Relationship Between Cathode Spot Formation and Injector Properties During Local Helicity Injection on the Pegasus-III Experiment

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Local Helicity Injection (LHI) is a plasma startup method employed on Pegasus-III that utilizes localized arc plasma sources that are electrically biased to extract an electron beam into the main vessel parallel to the vacuum magnetic field. Metallic injector electrode surfaces can become the source of electron current rather than the arc plasma, leading to cathode spots that can damage the electrodes, decrease injector lifetime, and reduce LHI performance. The occurrence of these spots can be minimized by conditioning the electrode surfaces.

Scanning electron microscopy (SEM) is used to track the evolution of injector surface properties as they are conditioned. Three types of injector components have been imaged: the frustum, frustum shield, and washers. The frustum and its shield are both conically shaped pieces, with the shield fitting over the frustum. The washers or rings fit over the body of the injector, away from the outlet of the arc plasma. Pristine images of molybdenum injector components are imaged to use as a baseline for comparing against images of conditioned components. The SEM images of used components show surface damage typical of materials with a history of cathode spots and non-conductive oxide particles, confirmed by energy-dispersive X-ray spectroscopy (EDS). This damage is non-uniform, and its extent is a function of the region of the part that is examined. In particular, titanium gettering employed on Pegasus-III results in titanium deposition on one-half of the frustum shield, while the other half remains free of titanium. Further, there is an increase in surface melting on the frustum shield near the outlet of the arc plasma. The features identified by SEM are indicative of various types of processes experienced by the surface, including melting, oxidation, and contamination. This is consistent with existing literature on high-Z cathodes, where craters and surface erosion are observed following a cathode spot attack. The latter two are verified by EDS measurements, which indicate high levels of oxygen, titanium, and other contaminants on the sample.

Optical profilometry is used to support and quantify surface roughness observations made using SEM. While a smoother surface profile is expected with higher conditioning levels, current profilometry work indicates higher surface roughness with conditioning due to melting. This is due to textural irregularities induced by prolonged heating and recurrent cathode spot attacks. Further work involves identify areas on the components with minimal melting (so as to isolate micrometer and nanometer-scale damage caused by conditioning only) and conducting comparisons of roughness profiles associated with varying conditioning history.

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