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Diamond at High Gradients

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Diamond possesses extraordinary mechanical, thermal, and electronic properties – the name "diamond" is derived from "adamas," meaning "invincible" – and has been deemed the ultimate frontier and engineering material of the 21st century. Indeed, diamond has the potential to reshape or revolutionize a wealth of applications across quantum computing, power grid infrastructure, implantable bio-electronics, opto-electronics and, of special interest, across pulsed power and accelerator R&D. In this presentation, we will review three important applications that can greatly benefit from the use of diamond devices. In all these applications, diamond needs to be operated between 0.1 and 10 GV/m.

First, we will present our recent results outlining the feasibility of creating an ampere-class high-brightness field emitter cathode technology for high frequency and high gradient injector developments. Our cathode material of choice is ultra-nano-crystalline diamond (UNCD). UNCD possesses exceptional emission efficiencies and low intrinsic emittance. Emission originates from grain boundaries, an important characteristic that allows for a simple planar geometry with ~10 nm roughness thus bypassing the need for traditional high-aspect-ratio geometries which limit cathode operation to 20-40 MV/m. As a result, operation at high gradients at or above 100 MV/m is feasible. We will present and review survivability and conditioning of UNCD up to 100 MV/m and corresponding output charge relations.

Secondly, we will review diamond as an ultrafast high-power device called diode avalanche shaper (DAS). When a diamond DAS is exposed to a nanosecond kV pulse, resulting in a field of ~1 GV/m, it functions as an ultrafast closing switch. This closing takes place on a sub-nano-second scale caused by the formation of the streamer traversing the diode at ~108 cm/s. For reference, streamers causing lightning in air are known to move as fast. Modelling results will be presented to illustrate how many MW of power can be switched over ~10 ps. One of the most prominent applications of the DAS is in ultrawide band (UWB) radio/radar. The use of diamond over Si greatly enhances peak output power and shortens pulse lengths, thus greatly improving the detection resolution and range, e.g., important for vehicular radar.

Lastly, we will review diamond as a waveguide material that could solve current limitations in efficient wakefield generation of optical fields on the order of 1 GV/m in the THz range. Such gradients are of paramount importance for beam-driven wakefield accelerators for TeV-class colliders and for most basic sciences where electric fields of up to 1 V/nm can be used for time-resolved THz-driven chemical reactions and materials phase transformation/transitions. We will review recently published 1 GV/m UCLA experiments with quartz waveguides at FACET-II and outline a thermal hypothesis to show how using diamond could potentially tackle ≥1 GV/m and/or increase repetition rate at FACET-II.

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