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Imaging Dark Current at Microscale

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Dark current (undesirable field emission electron current) is proven to be one of electric breakdown triggers. Breakdowns are accompanied with x-ray flashes and ion-electron plasma bursts. At the breakdown location the material is often damaged –it is caused to melt, flow and re-crystallize –which indirectly suggests exceedingly high temperature at those locations. Breakdowns happen at microscale, but compromise/interrupt the normal operation of bench-size high power vacuum electronics devices (e.g., TWT) or large scale accelerator facility (e.g., GeV or TeV linear colliders or light sources). Most importantly, dark current induced breakdown limits the figure of merit of an accelerator, the acceleration gradient. To push accelerator research frontier, the breakdown phenomenon is studied with highest attention at the accelerator research centers.

There are two basic questions. First –why and where is breakdown initiated? Second –what are consequences after a breakdown occurred? To directly address these questions and unveil processes associated with the dark current that take place at microscale, we conducted a series of combined dark current imaging experiments by making use of custom DC and RF field emission microscopes. For copper, we found that after multiple RF breakdown events occurred, most dark current emitters were breakdown damaged locations. By conducting DC field emission imaging of nanodiamond and carbon nanotube structures, we argue that breakdown is initiated by dark current via Nottingham heating channel. Material's resistance to breakdown (stability) depends on its electronic band and crystal structure. Namely, the combination of electronic and lattice properties determine the level of temperature enhancement at distributed microscopic locations, and whether a solid state material stably performs or undergoes thermal runaway and evaporation followed by breakdown in the self-induced heating regime.

Authors: Prof. BARYSHEV, Sergey (Michigan State University); Dr SHAO, Jiahang (Argonne National Laboratory)

Presenter: Prof. BARYSHEV, Sergey (Michigan State University)

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