High intensity action of femtosecond and picosecond x-ray and optical lasers onto ruthenium and molybdenum films

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Refractory ruthenium (Ru) is a perspective material used as an extreme ultraviolet/soft x-ray (EUV/SXR) oblique reflectors or as a protective film capping multilayer mirrors preventing their damage under high radiation fluxes typical for next generation lithography machines and from particle debris. Molybdenum (Mo) is another example of widely employed refractory metal. Here we mean applications of Mo films in solar photovoltaics cells and experiments with ultrathin films – thinner than a skin layer for optical electromagnetic wave. Our studies unveil extremely high survivability of molten films made from these refractory metals.
Properties of the refractory metals Ru and Mo are purely known in a warm dense matter regime. In this regime the densities are comparable to the solid state densities while temperatures are ~1 eV. Their properties in the two-temperature warm dense matter regime are even less known. For considered here cases of ultrashort durations of laser pulses the two-temperature effects are very significant. Electron temperature is higher than ion temperature in the two-temperature states created by ultrashort illumination.
The straight-through description from two-temperature (2T) to one-temperature (1T) warm dense matter states is necessary for quantitative calculations because pulse duration is shorter than duration t_{eq} of the 2T to 1T transit process while the electron-ion temperature equilibration time t_{eq} is shorter than acoustic time scale $t_s = d_T/c_s$ defining the rate of hydrodynamics processes; here d_T is thickness of a heat affected zone, c_s is speed of sound. This straight-through description of thermodynamics and kinetics of 2T and 1T states is presented in the report for PNP16. We develop two-temperature equations of state for Ru and Mo, calculate by DFT (density functional theory) their electronic spectra, find their electron-ion coupling parameters, and define two-temperature thermal conductivities; it is shown that the electronic spectra rather weakly react to exciting of electron subsystem. With this input we run our two-temperature hydrodynamic code. Another important achievement is creation of reliable embedded atom model (EAM) interatomic potential for Ru. This potential is used for defining of strength of Ru and molecular dynamics description of nucleation and ablation under laser action. Results are compared with experimental data.
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