Stable Field Emitters Using Inverse Opal Structures

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Carbon nanotube (CNT) arrays have been developed for a variety of miniaturized electronic devices, such as vacuum tube diode/triodes, miniature x-ray sources for spectroscopy/imaging, and ionizers for miniature mass spectrometers. The sharp tip and low work function of CNTs make them ideal materials for field emission (FE) devices, however their stochastic microstructure leads to deformation at low applied mechanical/electrical loads; this causes emission instability, low S/N ratio, device shorting and failure. Decreasing the gap between device components is necessary for enhanced performance and miniaturization, however variations in CNT height often lead to device failure. There is a need for alternate cold cathode materials that are as efficient, robust, and poor-vacuum tolerant as CNTs, but with improved rigidity to enable high-reliability, close-gap (<5μm) electrode integration for low voltage operation. Inverse opal structures offer many of the desired geometric/electronic features for FE applications as well as uniform array height, similar to Spindt-type cathodes[1], and are more structurally robust than CNTs. Inverse opals can be fabricated using any conductive material, which allows for optimization of both FE and structural properties.

This work evaluates how variations in inverse opal tip height, sharpness and spacing impact the field emission performance of inverse opal diodes/triodes. To fabricate the inverse opals, polystyrene spheres are deposited on a conductive surface, generating an opal template. The template is electroplated then removed (Fig. 1a). The remaining inverse opal is electropolished to sharpen the tips (Fig. 1b). Nickel inverse opal triodes, with a cathode/gate gap of ~75μm, demonstrate emission at threshold fields of ~10 V/μm (Fig. 2a). These are non-optimized arrays tested as a proof-of-concept to demonstrate viability of the idea. The anode current is modulated via changes in the gate voltage (Fig. 2b), as expected for a triode device. This work characterizes the relationship between tip radius, aspect ratio, and sphere size while reducing the cathode/gate gap to less than 50μm. Optical photolithography techniques are used to create a monolithically integrated gate structure onto the inverse opal cathode with cathode/gate gaps of 5μm or less. The integrated inverse opal gate/cathodes are incorporated into a triode device and evaluated in terms of the threshold voltage.

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[1] Spindt, C., Brodie, I., Humphrey, L., Westerberg, E. R., Physical Properties of thin-film field emission cathodes with molybdenum cones, Journal of Applied Physics, 1976.

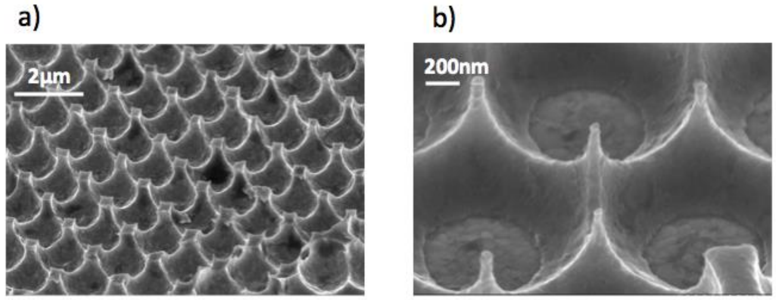

Figure 1: (a) Nickel inverse opal. (b) Electropolished nickel inverse opal with sharp tips.

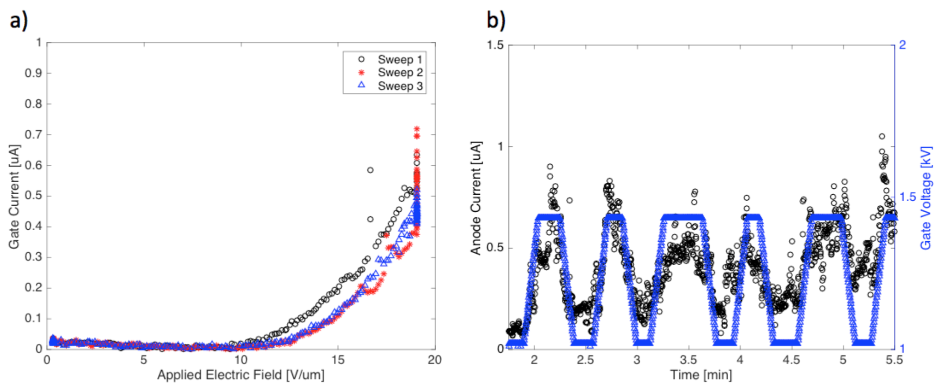

Figure 2: (a) Triode testing of nickel inverse opal cathode shows threshold fields of 10V/µm for 3 voltage sweeps on a single sample. (b) Anode current (held at 1.4kV) modulation when gate voltages varied from 1.0-1.4kV.