CARBON NANOTUBE FIELD EMITTER DESIGN FOR IN SITU EPMA. Lucy F. Lim[1], Adrian E. Southard[1,2], Larry A. Hess[1], Carl A. Kotecki[1], Stephanie A. Getty[1], John G. Hagopian[1,3], [1]NASA Goddard Space Flight Center (lucy.f.lim@nasa.gov) [2]USRA [3]Advanced Nanophotonics, Inc.

In the mini-electron probe ("EPMA") flight concept [1] electrons are drawn out of an addressable-element carbon nanotube ("CNT") field emitter array by the cathode/grid extraction voltage, then accelerated by a miniature electrostatic lens stack into a planetary/asteroidal/cometary surface, thus exciting X-ray line emission characteristic of the elemental composition of the surface. The X-rays can then be measured by a silicon drift detector similar to those used in laboratory energy-dispersive spectroscopy (EDS) and analyzed using standard EPMA techniques to give the surface composition of the region illuminated sequentially by each electron-beam spot (100 μm). In this way, a grid of e-beam spots activated in sequence will non-destructively produce a fine-scale map of elemental composition.

The focus of this abstract is the technical development of the addressable CNT-based emitter array.

Cathode Design: The critical new technology enabling the mini-EPMA instrument is the addressable array of field emitters. Each field emitter is a carbon nanotube "forest" grown in a circular 100 μm region on a wafer substrate. The key challenge was to achieve robust nanotube growth on a wafer patterned for electrical addressability.

Two candidate catalysts and several combinations of silicon-on-insulator (SOI) or quartz substrates with conductive metal layers were tested. Nanotube growth had been demonstrated on unpatterned wafers of both types.

Several candidate designs using dielectric wafers proved unsuitable for fabrication for various reasons, including formation of metal silicide layers during nanotube growth producing a surface incompatible with wire bonding and inhibition of satisfactory nanotube growth on the metal conductive traces, most likely caused by alloying of the metals with the catalyst. Examples of unsuccessful growth are shown in Fig. 2.

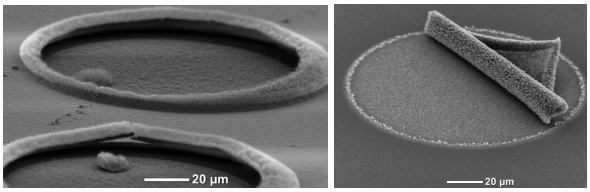

Fig. 2: Examples of unsatisfactory CNT emitter growth and adhesion. Growth is observably stunted in the centers of the emitters and bundles of nanotubes are visibly detached from the substrate.

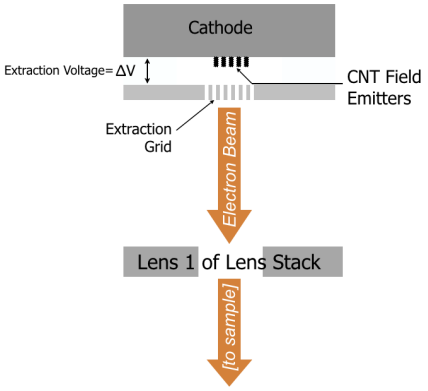

Fig. 1: Cartoon diagram of electron source operation (not to scale)

