Development of a Nanocrystalline Diamond (NCD) Membrane for Vacuum Pressure Separation and Patterned Electron Beam Image Transfer

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X-ray imaging has long been a staple in airport security. However, X-rays have trouble differentiating between organic materials with similar densities resulting in false positives. Lowering the rate of false positives on scans, results in less time consuming and expensive secondary searches. By expanding our current detection capabilities, we stay prepared for detection of next generation threats as they emerge. Advanced airport scanner designs utilizing Differential Phase Contrast (DPC) X-ray imaging generate richer signatures and can significantly lower the false alarm rates, but require high-current structured X-ray sources [1].

These requirements can be achieved by using a patterned light source to illuminate a high efficiency photocathode, generating a structured electron beam pattern which can be accelerated to the energies needed to produce X-rays with a corresponding pattern [2]. While new photocathodes are capable of very high currents [3] of patterned electron emission, they require high vacuum (10-9T) for operation. A pressure separating membrane is needed between the photocathode and the X-ray source for improved lifetime, but this membrane should also preserve the pattern needed to create the structured X-rays for DPC imaging applications.

We have developed a process to create free standing nanocrystalline diamond thin films which can be used as a pressure separating membrane to separate regions of UHV from higher pressure or "dirty" volumes. Preliminary results show pressure separation of greater than 4 orders of magnitude using these diamond membranes. In addition, while not truly electron transparent, these thin film diamond membranes (100nm to 800nm thick) are capable of electron beam pattern transfer by emission of backside secondary electrons with the same pattern as the incident electron beam. Due to the negative electron affinity of the nanocrystaline diamond [4], amplification of greater than 2x the incident beam current is also observed. Investigations using COMSOL [5] into the thermal properties of these thin films under the high currents needed for X-ray work revealed that structuring of the diamond membrane surface improves thermal management. Optimization of secondary electron amplification will also be presented.

[1] Wells, K., and D. A. Bradley. "A review of X-ray explosives detection techniques for checked baggage." Applied Radiation and Isotopes 70.8 (2012): 1729-1746.
[2] Hesselink, L., Pease, F., Pianetta, P., Maldonado, J. R., Cheng, Y. T., Ryan, J. "Photo Emitter X-Ray Source Array (PeXSA)", US Patent Application, UA 14/026,697
[3] Maldonado, J. R., Cheng, Y. T., Pianetta, P., Pease, F. W., & Hesselink, L. (2014). A cesium bromide photocathode excited by 405 nm radiation. Applied Physics Letters, 105(2), 021108.
[4] I. L. Krainsky, V. M. Asnin, G. T. Mearini, and J. A. Dayton, Jr., Phys. Rev. B 53, (1996)
[5] COMSOL. COMSOL Multiphysics: Version 5.2. COMSOL, 2015.

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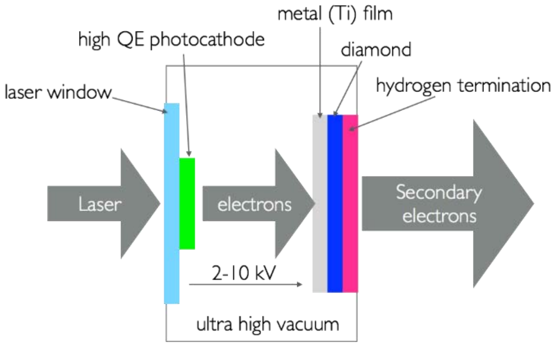

Figure 1: Schematic of X-ray DPC source application requiring pressure separation and secondary beam generation for high currents.

