# High-Current Cold Cathode Employing Diamond and Related Films

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***Abstract*—Results of recent experiments with diamond-coated electron-field-emission cold cathodes are presented. The cathodes offer an almost instantaneous response to field variations and can deliver high current densities. As shown, diamond and diamond-related films deposited on the surface of a cathode significantly increase the number of emission centers and can substantially improve the homogeneity of electron emission. The emission current can be increased via increasing the $sp^2$ graphitic phase concentration in the film.**

***Index Terms*—Cold cathode, CVD diamond film, field emission.**

HIGH-CURRENT-DENSITY CATHODES are needed for the development of portable X-ray tubes, compact microwave amplifiers, high-power microwave generators, and the next generation of microwave compression systems [1] for future electron–positron colliders. Electron-field-emission cold cathodes may deliver the desired high currents if—as demonstrated hereinafter—their emission properties are improved by using diamond-containing films deposited on their surfaces.

In this paper, the results of recent experiments with cathode prototypes of the aforementioned kind are presented. Such cathodes offer an almost instantaneous response to field variations and may also deliver high current densities because their emission is enhanced by micro- or nanocrystalline films that contain diamond. The main goals of the research work were as follows: 1) to develop a method for the deposition of diamond films with different morphology on the cathode surface; 2) to synthesize diamond films with high $sp^2$ graphitic phase concentrations to enhance the emission; and 3) to compare the emission properties of diamond-containing films with different morphologies and compositions. To study the emission properties of the cathodes, they were subjected to $\sim$100-ns high-voltage pulses with amplitudes up to 100 kV.

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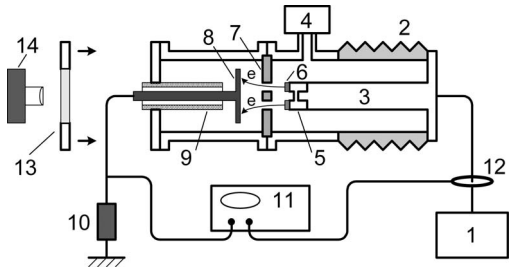


Fig. 1. Experimental setup to characterize the field electron emission of diamond-coated cathodes. (1) High-voltage pulser. (2 and 9) Isolators. (3) Cathode holder. (4) Vacuum pump. (5) Movable cathode head (substrate). (6) Diamond film. (7) Anode (copper grid). (8) Collector. (10) Low induction resistor. (11) Scope. (12) Rogowski coil. (13) Quartz window. (14) Camera.

The experimental setup is shown in Fig. 1. The cathode assembly is tested in a vacuum chamber (at $10^{-6}$ torr or less) and consists of a cathode holder that supports a disposable cathode head (5) with the deposited film (6). The anode is a wire grid (with the cell size $3 \times 3$ mm) made out of copper. The distance between the cathode and anode can be adjusted by moving the cathode head along the chamber axis. The emitted electrons, after acceleration, pass through the anode grid and are gathered by a collector (8). The resulting beam current is measured using a noninductive resistor (10). The collector can be replaced by a quartz window (13), through which photographs of the cathode can be taken.

The cathode head is a molybdenum cup 21 mm in diameter and 4 mm tall with 2-mm-thick walls. Diamond films with various morphology and different contents of the $sp^2$ graphite phase are deposited by chemical vapor deposition (CVD) at the front end of the cup, resulting in an emitting surface that is shaped as a ring with 18-mm-inner and 21-mm-outer diameters. The deposition is done in the CVD reactor [2] under the pressure of 200 torr and typically over the period of 20 min. The CVD reactor uses 6 kW of microwave power. Fig. 2 shows typical photographs of molybdenum cathodes without diamond films [see (a)] and cathodes coated with diamond films with low [see (b)] and high [see (c)] $sp^2$ graphitic phase concentrations. For case (b), the reactor gas mixture is $Ar/H_2/CH_4$, and for case (c), it is $Ar/H_2/CH_4/N_2$.

For these cathode prototypes, the field emission is observed to start on the microtips on the cathode surface, which leads to heating and explosive evaporation of the spikes, during which microplasma jets form. These jets are primary sources of electrons being emitted. Emitting spots resulting on the cathode surface can be distinctly seen in Fig. 2.

Note also that heating and exploding microtips may force ejection of the cathode material. The trajectories of incandescent microparticles can be seen well in Fig. 2(c).

