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Determination of charge state, energy and angular distributions of tin ions emitted from laser produced plasma based EUV sources.

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Abstract. We have performed time of flight (TOF) analysis to determine the intensity of ion distribution from tin based plasma for a range of charged tin ions (Sn^{1+}–Sn^{10+}). A Nd:YAG laser operating at 1064 nm with a full width at half maximum pulse duration of 5.2 ns was used to create the plasma under vacuum with a base pressure of 10^{-6} Torr. The plasma formation occurred on a custom made optical system, which could be rotated with respect to the detector so TOF analysis could be preformed at various angles of emission, while maintaining a normal angle of incidence for the laser pulse with respect to the target. The detector used was an energy sector analyser (ESA), which is a well-characterised diagnostic capable of measuring ion energy and discriminating by charge state. Analysis was performed on ions of various charge states, with energy/charge state ratios ranging from 3 keV to 50 eV, for angles of emission from the plasma ranging from 90 to 15 degrees.

1. Introduction

As components used by the semiconductor industry get smaller, it is necessary to develop light sources that are of short enough wavelength to fabricate these at the required dimensions. The traditional lithography process uses quartz lenses but at shorter wavelengths these lenses would absorb, rather than refract extreme ultra-violet radiation (EUV). A suitable replacement to these lens systems has been found in molybdenum silicon (Mo/Si) multilayer mirror systems. Due to their reflectivity ($\sim 70\%$) at 13.5 nm [1], this means that source designers must optimise the EUV flux emitted by the source in this range, as it can be reflected 9, 11 or 13 times in the lithography process. Laser produced plasmas (LPPs) can be made to significantly emit at the appropriate wavelengths [2,3]. For ranges of ion stages for atoms $50 < Z < 70$, 4p-4d and 4d-4f transitions have been shown to provide an unresolved transition array (UTA), which comprises of possibly millions of individual lines and these tend to be the brightest features in these spectra. Sn^{8+}–Sn^{13+} have been found to emit in the required region whereas only Xe^{10+} emits at 13.5 nm. For pure tin the UTA is quite broad with a full width half maximum of 2–3 nm. The bandpass for the multilayer mirror systems in the EUV photolithography process is typically 2% of 13.5 nm and the width of the pure tin UTA is more than ten times greater, so it is important to optimise emission within the mirror bandpass.

However, ions that are emitted from these LPPs may cause significant damage to the components in a real world projection lithography system [4]. Fast ions, impinging on multilayer optics, can lead to the sputtering of mirror layers and debris, deposited on multilayer optics, can degrade in-band reflectivity. In order to effectively mitigate this damage it is necessary to understand how fast and in what direction different ions are emitted. In previous studies by Hayden *et al* [5], the influence of the viewing angle on the observed EUV spectrum and the inferred conversion efficiency of a LPP were investigated at both 45 and 90 degrees. An increase in the spectral brightness and sharpening of the peak at 45 degrees was noted, compared to that at 90 degrees and the in-band emission increased from 5.7 to 14 mJ/2π sr. This anisotropic EUV radiation emission motivated the investigation of the distribution of ions from LPP sources. Reported here are preliminary measurements of the charge state, energy and angular distributions of ions emitted from laser produced plasmas, from tin based targets, that have potential for use as sources of EUV radiation.

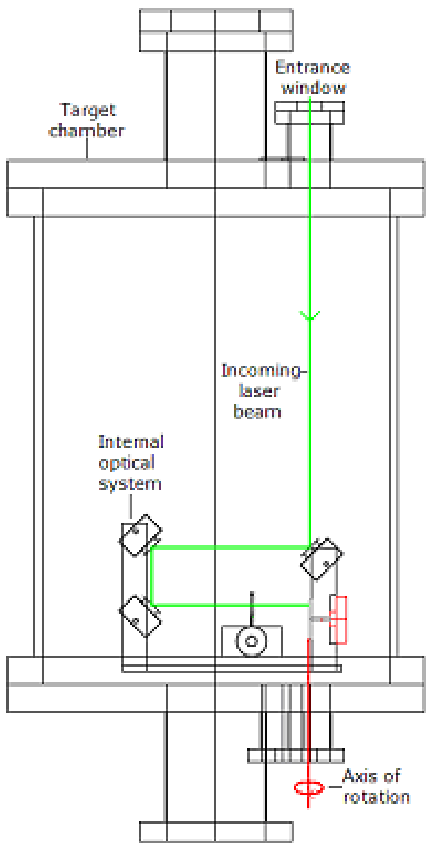

Figure 1. Schematic of target chamber used, including the internal optical system.

