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A High Performance Diamond Thin Film Cold Cathode

November 30,1993

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Summary of Progress

In this reporting period, we have investigated the low power performance of amorphic diamond thin films deposited under various conditions such as laser power, thickness, gas pressure and background vacuum. We have found that higher power density gives better field emission as shown in Figure 1. This has been correlated to a larger number of particles on the sample which seems to increase with increased power density. In addition, the best films seem to have a bulk resistivity in the few hundred ohm-cm range. The reason for this is not very well understood at this time.

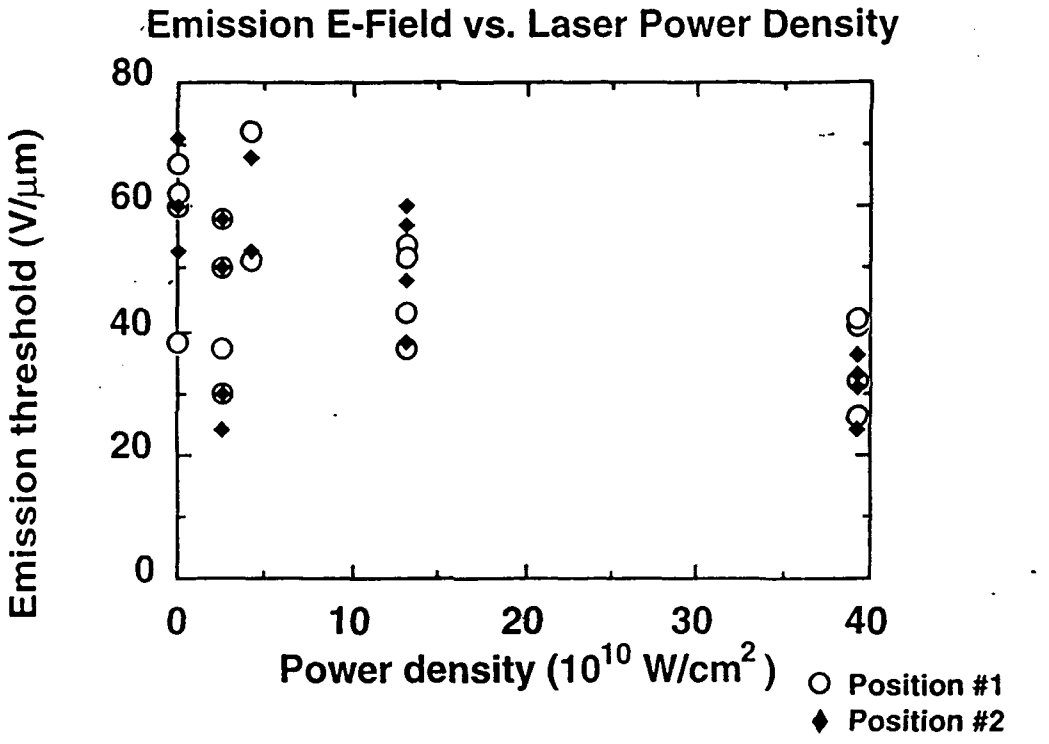

Figure 1: A chart showing the relationship between laser power density and electron extraction field

During these investigations, we have found a phenomenon, which we call 'conditioning'. Conditioning is shown in Figure 2 which shows several successive I-V curves taken on the same point on an amorphic diamond sample. It is seen that a relatively high voltage is required to turn on electron emission when the voltage is applied for the first time. After the first turn-on, the voltage required to emit the same current is decreased. This decrease in voltage is random, but increases with increased maximum current extracted from the sample as shown in Figure 2. This means that a high extraction field sample can be turned into a lower extraction field sample by just

passing a high current through the sample. The exact reason behind this is not known at this time. No damage is observed on the sample surface under the microscope. This phenomenon is of extreme importance to the goals of the project.

