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Plasma Physics and Radiation Hydrodynamics in Development of EUV Light Sources for Lithography[1]

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Understanding of radiation generation in laser-produced high-Z plasma (LPP) is important for inertial fusion, astrophysics and x-ray source development. Extreme ultraviolet (EUV) light of 13.5 nm wavelength is strongly desired for manufacture of next-generation microprocessors with node size less than 45 nm. A commercial EUV lithography system would require output EUV power of about 400 W into a solid angle of 2π str within a 2% bandwidth (BW). Laser-produced tin (Sn) plasma at electron temperature of 30-70 eV and ion density of 10^{17-20} cm^{-3} is an attractive light source due to its compactness and high conversion efficiency (CE) from laser to EUV light [1]. The critical issues for practical use are high CE and damage caused by target debris. Many 4d-4f transitions of Sn^{8+} to Sn^{13+} ions mainly contribute to strong emission around 13.5 nm. We first discuss the importance of satellite lines, opacity and photo excitation in radiation transport, especially in high density plasmas produced by 1 μm laser. Experiment and simulation indicate that the maximum CE of 3% is limited by these effects for 1μm laser. We show that the use of a long wavelength laser, such as CO_2 laser, results in higher CE of 3-6%, since the spectral efficiency, the ratio of 13.5 nm emission within 2% BW to total radiation, increases with the reduction of the plasma density. We present theoretical and experimental results of the CE dependence on laser intensity, pulse duration and laser wavelength. Radiation hydrodynamic simulations agree fairly well with EUV spectra observed in the experiments. High energy ions up to 10 keV generated in LPP cause damage to a collecting mirror. We show that the maximum energy is essentially determined from the ratio of plasma radius to Debye length. We also show that the use of the long wavelength laser also reduces the ion energy. We discuss mitigation of high energy ions by a magnetic field and the stability of plasma expansion taking finite ion Larmor radius effects into account.

[1] K. Nishihara et al., Conversion Efficiency of LPP Sources, EUV Sources for Lithography (SPIE Press, Edited by V. Bakshi, (2006)).

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