

# Laser Patterning of Diamond

## Microelectronics

Diamond possesses unique material properties; high strength, good stability, large bandgap, excellent thermal conductivity, low absorption cross-section, and high dielectric strength. Diamond surfaces are reported to have a low or negative electron affinity.<sup>2,3</sup> Diamond has tremendous potential as an advanced, high temperature electronic material, and considerable research has been conducted to try to capture the benefits of this material system in engineering applications. A large body of this work has been on diamond films grown by chemical vapor deposition (CVD) on planar substrates. These films are commonly referred to as diamond-like carbon films (DLC films), because their polycrystalline nature includes significant  $sp^2$  bonded carbon in grain boundary regions.<sup>4</sup> These defects structures lower the bandgap from 4.5 eV to below 3 eV.<sup>5</sup> Diamond has been successfully doped with p-type elements such as boron, whereas n-type doping has proven elusive.<sup>6</sup>

The Diamond Microelectronics Group at Vanderbilt uses microwave assisted, plasma enhanced chemical vapor deposition (MPECVD) to grow micron thick diamond and nanodiamond films. These films have found application as high temperature pressure and chemical sensors,<sup>7</sup> and most notably, as electron emitters.<sup>8</sup> Professor Hofmeister has worked with Professors Davidson and Kang at Vanderbilt University (VU) to develop diamond emitters for high power and radiation hardened switching applications. A basic premise of this work is the use of nanostructured emission tips. A very tight radius of curvature at the emission tip is known to enhance electron emission by reducing the tunneling barrier to electron emission.<sup>9</sup> Diode and triode structures are fabricated at VU in two basic configurations: vertical and lateral. Vertical devices (based on the Spindt-type cathode array<sup>10-13</sup>) are grown in silicon molds.<sup>14</sup> We have achieved currents that scale as high as 100 A/cm<sup>2</sup> in small samples with nine diamond tips,<sup>5</sup> however, larger planar devices (1 cm<sup>2</sup>) with millions of tips have been limited to total currents of 100 mA. In an effort to mitigate the problems of closely space anode/cathode arrangements in planar devices and provide switches and emitters for hybrid packages, we have pursued lateral devices as a means to achieve high currents in chip-type architectures.<sup>1,15,16</sup>

At UTSI Hofmeister has continued collaboration with Davidson and Kang by investigating the fabrication of lateral emitters by photo-machining. This work has been accomplished with J.P. Sercel Associates in New Hampshire using UV excimer lasers. First, a nanodiamond film is grown by CVD on a silicon-on-insulator (SOI) wafer. The current fabrication technique uses photolithography and reactive ion etching to form the structure shown in Figure 40. There is a concern that the chemical species used in RIE could damage the insulating layer of the device and there are also the feature size limitations of the photolithography and etching process. The current UV laser machining approach is promising, but has feature size limitations as well. In the first test of the technique, a line grid of 3 micron spacing was used to photomachine a nanodiamond film. The resulting microstructure is shown in Figure 41.

Figure 40 – Nanodiamond  
Microelectronic anode and cathode  
formed by RIE on an SOI wafer (ref. 1)

