Time-resolved evolution of the sputtered species ground state densities in a HIPIMS discharge

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Abstract

Laser-induced fluorescence (LIF) combined with resonant optical absorption spectroscopy (ROAS) was utilized for characterization of an Ar-Ti HIPIMS discharge. As a result of the LIF measurements it was found that the particles velocity distribution rapidly decays during the plasma off-time, and the time-behaviour of the measured densities is strongly determined by the experimental conditions. The time-resolved ROAS measurements elucidate dramatic changes in both ground state (GS) and metastables (MET) densities of all the studied species, namely ArI, TiI and TiII. It was also found by ROAS that, Ti and TiII ground state densities may somewhat decrease during the plasma on-time and increase to its maximum (about 6·1014 cm-3) under our conditions at the end of the off-time. The Ti ionization ratio was found to be equal to about 0.4, with the possible increase up to 0.9 at the end of the plasma pulse. Generally the obtained results indicate highly non-uniform spatial and temporal behaviour of the sputtered species in HIPIMS with the distinct differences found for plasma on- and off-time.

Experimental setup

Figure 2. Schematic view of the LIF diagnostics setup. M – mirror, BS – beamsplitter, PMT – photoMultiplier Tube. (Right) Top-view of the HIPIMS reactor with the beam from the laser and hollow cathode lamp (HCL) for LIF and ROAS diagnostics.

Species of interest

Figure 3. Appearance of the Ar-Ti plasmas in the HIPIMS reactor.

LIF principle

Figure 4. Illustration of the LIF principle for ground state density determination.

LIF results

Figure 5. Time-resolved evolution of Ti spectral lines broadening (left), and Ti density (right) measured by LIF in HIPIMS discharge during the off-time at two Ar pressures. Pulse duration = 20 μs.

ROAS results

Figure 6. Time-resolved absolute densities (a), and Ti ionization ratio (b) in HIPIMS. Pulse duration = 20 μs.

ROAS vs LIF

Figure 7. Time-resolved TiI metastable densities (a), and TiI and TiII sublevels populations (b, c). Pulse duration = 20 μs.

Summary

- LIF diagnostics applied to the HIPIMS discharge reveals fast relaxation of the particles velocity distribution during the plasma off-time, which underlines the fast thermalization after the plasma pulse.
- The time-evolution of the measured Ti and TiII densities depends mainly on the Ar pressure and on the distance from target.
- The ROAS results generally agree with those of LIF, and clarify the HIPIMS plasma processes which take place during the on- and off-time.
- Among the new effects found by ROAS in HIPIMS are: the inversion of the energy sublevels for ArI, TiI and TiII as well as the drop of the ground state densities during the on-time which agree with the previous works [5, 6], although these effects should be clarified additionally.
- The total Ti ground state density measured by ROAS reaches about 6·1014 cm-3, and it is found to be proportional to the pulse duration.

References


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