Particle charging by EUV and EUV-induced plasma

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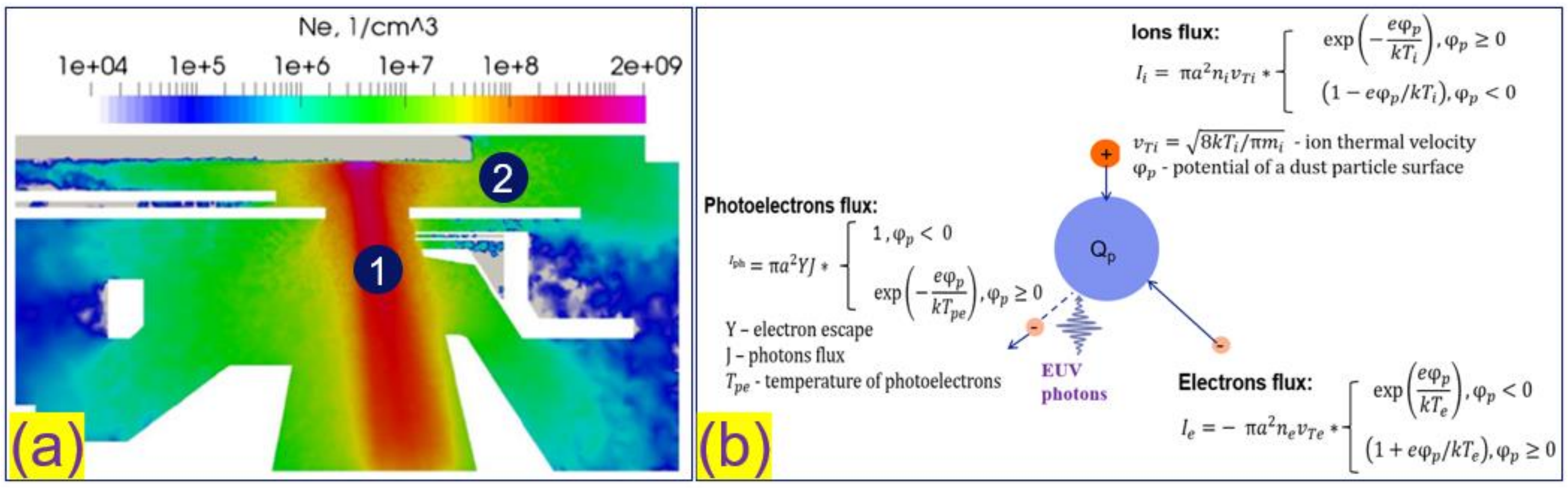
Introduction

EUV Lithography is the technology of choice for High-Volume Manufacturing (HVM) of sub-10nm lithography. One of the challenges of the EUV scanner is to keep away all (nano)particles from the critical imaging surfaces, especially the mask containing the information to be imaged onto the wafer, in the plasma induced by the 92 eV EUV photons in the scanner background gas.

The force balance on these particles, is often dominated by coulomb forces due to the presence of EUV induced plasma. Therefore, understanding and control of particle charge is crucial. Typically, the particle charge is determined by the flux balance conditions of different plasma components: electrons, ions and photons. The charging strongly depends on the size of the particles, as well as on location with respect to the EUV beam and the local plasma conditions.