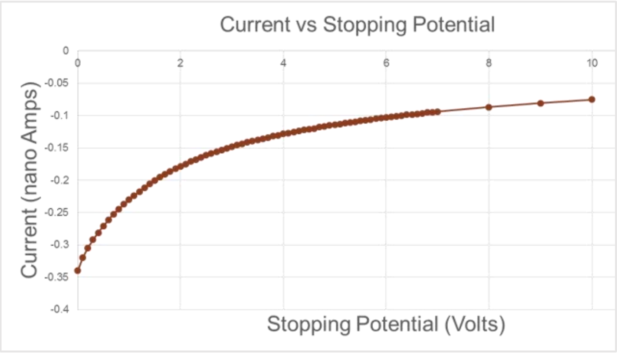

Figure 2: Backside electron beam current vs stopping potential experiments indicate the beam is predominantly composed of secondary electrons.

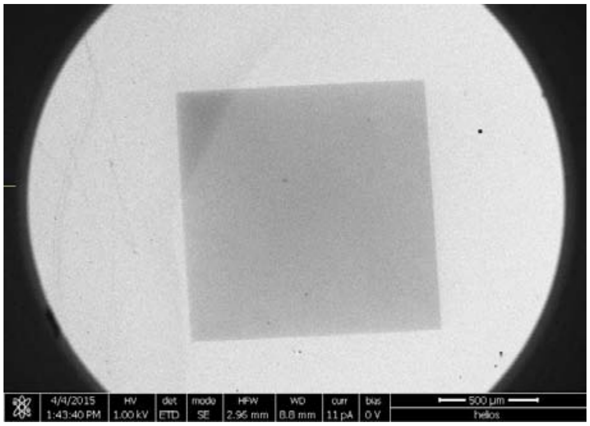

Figure 3: SEM micrograph of a processed diamond window used for pressure separation. Note that this example is not microstructured.

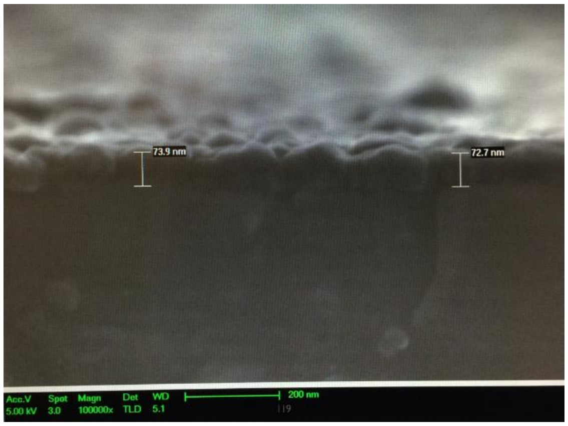

Figure 4: Diamond film cross section. The substrate is removed leaving a freestanding film. Note that this example is not microstructured.

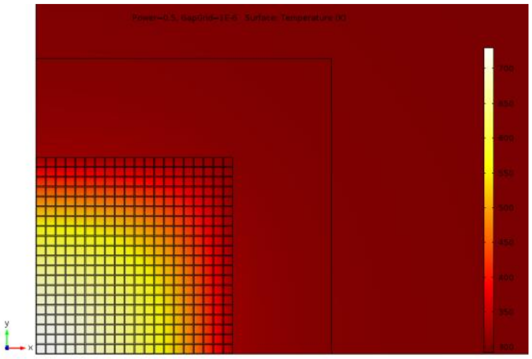

Figure 5: Thermal Simulations of thin film heating on microstructured NCD membranes using COMSOL. (¼ section view)

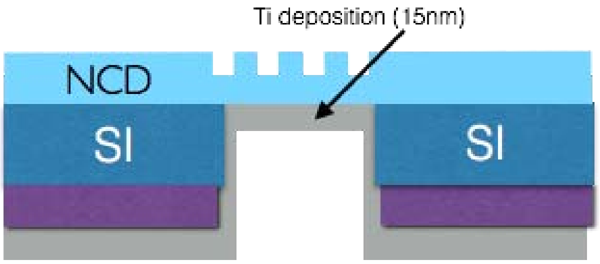

Figure 6: Schematic of microstructured NCD membrane structures for patterned electron beam transfer. Simulations of this process show improved thermal properties and secondary emission for high current applications.