Simulation into the Mechanism of Cathode Spot Formation under Ion Bombardment

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***Abstract*-- The plasma-surface interactions in vacuum arc lies in the theory of cathode spot dynamics, which is decisive to the whole vacuum arcing process such as arc erosion and post-arc recovery. To help understand the complex cathode spot dynamics, in this work the formation of cathode spot under an external plasma environment is investigated by Molecular Dynamics (MD) simulation. The atomic structure of the copper substrate is built as the cathode, with the external plasma environment simplified as the distribution of copper ions with a certain velocity inserted above the surface. The mechanism of the crater formation induced by ion bombardment is proposed by this scaled-down model. It was found that the pressure effect of ion bombardment is mutually decided by the ion energy and substrate temperature. This work contributes to further cathode spot modelling and supports the design of vacuum circuit breakers so as to reduce erosion and maintain dielectric strength.**

Background & Main Results

During the diffuse vacuum arc, small luminous spots are observed on the cathode surface, which are defined by the cathode area that current flows through with high current density. In the meantime, these spots are found to produce small cathode craters after cooling down, which could erode the electrode and decrease the dielectric strength of the vacuum gap [1]. To assess the influences of cathode spots, an understanding of cathode spot dynamics is essential. At present, the cathode spot simulations are mostly analysing the reactions of the cathode which is assumed as a unity fluid under the given external plasma environment by hydrodynamics (HD) without considering the current transfer [2]. The effects of plasma on the surface are coupled by setting the surface boundary conditions, including energy flux density, current density, and pressure. As a result, the formation of the cathode spot is presented by the development of the cathode crater [3].

In this work, the formation of the cathode spot is simulated by Molecular Dynamics (MD) in LAMMPS. The physical process of the formation of the cathode crater is also set under the distribution of external plasma ions. However, the cathode is modelled by its atomic structure, so that the surface deformation and surface evaporation could be directly observed on the molecular level. In the meantime, the input of plasma ions is directly described by the ion distribution which bombards the cathode surface, instead of setting boundary conditions in HD simulation.

The simulations in this work are categorised into three types: single ion bombardment, continuous local ion bombardment, and regional ion bombardment. In the first and second types, the influences of incident ion energy and bombarding frequency on the crater formation are discussed, respectively. In the third type, ion current, ion current density, ion energy, and bombarding frequency are jointly discussed. The structural deformation and the evolution of temperature distribution are observed as the output, which is used to analyse the relationship between ion current density distribution and the crater morphology. Figure 1 presents an example of the evolution of local temperature during continuous ion bombardment.

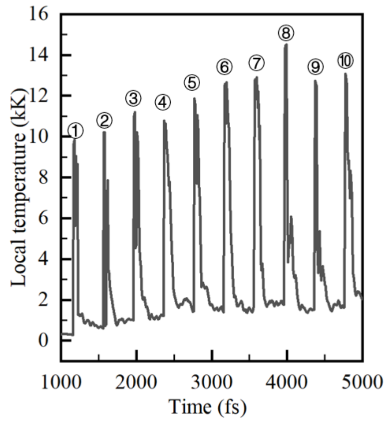

Fig. 1. The evolution of local temperature during the first ten ion bombardments with the bombardment frequency as 400 fs.

Conclusions

This work investigates the cathode spot formation mechanism in vacuum arc conditions. A MD model is built up and different plasma ion input distributions are studied. It is found that the pressure effect of single ion bombardment is decided by the incident ion energy and substrate temperature. Ion bombardment is found to have an effect of the local heating on the bombarded site, where the temperature increases sharply by ion bombardment and then decreases slowly by heat conduction. Even for low ion energy, an obvious pressure effect exists when the bombarding frequency is higher than the local temperature relaxation.

References

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