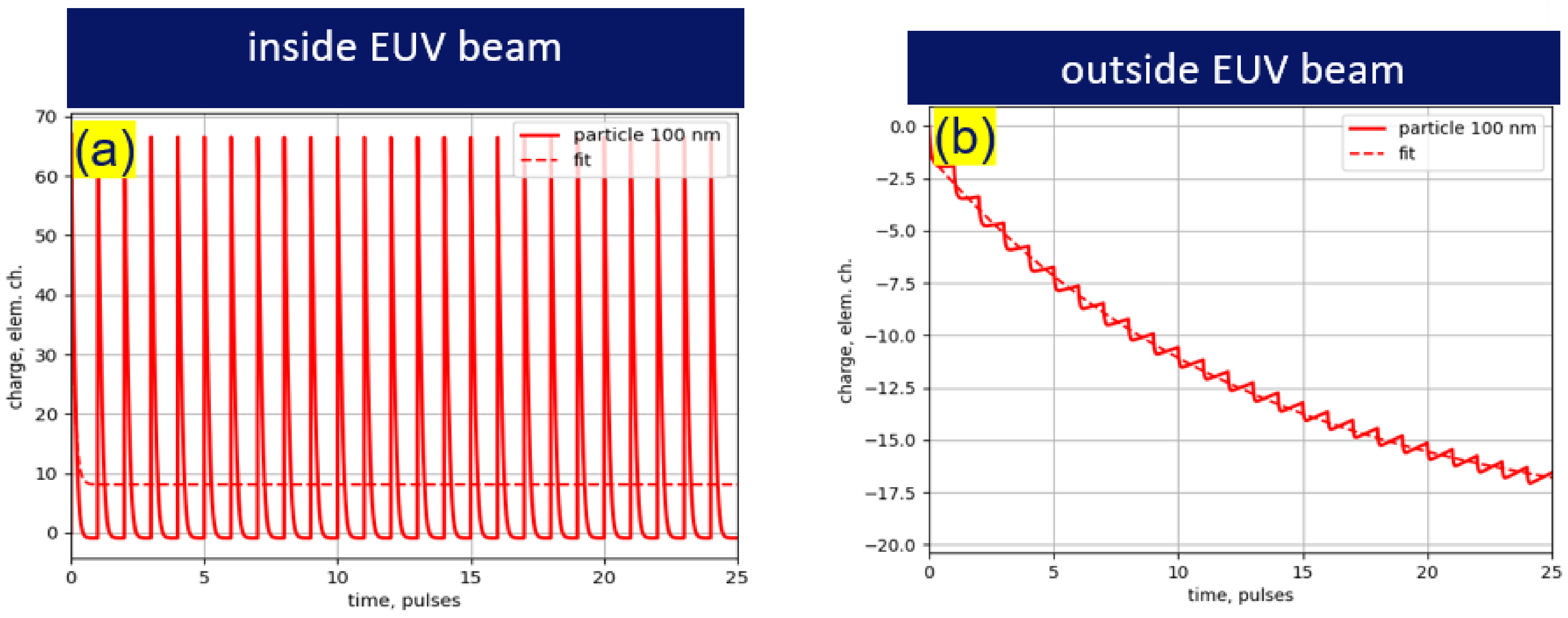


Left: Cross section of scanner and EUV beam close to the mask; Right: overview of fluxes driving charges

Particle Charging

The EUV photons charge particles positive by expelling electrons from it. In EUV Lithography tools, the EUV beam is pulsed with a period of 20 µs. This causes a periodic oscillation of the charge on a particle inside the EUV beam region (left figure): the particle charges positively during an EUV pulse due to photo-electric effect, and charges negatively between pulses due to the EUV-induced plasma.

Particles outside of the EUV beam have the traditional charging mechanisms with a balance between electron and ion fluxes making it negative due to higher mobility of electrons. The particle charge increases stepwise with the EUV pulses.



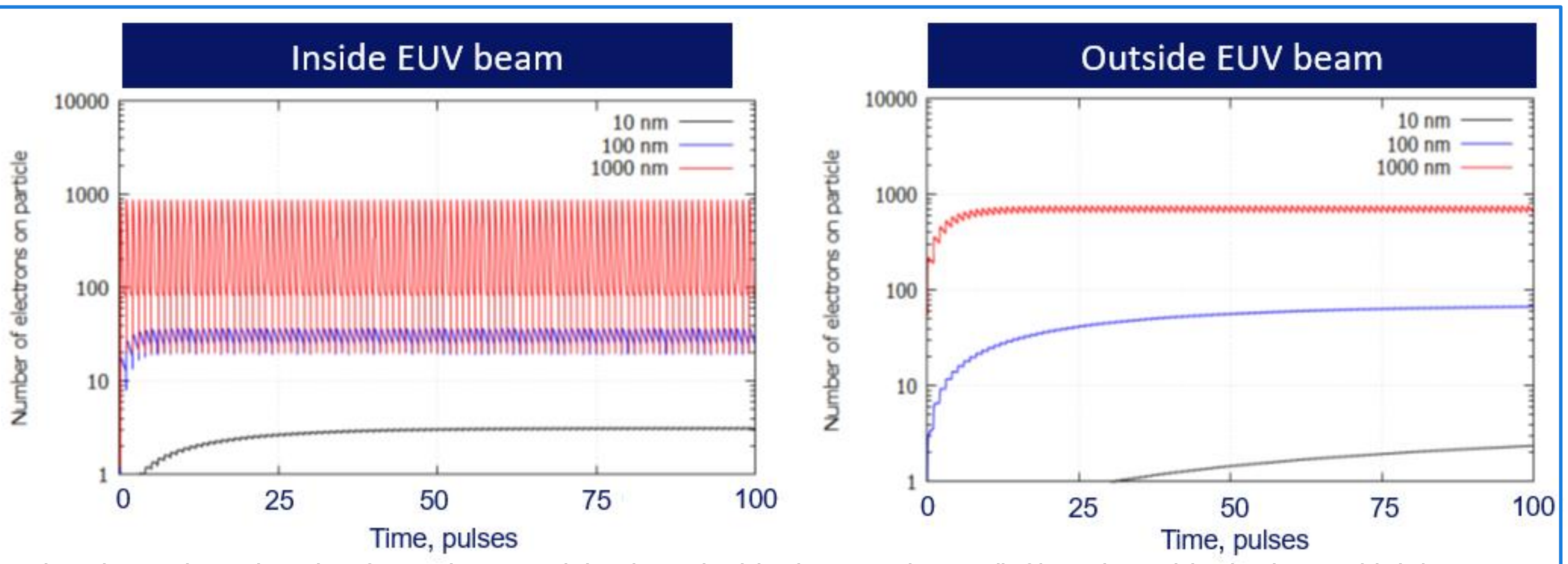
Left: Oscillating particle charge inside the EUV beam; Right: Stepwise charge evolution over multiple pulses for particle outside the beam

