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Enhanced Vacuum Gap Insulation Between Non-Arc Metal Components in Vacuum Interrupters by Ion Implantation

High-voltage and high-capacity vacuum interrupters adopt a multi-stage floating shield structure, which can be regarded as an insulation system consisting of multiple vacuum gaps connected in series and parallel. Breakdown occurs not only in the vacuum gap of the main contact but also in unintended regions such as the gaps between shields or between shields and conductive rods. To improve the overall insulation performance of the vacuum interrupter, treatment of non-arc metal surfaces is required. This paper investigates ion implantation on the surfaces of stainless steel ball-to-ball and ring-to-ring electrodes, which are then installed in the vacuum interrupter to simulate non-arc metal gaps. The experiments compare the effects of different types, doses, and acceleration voltages of implanted ions on breakdown voltage improvement. Surface analyses were conducted to examine the surface morphology and elemental composition of the electrodes before and after ion implantation. The results indicate that ion implantation effectively increases the initial breakdown voltage of vacuum gaps. However, as the number of breakdown events increases, the implanted ion layer gradually deteriorates. The improvement in voltage withstand capability is influenced by ion species, implantation dose, and acceleration voltage. The underlying mechanism is attributed to the enhancement of the electrode surface work function due to metal ion implantation. This work provides a theoretical foundation for enhancing the performance and miniaturization of high-voltage vacuum interrupters.

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