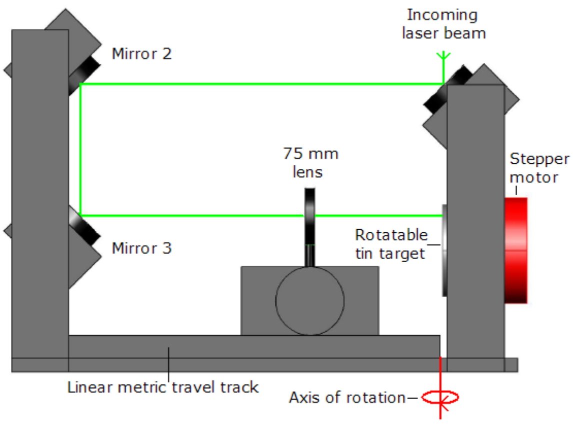

Figure 2. Internal optical system.

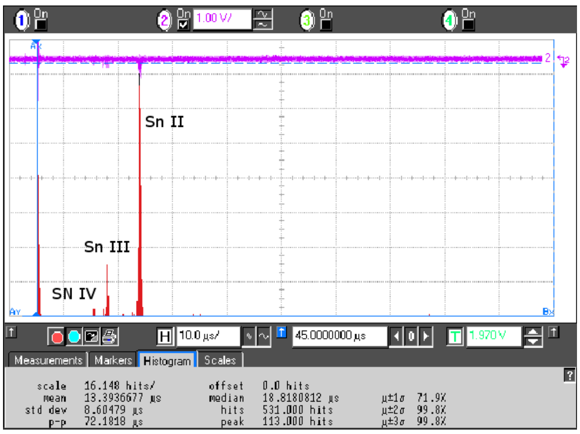

Figure 3. ESA signal recorded on an Infinium Oscilloscope.

2. Results and discussion

Data was recorded for the following angles of emission of the ions with respect to the target normal: 15, 20, 30, 40, 45, 50, 60, 70, 80, 90 degrees. The potential applied to the analyser, ΔV, determined the energy/charge (E/q) state ratio of the ions that reached the MCP's, values of ΔV used were 1300 V to 100 V at 100 V increments and 75 V, 50 V and 25 V. For a set angle and a given ΔV, three plasmas were formed before changing to a fresh point on the target. This process was then repeated twice before changing to a different value of ΔV. Theoretical predictions of the ion stage that could reach the MCP's were obtained by solving equation (1):

$$\text{charge state} = \frac{md^2}{2t^2\Delta V}\left(\frac{r_1}{r_2} - \frac{r_2}{r_1}\right), \tag{1}$$

where m is the mass of the ion, d is the distance from the plasma formation to the multichannel plate detectors, t the ion flight time and r_1 and r_2 the radii of the analyser electrodes. Figure 3 shows a recorded ESA signal while figure 4 also shows the theoretical predictions obtained using equation (1).

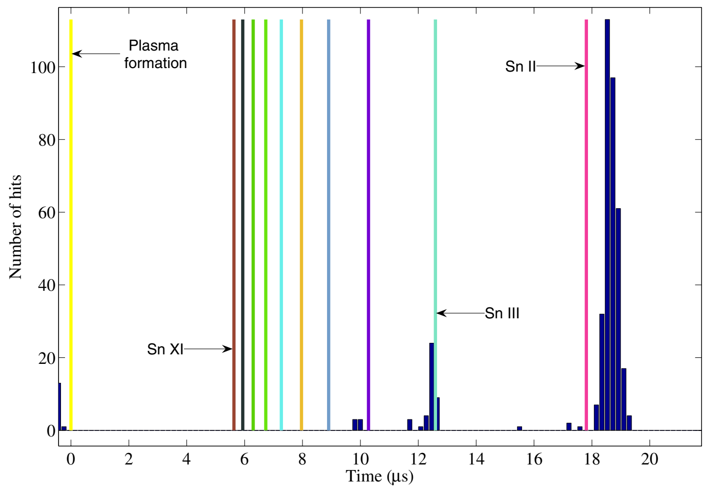

Figure 4. Theoretical and experimental plot of the ESA signal.

