Modeling and simulation of laser produced plasma sources for EUV photons generation

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This work describes detail results of modeling analysis, simulation, and optimization of laser-produced plasmas (LPP) for the development of an efficient and debris-free photons source for extreme ultraviolet lithography (EUVL) which is currently the most promising technology for the manufacture of the next generation computer chips. The efficient release of 13.5 nm radiation by the plasma is related to plasma opacity, which depends on level populations of different ionic states, ionization balance, and electron density and temperature. For obtaining the highest conversion efficiency (CE, conversion from laser to EUV in-band, 13.5±1%, radiation) from the LPP source, ideal plasma temperatures and densities should be created for the longest possible period of time with the maximum collectable size. Accurate and comprehensive multidimensional modeling of various processes involved in laser target interaction can help in predictions of plasma behavior and achieving the most favorable conditions for maximizing EUV photons generation and collection. Any potential increase in CE is directly translated into huge economical benefits to consumers and to the semiconductor industries.

Models and Methods

All simulation results were obtained using our HEIGHTS package. The package was tested, benchmarked, and utilized to simulate the entire cycle of plasma evolution in LPP devices. To get realistic picture of plasma development these main processes should be accurately described and self-consistently integrated: laser photons interaction with solid/liquid target, vapor and plasma; target thermodynamics, vaporization; ionization and thermal conduction in plasma; vapor/plasma hydrodynamics; plasma radiation and radiation transport in full range and in the specified in-band range. These processes were systematically and comprehensively studied in the framework of EUVL source development, their influence on LPP optimization was investigated. Different energy source parameters, such as laser beam wavelength, pulse intensity, spot size and duration, dual-beam systems as well as various target geometries were analyzed to find optimum condition for EUV photons emission and collection.

Simulation Results

Simulation results include:

1) Influence of major laser beam parameters on plasma evolution from tin foil (tin is considered the best target for the highest CE); prediction of plasma characteristics in temporal and spatial scales in systems with CO_2 laser (10.64 μm wavelength) and several harmonics of Nd:YAG laser (1065 nm, 532 nm, 355 nm and 266 nm wavelengths). Modeling results were benchmarked with our in-house (CMUXE Lab) and other experimental studies that allowed making realistic predictions for a wide range of parameters and to predict the optimized conditions for EUV source from planar target.

2) Effect of target geometry and size on EUV source efficiency. Plasma evolutions from planar, spherical, and grooved targets were studied in details. Several unique experimental results of the conversion efficiency of various target geometries were explained by our HEIGHTS simulation. Ways for optimization were also proposed.

3) Analysis of hydrodynamic confinement in LPPs and its effect on EUV photons output. This 3D modeling included simulation of multi-laser systems with spherical targets, comparative analysis of plasma characteristics evolution from tin foil and small tin droplets.

4) Optimization of LPP sources from small spherical targets for efficient EUV photons output and minimized thermal and ionic debris production to extend LPP device components lifetime.

These results were described in more than 10 peer-reviewed publications and several technical reports.