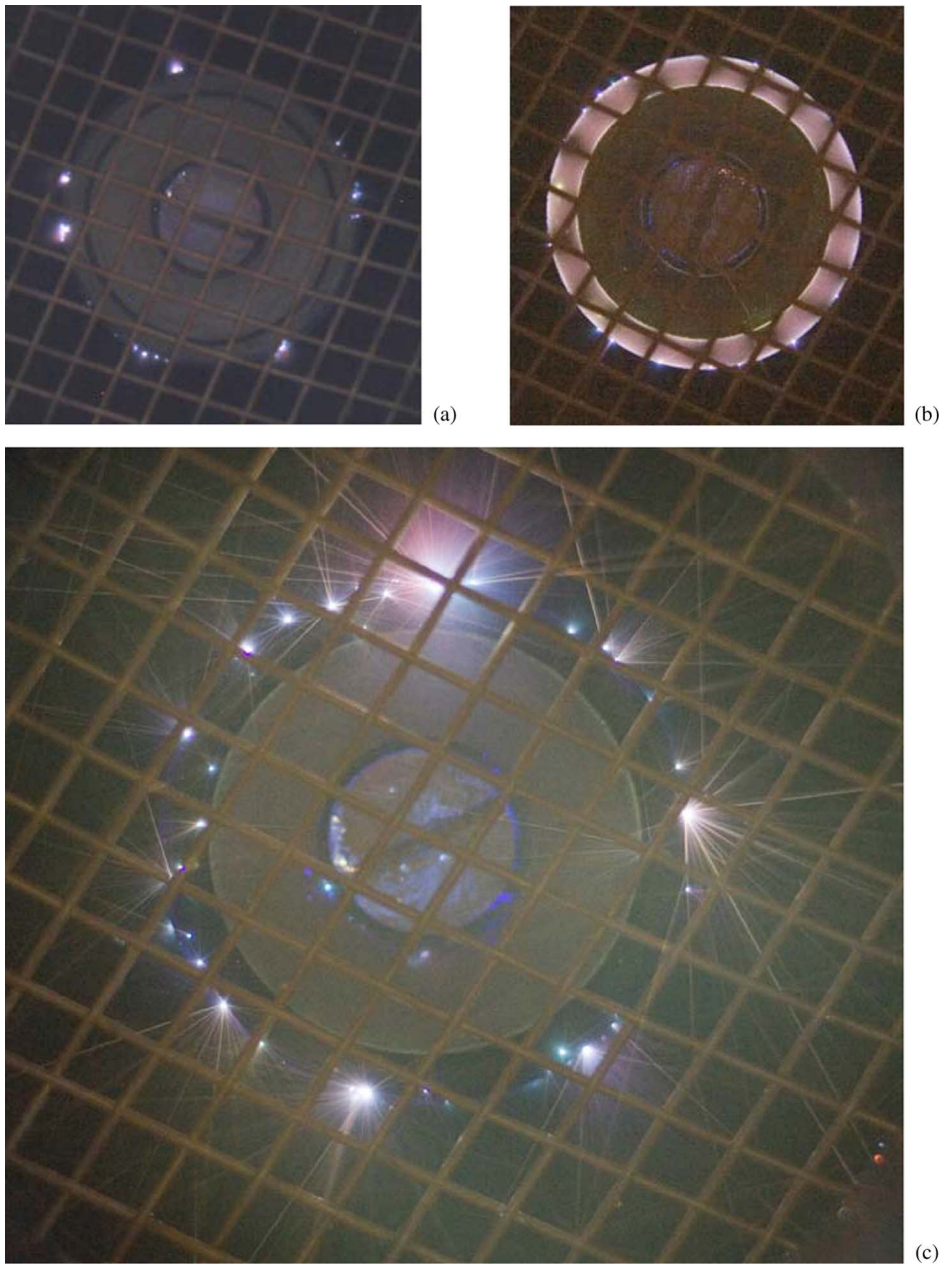


Fig. 2. Photographs of the emitting spots (photographs are made through the quartz window with the anode grid in the way) when high-voltage pulse is applied (peak voltage of ∼100 kV and pulse duration of ∼100 ns). (a) Uncoated molybdenum cathode. Cathode coated with a diamond film with (b) low and (c) high $sp^2$ graphitic phase concentrations (the distance between cathode and anode is 3.5 mm).

The results have shown the following: 1) Diamond and diamond-related films deposited on the surface of a cathode significantly increase the number of emission centers and may substantially improve the homogeneity of electron emission, and 2) the emission current can be increased via increasing the $sp^2$ graphitic phase concentration in the film. The current density of $\sim 300/\mathrm{A/cm}^2$ (total current divided on cathode square) has been demonstrated.

## REFERENCES

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