Particle charging by EUV and EUV-induced plasma

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EUV is used extensively in advanced manufacturing and metrology of semiconductor devices. In these applications, submicron particles must be kept away from critical surfaces to be imaged or exposed, or to be measured. Coulomb forces often dominate the force balance for submicron particles, even at relatively minor surface potentials. Understanding and control of particle charge is thus crucial.

In vacuum, EUV will charge particles positively by photoelectric effect, but in the vicinity of surfaces the photoelectric effect of the surface may dominate and the particle may charge negatively instead. At finite pressures, the different contributions from photons, electrons and ions, each with its own timescale, will result in a complicated charge behavior over time. For the pulsed EUV beam and corresponding transient EUV-induced plasma, no analytical equations exist for the potential or charge of a free particle, and PIC modeling is used to determine the evolution of particle charge over time.

It will be shown that for that micron-sized particles shortly attain a positive charge during the EUV pulse, then flip to a negative charge, after which they reach an equilibrium between electron and ion currents at a quasi-steady negative charge; this process will be reset for every new EUV pulse. For submicron particles, reaching equilibrium between electrons and ions will typically take longer than the pulse interval, and negative particle charge will build up over multiple pulses until a global equilibrium is reached between the photo-ionization and the electron currents, at a relatively high negative charge.

For particles close to the EUV beam, the transient positive charging due to photo-electric effect is absent, but the plasma extending outwards from the beam will still result in a flux of electrons and ions to the particle, so similar charging and charge compensation effects as outlined above will occur.