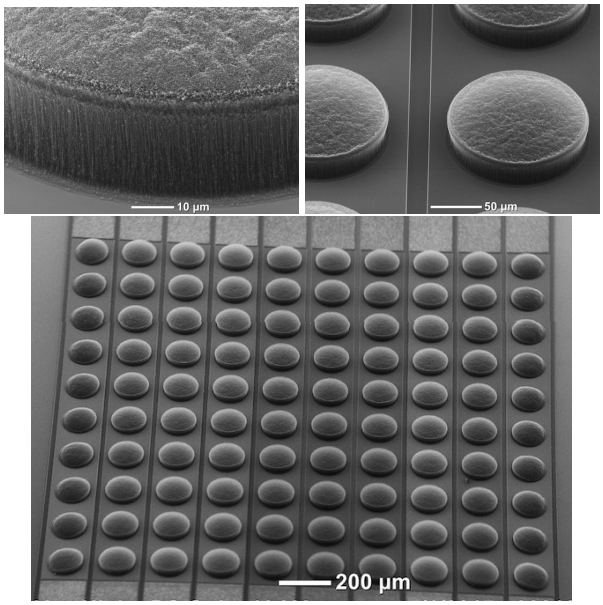

Fig. 3: SEM micrographs of a successful 10x10-element carbon nanotube cathode prototype. Each circular "forest" of nanotubes serves as a field emitter when addressed, providing electrons to the e-gun in order to stimulate characteristic X-ray emission from the target material. This cathode shows consistent growth, good CNT density within forests, and good adhesion of the CNTs to the substrate.

In the successful design (Fig. 3) the CNT emitters have been grown on the surface of a patterned SOI wafer. Final emitter height can be varied by changing parameters of the growth conditions. The conductive silicon layer carries the signal to the entire row of nanotube

emitters. Grooves etched through the silicon layer prior to growth provide row-wise electrical isolation. Outside the growth region, metal leads were deposited for each row to facilitate wire bonding (Fig. 4).

Emitter Testing: Integrating a single cathode with an extraction grid to implement individual emitter addressing is labor intensive and relatively large numbers of cathodes can be grown on a single wafer with approximately the same effort required to grow one cathode. Thus, we have fabricated a custom test fixture (Fig. 5) in order to apply the extraction voltage across an entire chip simultaneously and measure the resulting current. This full-chip testing serves as a screening step to ensure that only working cathodes are selected for grid integration. We also plan to apply the full-chip current emission results to correlation of field emission performance with characteristics such as emitter height, morphology, uniformity, and other qualities observable via electron microscopy or Raman spectroscopy; and also to evaluate degradation mechanisms (*e.g.* nanotube erosion via sputtering [2] or nanotube detachment from the substrate [3]) in cathodes with observed reductions in performance.

Fig. 5: Test fixture for whole-chip cathode activation. Twelve cathodes at a time can be loaded although only one at a time is activated.

At time of submission, three cathodes had been tested continuously at extraction voltages of -750 V for >14 hours (overnight) while maintaining acceptable electrical emission (here, > 5 μA). Three additional cathodes had been tested at constant voltage over 2 hour time periods. None of these have yet been tested to failure. Lifetimes of hundreds of hours have been demonstrated for CNT emitters in the literature (*e.g.*, [4])

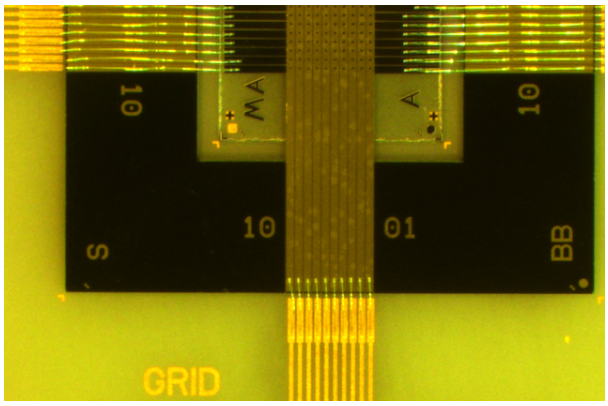

Fig. 4: View of the integrated cathode/grid package. The nanotube array emitters (Fig. 3) sit underneath the apertures of the extraction grid (top center). The horizontal wire bonds enable addressing of the cathode rows, whereas the vertical bonds address the grid columns.

Integration with extraction grid and fan-out board: The cathode is electrically mated with the extraction grid and fan-out board (Fig. 3) via wire bonding. Like the cathode, the extraction grid is made from an SOI wafer using microfabrication techniques. The grid column element is brought up to the extraction voltage relative to the active row of the cathode, thus addressing a single element of the CNT emitter array.

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