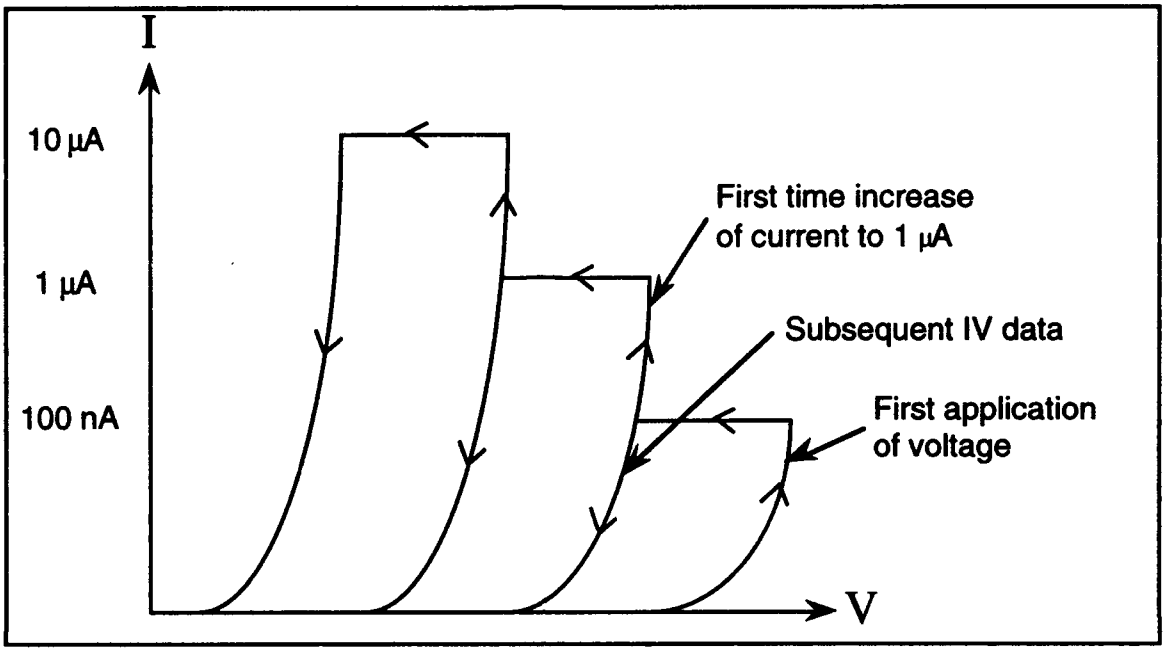

Figure 2. The effect of a cathode conditioning by increase in extracted current.

From the preliminary data taken at low power levels, these cathodes appear to be very rugged. To demonstrate the feasibility of SIDT's amorphic diamond as high current pulse emitter, the relevant DC characteristics of our material have to be determined. We have so far concentrated on completing the set-up and testing of these relevant DC characteristics as well as setting up pulse testing capabilities.

To ensure a material is sufficient for high current pulse applications, one has to make sure that the material survives well at the DC equivalent current density (J_{dc}), where J_{dc} is given by:

$$J_{dc} = Q_{pulse} * \Delta$$

where Q_{pulse} is the charge per pulse per unit area and Δ is the duty cycle..

For the case of a 1000A/cm^2 pulse of 1 micro-sec duration, $Q_{pulse} = 10^{-3}$ Q/cm^2. And $\Delta = 10^{-4}$ for 100 pulses per second at 1 micro-sec pulses. Therefore

$$J_{dc} = 0.1 \text{ uA/cm}^2.$$

Our testing shows that our material can easily satisfy such requirements and we have extracted currents upwards of 10 A/cm^2 under dc conditions. We have also done several life-time test runs, one of which is shown in Figure 3. This test was done at 4 mA/cm^2 which is several orders of magnitude higher than that calculated above. The data shows that there is a lot of noise i.e. the current charges over time but it is random due to the inherent field emission noise. But over all, the cathode does not seem to degenerate even after we have extracted a total charge of more that 1000 C/cm^2 at 1000 V in a vacuum level of 5 x 10^{-6} torr. This compares very favorably with only 10^{-3} C/cm^2 total charge extracted during a 1 μs pulse of 1000 A/cm^2. This means that under pulse conditions, the cathode can survive at least a million pulses of 1000V.

Though the effect of higher voltage on the ion bombardment energy is significant, it is not expected to be five or six order of magnitude. Hence, we expect the current from these cathodes to be limited by the rate of heat removal from the cathode. Since I^2R determines the heat generated at the cathode, we strive to obtain as low a resistivity as possible but obtain a broad area emission with larger number of emission sites as well. These are two contradictory requirements and will need to be optimized after careful experimentation. Another approach will be to deposit amorphic diamond on high thermal conductivity CVD diamond to conduct away the heat as quickly as possible.

