ABSTRACT

Microscale gaseous discharges under extremely small scale (< 10 µm) are quite different from their macro scale counterparts in many aspects. As recent research reveals, this difference is caused by ion-enhanced field emission, which refers to field emission that is activated by the uniquely high electric fields and enhanced by ions generated from the discharge. By investigating several interesting examples of how microscale discharge behaves differently from large scale discharge, this dissertation tries to reveal how field emission and microscale discharge interact with each other in detail.

The microscale breakdown phenomenon is studied by using PIC/MCC simulations. The study reveals the roles of ions and field emission (and their mutual relationship) and the extent to which ions enhance field emission and how this leads to breakdown. These simulations reveal that the net positive space charge that accumulates in the electrode gap enhances the electric field, subsequently enhancing field emission from the cathode. Because the emitted electrons generate additional ions in the discharge, a positive feedback mechanism occurs where the field emitted electrons produce the ions that enhance the electric field. It is revealed that this coupling between field emission and the discharge is necessary in order for breakdown to occur. Quantum simulations are also carried out to investigate how ions generated from the discharge enhance the field emission in detail. The modified Paschen’s curve is introduced to correctly predict microscale breakdown.

The PIC/MCC simulation also provides important information of the electron energy distribution of microscale discharge. A non-continuous distribution with discrete peaks corresponding to specific inelastic collisions is observed. The relative magnitude of these peaks and shape of the energy distribution can be directly controlled by the parameter pressure times
distance \((pd)\) and the applied potential across the gap. These parameters dictate inelastic collisions experienced by electrons and as both increase the distribution smoothes into a Maxwellian-like distribution. By capitalizing on field emission at these dimensions, it is possible to control the energy distribution of free electrons to target specific, energy dependent reactions.

Microscale glow discharge is selected as a post-breakdown example of how field emission interacts with microdischarge. A current-driven PIC/MCC mode is introduced to simulate microscale glow discharge, and the effect of field emission on discharge is discussed. As the study reveals, field emission helps to reduce the cathode fall voltage and cathode fall thickness. For microscale glow discharge, the impact of field emission is very similar to the impact of strong secondary emission. However, high secondary emission coefficient (>0.1) is usually not obtainable, field emission is then very important for the manipulation of micro-glow discharges.