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In-situ observation of field-induced nano-protrusion growth on a carbon-coated tungsten nanotip

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Nano-protrusion (NP) on metal surface and its inevitable contamination layer under high electric field is often considered as the primary precursor that leads to vacuum breakdown, which plays an extremely detrimental effect for high energy physics equipment and many other devices. Yet, the NP growth has never been experimentally observed. Here, we conduct field emission (FE) measurements along with in-situ Transmission Electron Microscopy (TEM) imaging of an amorphous-carbon (a-C) coated tungsten nanotip at various nanoscale vacuum gap distances. We find that under certain conditions, the FE current-voltage (I-V) curves switch abruptly into an enhanced-current state, implying the growth of an NP. We then run field emission simulations, demonstrating that the temporary enhanced-current I-V is perfectly consistent with the hypothesis that a NP has grown at the apex of the tip. This hypothesis is also confirmed by the in-situ observation of such a nano-protrusion and its continued growth during successive FE measurements in TEM. We tentatively attribute this phenomenon to field-induced biased diffusion of surface a-C atoms, after performing a finite element analysis that excludes the alternative possibility of field-induced plastic deformation.

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