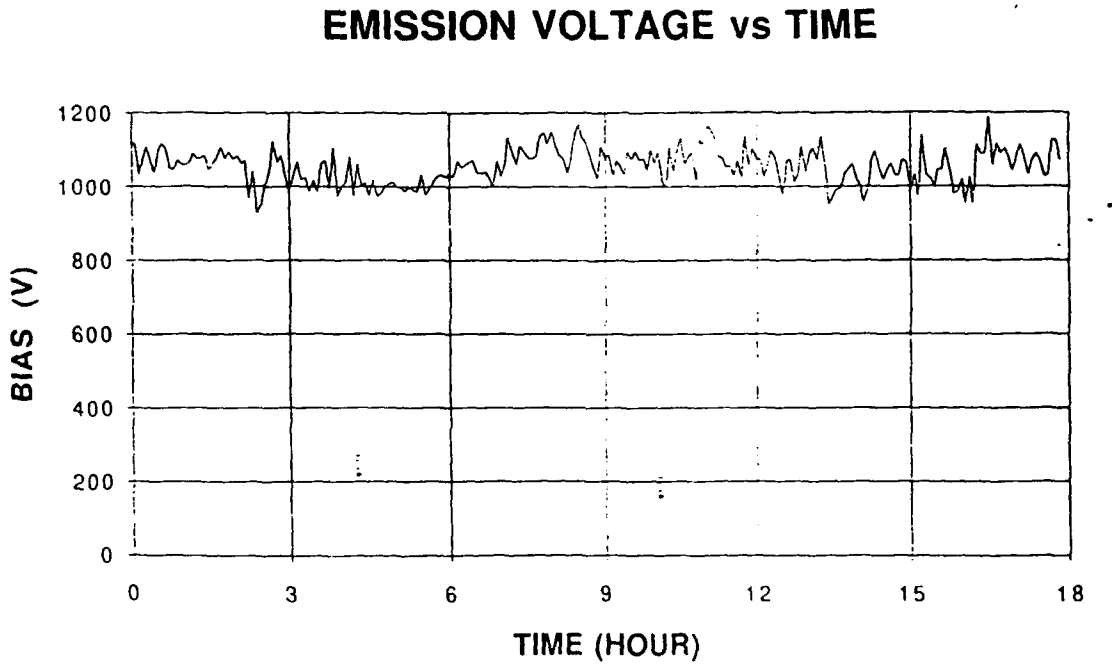

Figure 3. Lifetime data on an amorphic diamond sample at 4 mA/cm^2 at 1000 V and 5 x 10^{-6} T pressure.

In addition to this, we have been designing a new electronic setup which will allow us to do very short pulse measurements. With the new setup, we will be able to go to much higher pulse powers without destroying the test setup. Initial attempts at this failed due to long leads used between the test head and the power supply to the vacuum chamber. This results in a large amount of charge stored in the cable which gives erroneous results due to arcing at the sample. This arcing invariably damages the sample. Figure 4 shows a simple electrical schematic of a new high speed switch which will be mounted directly on the vacuum chamber.

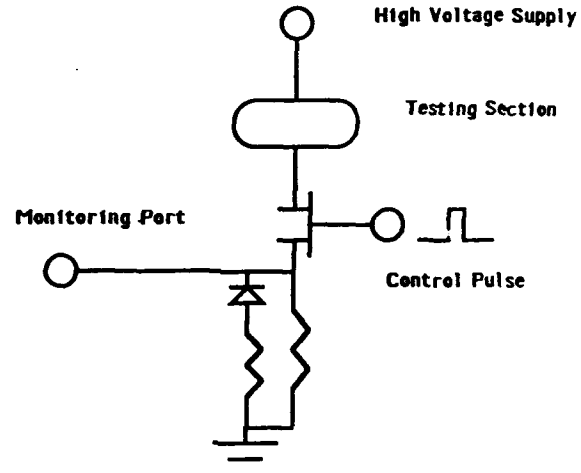

Figure 4. A simple schematic of a circuit designed for pulse testing of amorphic diamond samples at low voltage.

We have found a test facility which will allow us to test on amorphic diamond samples at Phillips Labs in Albuquerque, N.M. We have already received 50 mm diameter beam samples ready to be coated. But we do not expect samples to be tested until April 1994. This will lead to delays in obtaining final results. Hence we are asking for a three month extension of the project.