The largest peak to the right of the plot corresponds to singly charged tin, with the charge start increasing incrementally towards shorter times. Using this method it was possible to distinguish different ions and determine their relative intensities. To obtain the data shown in the polar plot of figure 5, at given angle, the total number of hits for each ion stage was summed over all values of ΔV. Conseqeuently the plot indicates the significance of each charge state, regardless of the ion energy. The plotted data is from the second laser shot on each piece of fresh target as this resulted in the brightest plasma, free from surface oxidation of the target. This plot is only an indication of the relative ion signal due to saturation of the signal at lower ion stages. It is expected that the number of ions detected at the lower charge states will greatly increase when this saturation is taken into account. This will enhance the dominance of lower charge states particularly at low emission angles. For the data recorded at 15 degrees, the smallest angle achievable to the target normal, the dominant ion stages seem to be Sn^{1+} (generally with an energy range of 0.9–2.8 keV) and Sn^{2+} (generally with an energy range of 1.8–5.5 keV). Ion emission was found to decrease with increasing angle from the target normal with lower Sn ion stages dominating the emission at the lower emission angles.

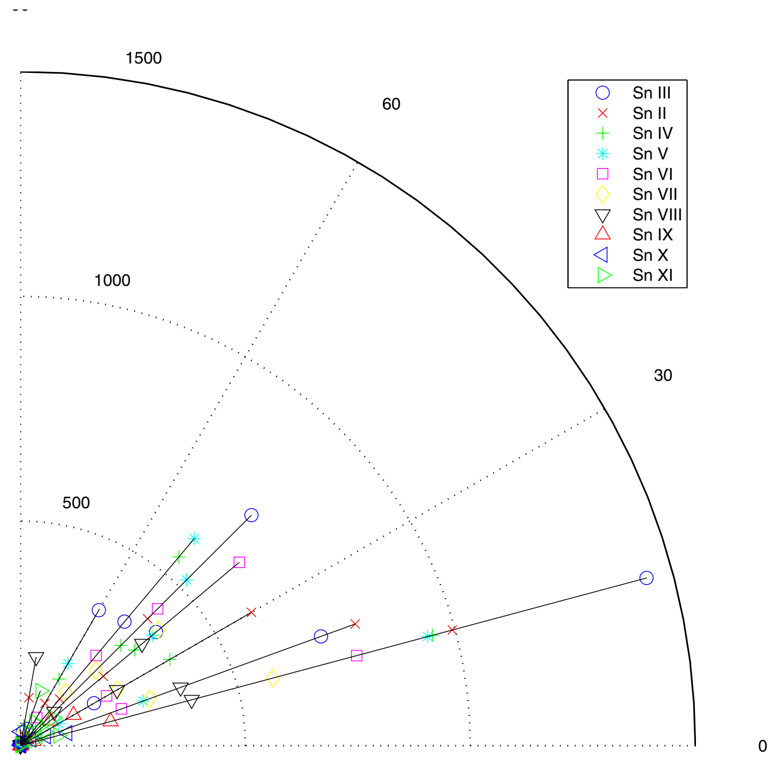

Figure 5. Polar plot showing the relative ion signal as a function of angle for Sn^{1+}–Sn^{10+}.

3. Conclusion

In conclusion, we have demonstrated that the viewing angle of a tin laser produced plasma formed from a solid planar target has a significant influence on the range of ion stages emitted. An anisotropic distribution was noted with largest emission towards target normal and minimal emission at 90 degrees. The dominant ion stages were found to be Sn^{1+} and Sn^{8+}. A more detailed analysis of the data should provide information that is relevant to those seeking to mitigate against ion damage within a potential EUV source.

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