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TIME-RESOLVED OBSERVATION OF LASER-ASSISTED DISCHARGE PLASMAS FOR EUV SOURCES*

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A Z-pinch plasma is one of the candidates of high power extreme ultraviolet (EUV) sources for the next generation semiconductor lithography. The laser-assisted discharge-produced plasma (LADPP) utilizes a laser ablation technology to form a localized distribution of the target gas. This scheme enables us to stabilize the location of high density hot plasmas which emit EUV light. In order to improve the conversion efficiency (CE) from the electrical input to the EUV emission, which is at most 1.5% so far, it is important to understand the temporal and spatial dynamics of the hot plasmas. A time-resolved observation helps us understand the dynamics of LADPP and gives us a direction to improve CE. We fabricated a birdcage discharge head with a plane tin cathode and a stainless steel ball anode, which enables us to access to the plasma easily. A pulsed laser light with a fluence of 10^{10} W/cm^2 was irradiated at a tin cathode surface to deliver tin vapor to the 5 mm electrode gap, where the high voltage was applied. High density hot plasmas were produced by the electromagnetic compression and the ohmic heating owing to the pulsed high current (20 kA, 150 ns) after the gaseous breakdown. The plasma compression process depends on the delay time *dt* from the laser irradiation to the breakdown because the laser produced vapor expands quickly, resulting in the change of the gas distribution. The EUV emission intensity was maximum when *dt* was 300 ns, while the emission region was minimum. The breakdown did not occur for *dt* smaller than 280 ns because the gas density might not be sufficiently large for the breakdown. The time-resolved imaging of the EUV emission using a gated pinhole EUV camera showed that the hot plasma was produced at first near the laser spot at the cathode and migrated toward the anode quickly. The migration of the hot plasma results in the enlargement of EUV emission region, which is unfavorable for a light source. The observation implies two mechanisms for the migration. One is the pressure wave propagation. The other is the collisional ionization of tin ions with electrons accelerated by the induced electric field, which is on the order of 1 MV/cm.

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UNIFIED MODELLING OF NEAR-ELECTRODE NON-EQUILIBRIUM LAYERS IN HIGH-PRESSURE ARC DISCHARGES*

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An adequate description of near-electrode plasma layers is a key element of a theory of plasma-electrode interaction in high-pressure arc discharges. Published papers deal with different aspects of near-electrode plasma layers and employ different approaches (see, e.g., review[1]), however most of them have one point in common: the layer is a priori divided into a number of sub-layers with different properties (such as a layer of thermal non-equilibrium, an ionization layer, a near-cathode space-charge sheath etc.), each sub-layer is described by its own set of equations, and solutions in adjacent sub-layers are matched in some way or other at a boundary between the sub-layers. In other works, treatment of the space-charge sheath is omitted at all.
In this work, current transfer through near-electrode layers is treated on the basis of direct numerical simulation of the layer, without dividing it into sub-layers with different properties. Governing equations include equations of conservation and transport equations for the ions, the atoms, and the electrons, equations of energy for the electrons and the heavy particles, and the Poisson equation. The equations are solved numerically in 1D without any further simplifications, in particular, without explicitly dividing the near-cathode layer into a space-charge sheath and quasi-neutral plasma. Results of numerical simulation of near-cathode and near-anode layers in an atmospheric-pressure argon arc and in high-pressure mercury arcs with tungsten cathode are given: distributions of plasma parameters across the layer, current-voltage characteristics, energy flux from the plasma to the cathode.
The results on near-cathode layers are compared with those obtained in the framework of an approximate approach based on separate consideration of the space-charge sheath and the ionization layer. Agreement between the two models is good for the Ar plasma at low potential drop values, but not so good for the Ar plasma at high potential drop values and for the Hg plasma.

1. M. S. Benilov, “Understanding and modelling plasma-electrode interaction in low-current high-pressure arc discharges (review)”, J. Phys. D: Appl. Phys. (submitted).

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