Stable Field Emission from Nanoporous Silicon Carbide Tips Patterned by a Focused Ion Beam

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Research on cold-cathode electron field emitters has been underway for decades, motivated by technological breakthroughs potentially enabled by the desirable properties of field-extracted cold electrons compared to thermally-emitted electrons. For example, the use of carbon nanotube field emitters in display applications has been established for some time.[1] Intrinsic field-emission attributes such as minimal beam spread and fast response would also allow for disruptive advances in microwave and x-ray source technology, enabling new applications in areas of such as radar or imaging for medicine and security. Such applications, however, require an emitter capable of high emission currents, which so far has been the sole realm of thermal sources.

Here we report on a new type of cold cathode field emission electron source capable of extremely high emission, producing, for the first time, stable current densities at levels comparable to those of thermal sources. The refractory, high-band-gap emitter material consists of a nano-porous foam of silicon carbide (SiC) monolithically fabricated by electrochemical etching of a SiC wafer. One-dimensional arrays of fins, or two-dimensional arrays of pillars (Figure 1, a-c) are then formed by XeF2-assisted etching of the porous SiC using a focused ion beam (FIB). The gas-assisted FIB process is characterized by a high rate of absolute material removal, compared to the case of bulk SiC, and allows straightforward and reproducible shaping of pillars and fins with high aspect ratios (~20:1) without loss of material porosity.

Field enhancement under application of an electric field is defined by both the local morphology of the porous material (providing a continuous supply of nanoscale sharp emission points as the emitting surface wears) and the macroscopic shape of the FIB-sculpted emitter-tip array. Record stable emission in excess of 6 A/cm^2 at 7.5 V/μm and a maximum current density of 11 A/cm^2 at 9.0 V/μm are demonstrated (Figure 1, d). These values are comparable to those typically achieved using thermal sources, raising the realistic perspective of cold-cathode field emitters emerging as a disruptive technology in the near future.

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[1] W. A. de Heer, A. Châtelain, D. Ugarte, Science **270**, 1179 (1995).

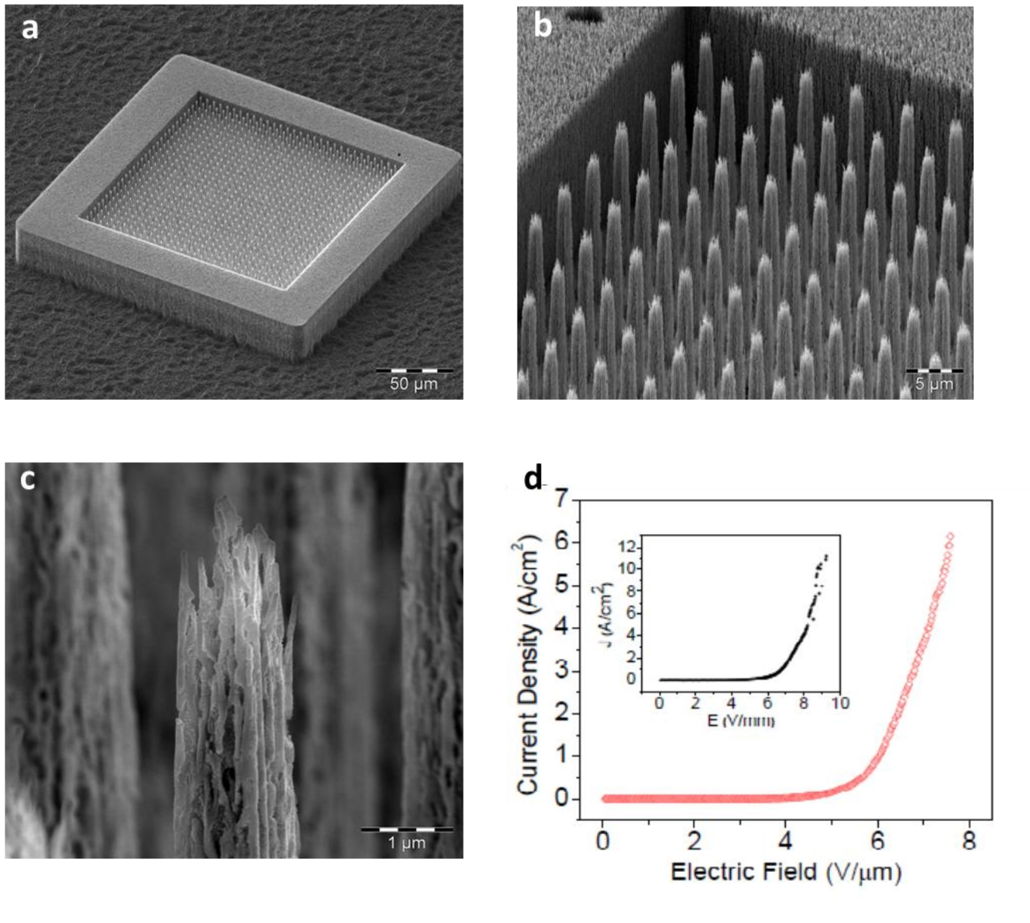

Figure 1: (a,b,c) Scanning electron micrographs (taken at 52º from surface normal, with increasing magnification) of a monolithic nanoporous SiC mesa on a SiC wafer, patterned into a 5-µm-pitch, 30x30 array of electron field emitters (height: 20 µm, average width: 1.5 µm) by XeFe2-assisted etching using a focused ion beam (Ga^+ ions, beam energy: 30keV, beam current: 2.5 nA, nominal beam diameter: 50 nm) . (d) Measured field-emission current density of array (J) vs. applied electric field (E). Inset: J vs. E measured to failure point of array.