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Mathematical and computational modeling of the gas breakdown in the planar magnetron discharge

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Magnetron discharge finds numerous applications in semiconductor manufacturing and high-power plasma switch in power grid. Due to the complex magnetic field topology, the gas discharge principle in magnetron is still not fully understood. In this work, we develop a physics-based mathematical model to describe the helium breakdown in the DC planar magnetron, where Paschen's law is invalid. In the mathematical model, the ionization coefficient and the ion-induced secondary electron emission (SEE) coefficient are derived by accounting for the effect of the three-dimensional magnetic fields in magnetron. The model is verified by means of one-dimensional particle-in-cell/Monte Carlo (PIC/MCC) kinetic simulations [1, 2]. The characteristic curve of the breakdown voltage as a function of the helium pressure predicted by kinetic simulations aligns with the mathematical model at the low pressure range 0.1 Pa - 100 Pa of practical interest. The kinetic model detect that electrons are in the runaway regime over the pressure range 0.1 Pa - 1000 Pa, where spatially periodical peaks of the ionization coefficient are observed. The phenomena of ionization peaks is found to be associated with the competing process between the energy gain of runaway electrons in the electric field and their energy loss in inelastic collisions.

References

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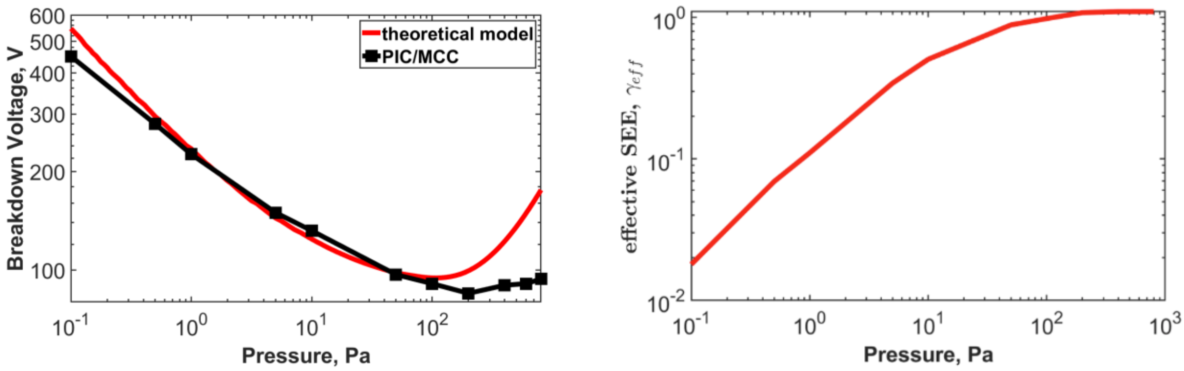

Fig 1. Left: The breakdown curve comparison between the theoretical model and PIC/MCC simulations. Right: Effective SEE coefficient as a function of pressure.