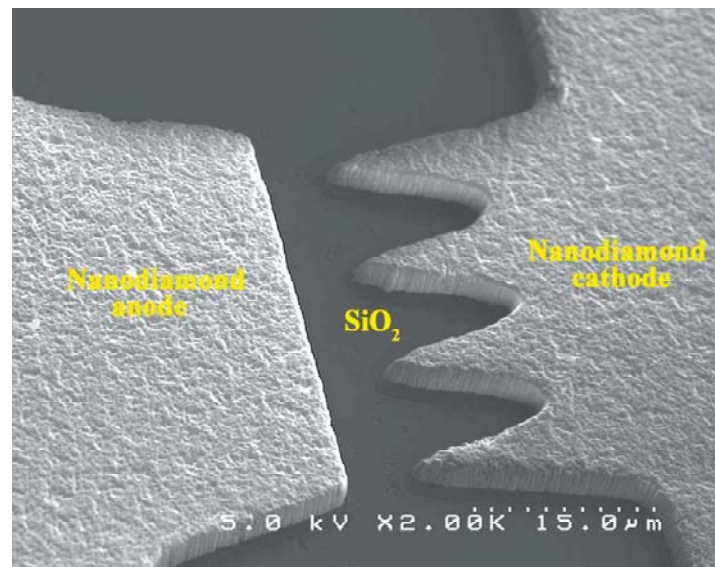
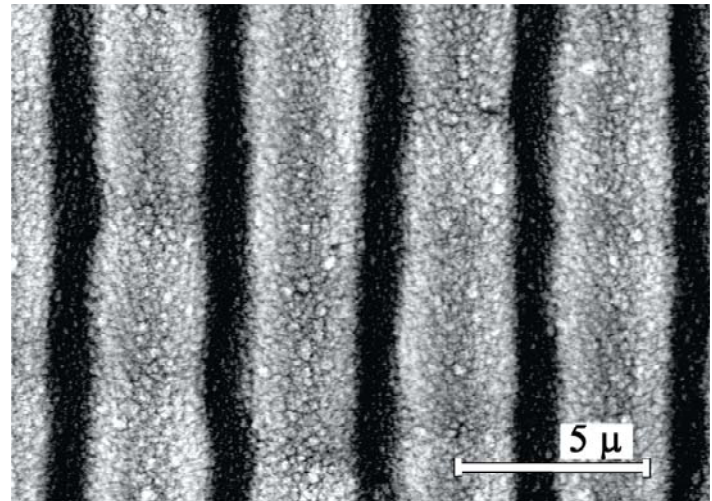


Figure 41 – Nanodiamond film  
photomachined with UV excimer laser  
using a 3 micron line grid



We hypothesize that pulse shape and polarization engineering can accomplish sub diffraction and diffraction limited focusing of femtosecond laser pulses for machining of feature sizes much smaller than currently achieved. For the emission devices, such as the one in Figure 40, a finer tool will allow devices to be constructed with lower turn-on voltage and less potential damage to the insulating substrate. The techniques practiced in UV mask projection are not applicable to femtosecond machining because the pulse durations are too short for beam homogenization. Therefore, we will use direct write techniques to form patterns on the diamond/SOI substrates.

Because of the durability of diamond and the thickness (>1 micron) of the films, it will be difficult to use sub-diffraction focused light and near field optics for the direct write diamond ablation experiments. Therefore, we must use far-field diffraction limited conditions for high aspect ratio, sub-micron feature construction. One technique will be to use high index fluids at the diamond surface to enhance the temporal focusing of femtosecond pulses.

One of the concerns of optical fabrication is the effect of laser ablation on the diamond film. The most common explanation of the laser ablation mechanism in diamond is that the laser pulse heats diamond to cause graphitization and subsequent pulses remove the

graphitized layer. Pure diamond can theoretically be ablated by multiphoton absorption. We intend to examine this mechanism with our parametric studies with on-line analysis (Raman and LIBS), and characterization experiments. The femtosecond laser repetition rate is controllable by the pulse picker such that we can study thermal and non-thermal ablation response in the DLC films. Films will be examined *in situ* by micro-Raman spectroscopy before and after ablation to determine the relative changes in  $sp^2$  and  $sp^3$  content. Detailed scanning electron microscopy studies will determine the morphology of ablated surfaces. Since the ablation rate of the film will vary with the structure, grain boundaries and doping level, and *in situ* method of determining the ablation depth will be employed. Laser induced breakdown spectroscopy will be used to monitor the ablated species such that we can control the depth in real-time and machine down to the polysilicon or insulating layer below the diamond films independent of film thickness and grain boundary character. In this manner we can correct for differences in ablation rate in a particular film. The electrical characteristic of laser fabricated devices will be tested at Vanderbilt University.

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**Sponsor: Center for Laser Applications**

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