Unipolar arcs on the first wall: gaining deeper understanding of arc ignition conditions and development of arc-prevention strategies

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The plasma-facing first wall components are subject to intense particle and photon radiation as well as strong electric and magnetic fields. Perhaps the most undesired, disruptive phenomenon is a plasma instability that leads to the ignition of a highly concentrated secondary discharge on the wall usually described as a “unipolar arc” [1]. It appears “unipolar” as the wall segment acts like a cathode, with unipolar arc spots being essentially the same as vacuum arc spots, and other components acting as the anode, depending on the electric potential distribution [2]. Ignition and operation of such arc spots is highly undesired for two main reason: (i) injection of plasma of the wall material into the fusion plasma, leading to radiative cooling and plasma instabilities, and (ii) reduction of the useful lifetime of the first wall due to arc erosion.

Although the phenomena of unipolar arcs have been known for decades, relatively little attention has been paid to further our understanding of these effects. Some work suggested that geometrical features like cracks on surfaces play a critical role [3]. Other work focused on the formation of “fuzz” under hydrogen or helium bombardment [4]. The dependence of arc ignition on hydrogen retention, for example, is little studied as it is difficult to emulate the first wall conditions and also have access to suitable in-situ diagnostics of the plasma and the material-surface condition. There is a need to address and understand the relations of material properties, surface modification under plasma conditions, and ignition of arc spots, and the consequences of arc spot operation for the subsequent arcing probability.

There is a rather large body of research on vacuum arcs (or “cathodic arcs” in the presence of gas) that considered plasma properties and application to coatings [5] and to high power switching [6]. It seems natural to utilize this knowledge base and to design approaches to studies of unipolar arcing with advanced diagnostic techniques, e.g. involving simulation, laser diagnostics, particle analysis and in-situ surface and materials characterization. We see an exciting opportunity to use small scale plasma facilities to study unipolar arcs and develop a foundational understanding that leads to arc mitigation techniques that can be applied in Tokamak plasmas.
Unipolar arc traces on an oxide-covered, floating shield

Electron micrographs of arc trances on metal vacuum arcs burned in the presence of a strong magnetic field.