of -23 volt to attract ions entering the analyzer. The grid G_1 acts as a potential barrier for ions. During the measurements, the potentials V_0, V_2 and V_3 are fixed constant while V_1 is swept above V_0. Such voltage sweep leads to the decrease in ion current so that only the ions with energies $E>eV_1$ pass the barrier and contribute to the collector current. The energy distribution function is therefore obtained by taking the derivative dI/dV_1 of the ion current.

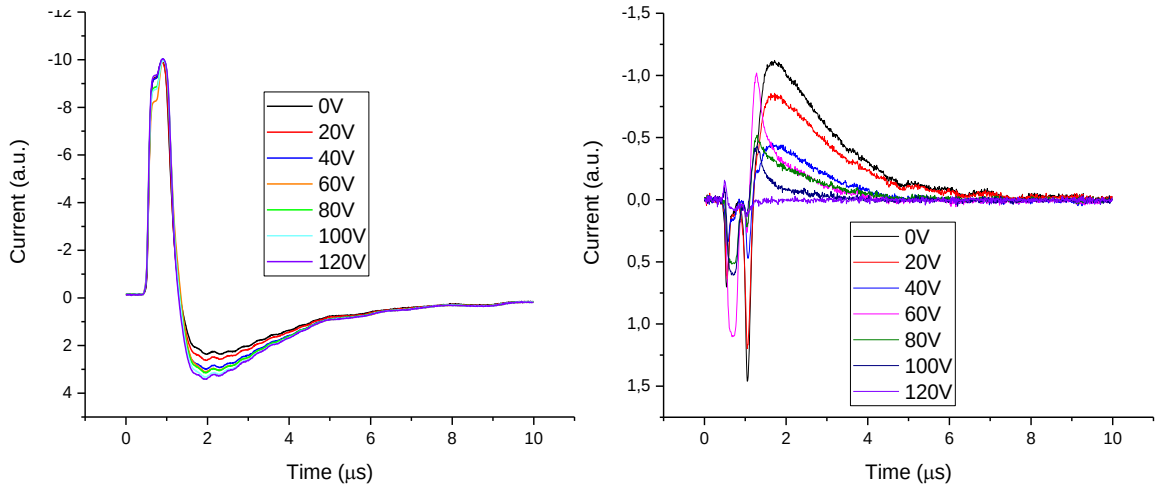

Fig. 3. Ion current at different V_1 values as recorded (left) and with the vacuum baseline subtracted (right)

Fig. 3 depicts the shape of the analyzer current at different values of V_1. All the measurements were performed in 30 Pa of H_2 with the upper grid potential V_0=-100V. The signal has a distinct baseline which is due to the displacement current within the analyzer. This can be eliminated by subtracting the pulse in vacuum. During the first 1.5 microseconds the useful signal can't be extracted because of the current amplifier oscillations. After 6 microseconds the signals drop below the noise level. Fig. 4 depicts the current-voltage curves extracted from the signals at various times. These are smoothed and differentiated in order to obtain the ion energy distribution function.

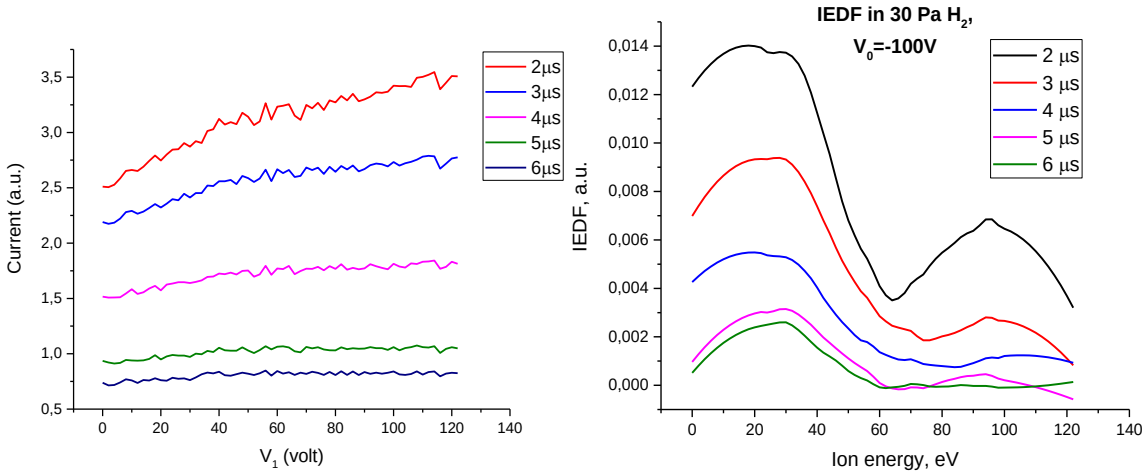

Fig. 4. IEDF integral as obtained from the current pulses (left), IEDF at different time moments (right)

We see that the ion spectrum is bimodal with two distinct peaks. However, the peak around 20 volt is not genuine but due to inaccurate performance of the analyzer at low V_1. Such is caused by ionization within the analyzer and, therefore, the distortion of the retarding potential. The second peak is due to acceleration of ions by the upper grid potential V_0. Therefore, the IEDF is peaked around 100 eV.

References

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