Size dependency

The charging mechanisms depend strongly on particle size. Considering OML theory, it can be shown that charging is faster for larger particles: dQ/dt ~ r^2 where r is the radius of particle.

The equilibrium potential depends only on plasma conditions, not particle size so that the steady-state charge $Q_s \sim r$.

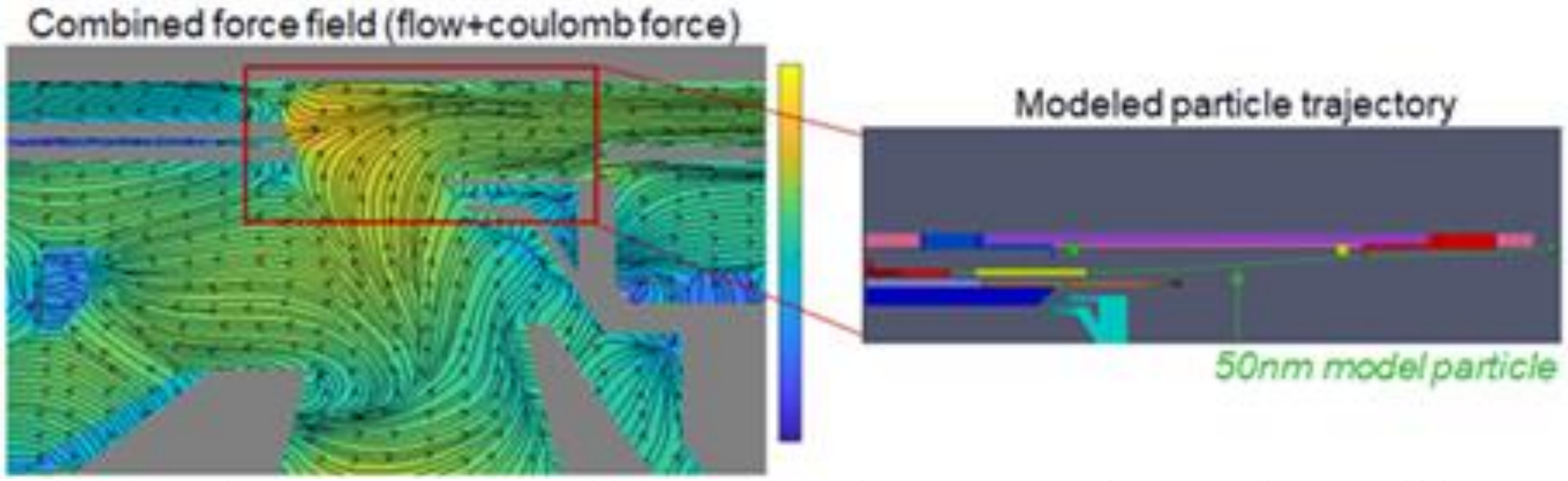
Therefore, the time required to come to this charge scales as τ ~ Qs/(dQ/dt) ~ 1/r. Thus, larger particles charge more quickly., This is illustrated for several sizes of particles both inside and outside the beam in the figures to the right.



Size-dependent charging for various particle sizes, inside the EUV beam (left) and outside the beam (right)

Conclusion and outlook

Combining these particle charge simulations with the dynamic mask potential and the resulting electric fields close to the mask gives the coulomb force on the particle ($F_C = Q_p \cdot E$). Under typical EUV scanner conditions, most other forces like gravity and ion/electron drag may be ignored, and besides the coulomb force only neutral drag should be taken into account. Thus, the charging simulations can be used to calculate particle trajectories for different particle sizes and for different pressure/flow conditions. This toolkit is used to design local flows and pressures such that no particles larger than a given critical size will reach the mask surface.



Left: simulations of the force map for a 50-nm particle in the mask area, just after an EUV pulse; more yellow means higher force (more blue means lower); arrows indicate local direction of force. Right: modeled trajectory for a 50 nm test particle