CO_2 laser-produced tin plasmas for next generation semiconductor lithography sources

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Abstract

Measurements of the in-band Extreme-Ultraviolet (EUV) emission from CO2 laser produced Sn (tin) plasma were recorded in order to obtain conversion efficiency values for next generation EUV Lithography sources. CE values were recorded for different laser gas mixtures, with maximum CE values of around 1.5% achieved.

1. Introduction

In order to progressively reduce the transistor size on silicon microchips for the continuation of Moore's Law, next generation Lithography processes for the semiconductor industry require the implementation of Extreme-Ultraviolet (EUV) light sources. An EUV lithography source operating at 13.5 ± 1% nm has been proposed to match the availability of Mo/Si multilayer mirrors and a Sn laser produced plasma is proposed as the source emitter due a large broadband emission feature centred at 13.5 nm for plasma in the temperature range of 30 – 40 eV. The research to date surrounding EUV emitting tin plasmas for lithography has mainly concentrated on using pulsed lasers operating at 1064 nm but theoretical modelling[1] and recent experiments[2] have shown that a move to CO_2 lasers operating at 10600 nm will have more intense in-band EUV emission at lower power densities, thus improving the EUV conversion efficiency. Consequently, we have measured the in-band (centred on 13.5 nm) and broadband EUV emission of a CO_2 laser produced tin plasma using a 0.25-m, absolutely calibrated spectrometer operating in the 9 – 17 nm spectral region. We have done this for a range of laser power densities and the EUV conversion efficiency has been measured at 45° to the target surface normal.

A Sn target was placed inside a vacuun chamber, which was kept at a pressure of $1x10^{-6}$ mbar. The laser energy was delivered by a CO_2 laser with 10 Hz max repetition rate, a max energy of 2 J and 20-70 ns pulse duration. The laser beam was focussed using a 5 cm focal length ZnSe lens onto the Sn target. The lens and target were both placed on computer controlled in-vacuum translation stages. This allowed for the lens to be moved in and out of focus, with a step size of ½ mm. In order to obtain information on the laser beam energy and pulse temporal profile, a ZnSe window was placed in the beam path at 45°, before entering the target chamber. A small portion of the main pulse was reflected away which was used for beam measurement. This was done twice for measurement of the laser energy and temporal profile.

II. Results

The spectra for the Sn plasma were recorded for various laser conditions. The ratios of the gas mixture in the laser chamber of helium (He), nitrogen (N_2) and carbon dioxide (CO_2) were varied with the result of producing different laser energies, temporal profiles and hence power densities. Spectra were then recorded at various lens positions in and out of focus, so as to determine the best position for maximum output of EUV light. A typical EUV emission spectra that was produced is shown in *figure 1*. The figure shows the unresolved transition array (UTA) for Sn centred around 13.5 nm.

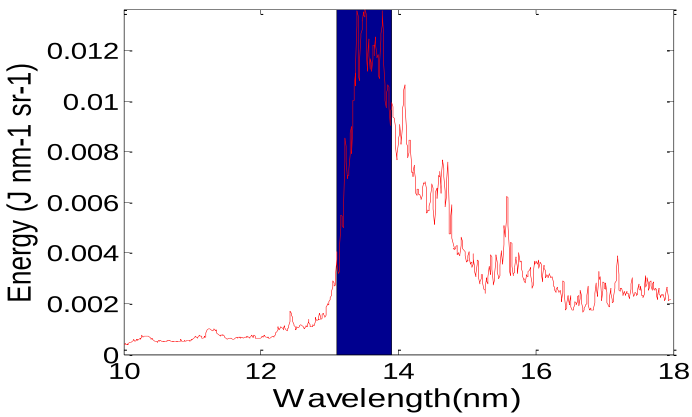

Fig 1: Typical EUV in-band emission spectrum for Sn irradiated with CO_2 laser centred around 13.5 ± 1% nm

The CE values were measured at various lens-target distances close to the focal length of the ZnSe lens. The lens position was moved 2.5 mm either side of the laser focus in half mm steps. The EUV output was found at each position and a plot of the CE's is shown in *figure 2*. Each data point is a three shot averaged measurement. The graph shows the results for He:N_2:CO_2 at 3 different gas ratios; 6:1:3, 7.5:0.5:2 and 5:2:3, each at 1 bar laser gas pressure. The on target laser energy for the shots at the 5:2:3 mix were 1.307 J, 1.384 J and 1.481 J respectively. Varying the gas ratios affected the output energy from the laser. The addition of more N_2 resulted in higher energy outputs but also produced a long tail associated with laser temporal profile, which reduced the in-band EUV emission. From *figure 2* it can be seen that the optimum lens position for EUV output is 1mm away from the laser focus. The CE values for various gas mixes were then measured for the optimum focusing conditions. The results of these are shown in *table 1* and are also for 3 shot averaged values.

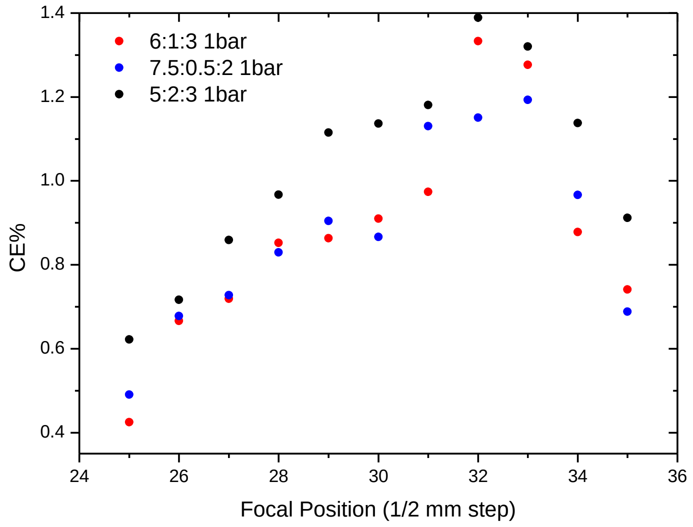

Fig 2: CE of in-band EUV emission for different gas mixes for a range of lens focal positions

Gas Mixture He:N_2:CO_2	CE %	Gas Mixture He:N_2:CO_2	CE %
5:2:3	1.39	6:1:3	1.23
4:3:3	1.37	7:1:2	1.21
4:2:4	1.36	7.5:0.5:2	1.15

Table 1: CE of in-band EUV emission for different gas mixes at optimum focus position

III. Conclusion

A test of CE at various lens positions found that the optimum lens position for EUV output is 1mm away from the laser focus. Using this information a test of the various gas mixtures was carried out and 5:2:3 was found to have the highest output of the in-band EUV light. The CE values produced are lower than predicted from theory[1] that due to its lower critical density, a CO_2 produced Sn plasma would generate CE's of 3-4%. The reason for this shortfall in the CE values may be due to the laser pulse irradiating the target. These profiles show the initial portion of the pulse may not be exciting the required transitions for EUV light emission and the long lived portion of the pulse after the peak is also not contributing to this. Incorporating a plasma shutter as described in experiments by Hurst and Harilal[4] show by clipping this tail due to the presence of N2 gas, could help improve the CE values, as well as tailoring the initial parameters of the system to produce improved temporal profiles for optimum EUV emission.

IV. References

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