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Utilization of soft x-ray emissions from nanosecond pulsed laser produced plasma for decontamination of reflective optics in extreme ultraviolet light lithography systems

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Extreme ultraviolet lithography (EUVL) is the process by which a soft x-ray is emitted from a laser-produced plasma and is focused on a semiconductor wafer, forming nanometer-scale patterns. In EUVL, a tin plasma emits $13.5 \pm 2\%$ nm wavelength and is reflected by EUV-optimized Mo-Si multilayered mirrors towards a mask pattern placed on top of a silicon wafer covered with light-sensitive layer. The whole process of laser generation, plasma production, and EUV incidence on the wafer occurs 50000 times a second. To form the plasma, a tin droplet target is expanded to a flat plane by a pre-pulse, which subsequently fired by a more energetic main pulse at 10^{11} W/cm^2 laser intensity, which produces a plasma with a laser-to-EUV conversion efficiency of 2%. [1] During the process of EUV generation, debris from the laser produced plasma are also produced and is deposited on the multilayered mirrors. A study by Shin et al, reported a reflectivity reduction for down to 10% after 4 million shots (80 seconds EUVL operating time), at a grazing incidence of 15 degrees [2]. This poses a serious problem on the sustainability of EUVL.

As a countermeasure to Sn debris deposition, the mirrors are currently removed from the lithography system and Sn is removed by physical means such as by CO_2 jet. [3] Another method in the removal of tin contamination is through the induction of hydrogen radicals from discharge sources such as an inductively coupled plasma discharge sources [4], which operate on the principle of stannane (SnH4) formation from the hydrogen radical reaction with tin. For discharge-based decontamination modes, major issues may involve mounting the cleaning device and ensuring its compatibility with the lithography machine, and the prevention of additional contaminant generation due to the cleaning device itself. Therefore, placing an external device might contribute to other forms of reflectivity loss.

This study investigates the feasibility of utilizing the tin plasma emissions as a means for ‘self-cleaning’, where the EUV-induced plasma is itself used to generate hydrogen radicals. One of the mechanisms that generate H radicals is photodissociation, which is found to be optimized at wavelengths from 70-110 nm, which is in the vacuum ultraviolet (VUV) region. [5] A 2-D radiation hydrodynamic code then investigated the effect of laser intensity on the VUV flux and found an enhanced emission when the laser intensity is decreased to 10^9 W/cm^2, which is two orders of magnitude from the current intensity used in lithography. The increase of laser to VUV conversion efficiency and hydrogen radical formation was also reported in our previous results. [6] In that study, the emissions from a wide-band extreme ultraviolet light (XUV), as well as VUV were focused on hydrogen gas at 5 Pa pressure using gold coated ellipsoidal mirrors [7], used for generating hydrogen radicals. Moreover, we have investigated the spectral enhancement in xenon using a VUV spectrometer for varying laser intensity. Currently, we are in the progress of implementing this cleaning mode by preparing tin disk, and plane targets to simulate the condition before and after pre-pulse injection. A 1064 YAG laser is aligned towards the center of a vacuum chamber at 10^{-4} Torr base pressure. AXUV photodiodes were placed at 27 and 45 degrees from the laser incidence direction. We are investigating the effect of laser intensity by varying input laser energy on the VUV and XUV emissions of the Sn plasma.

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