Optimization of Inverse Opal Structures for Application as Stable Field Emitters

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Carbon nanotube (CNT) arrays have been developed for a variety of miniaturized electronic devices, such as vacuum tube diode/triodes. 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. 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] but easier to fabricate, and are more structurally robust than CNTs. Inverse opal cathodes (Fig. 1) 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 aspect ratio, sharpness, and material impact the field emission performance of inverse opal diodes/triodes. Nickel inverse opals, with geometries optimized for sharpness and aspect ratio, were integrated into diodes (Fig. 2a) and their performance characterized. A 30% decrease in threshold field was observed when comparing 1μm optimized monolayer inverse opal cathodes to 1μm un-optimized cathodes (Fig 2b). Optimized 600nm inverse opal arrays have a higher emitter density but show negligible improvement in threshold voltage due to their lower aspect ratio. To demonstrate robustness of this system to extreme environments, a 600nm inverse opal diode was tested before/after exposure to 300C in vacuum. The emission curve before/after the test are similar, however the threshold voltage required for emission increased by 20% (Fig. 2c). This work additionally explores how to reduce the threshold voltage by varying the material of the inverse opal cathodes. Nickel inverse opal cathodes with optimized geometries are coated with various low work function materials via atomic layer deposition and their performance characterized. Additionally, 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 diode/triode devices 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.

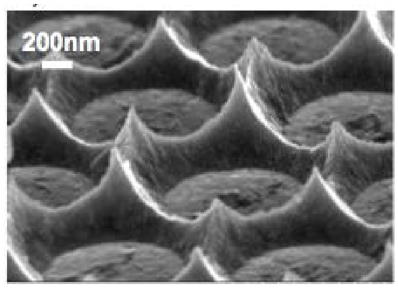

Figure 1: Nickel inverse opal cathode with an array of sharp tips (radius of curvature ~10nm).

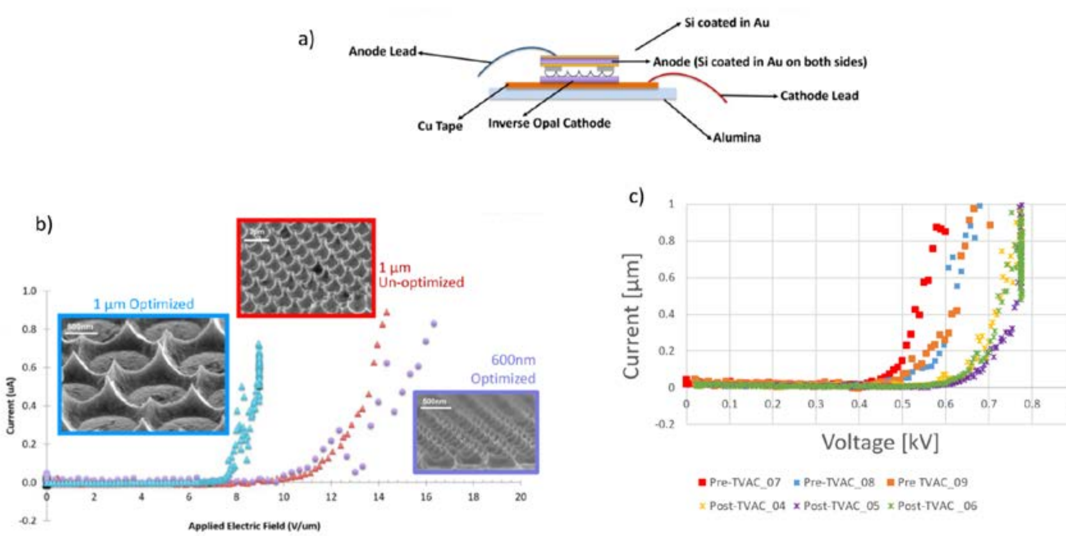

Figure 2: a) Schematic of diode test configuration, b) Field emission performance for various inverse opal cathode types, c) Field emission performance before/after exposure to 300C in thermal vacuum chamber.