Fabrication and field emission study of gated diamondlike-carbon-coated silicon tips

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We have fabricated a gated silicon field emitter array for which the silicon tips are coated with a diamondlike-carbon film (DLC). Silicon oxide disks were patterned on the silicon substrate, and the tips were formed using conventional dry etching. With the oxide caps covering the tips, the insulating layer, molybdenum gate film, and aluminum parting layer were deposited. At this stage the oxide caps were removed to expose the silicon tips and a DLC-carbon film was deposited onto the tips. © *1997 American Vacuum Society.* [S0734-211X(97)05302-X]

Silicon has become popular as a material for field emitters because of the advancement of silicon processing technology; however, its fragility and low thermal conductivity are still an obstacle in manufacturing practical silicon field emission displays. As an alternative, coating silicon tips with refractory metal, silicide, diamond, or diamondlike-carbon (DLC) films has been attracting attention.[1] Nevertheless, researchers to date have been concentrating on the investigation of coated tips but not on the fabrication of coated tips furnished with gate metal film. In this article we present a simple attempt to fabricate a gated DLC-coated silicon field emission array (FEA) and the performance of the samples fabricated.

Our fabrication step is very simple (Fig. 1). An array of silicon tips was fabricated on an n-type silicon wafer. With the oxide caps still remaining on top of the tips, the SiO_2 insulating layer, Mo gate film, and Al for use as a parting layer were deposited using electron-beam evaporation. At this stage, the oxide caps were lifted off to expose the silicon tips. The diameter of the tip was less than 200 Å. The DLC film was deposited using plasma-enhanced chemical-vapor deposition with 20 mTorr pressure until the thickness became 100 Å. After coating with DLC, the Al film was removed by dipping the sample in H_3PO_4:HNO_3:CH_3COOH:H_2O = 80:5:5:10 solution. Although the DLC film covered the entire surface of our sample, HF solution attacked through the DLC film and peeled off the Al film because the DLC film was very thin. A scanning electron microscope (SEM) image of the completed FEA is shown in Fig. 2. The diameter of the gate hole was 1.5 μm and the height of the tips was 0.8 μm.

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The $I-V$ characteristics were measured in a 10^{-8} Torr vacuum chamber. In Fig. 3(a), we show an $I-V$ curve obtained with the anode voltage of 300 V. The onset gate voltage for the emission was about 70 V and the current reached 8 μA at 120 V, while the leakage current to the gate was 1.5 μA at 120 V. The Fowler–Nordheim plot, shown in Fig. 3(b), reveals a fluctuation at low-voltage regime, but a relatively stable curve at high-voltage regime.

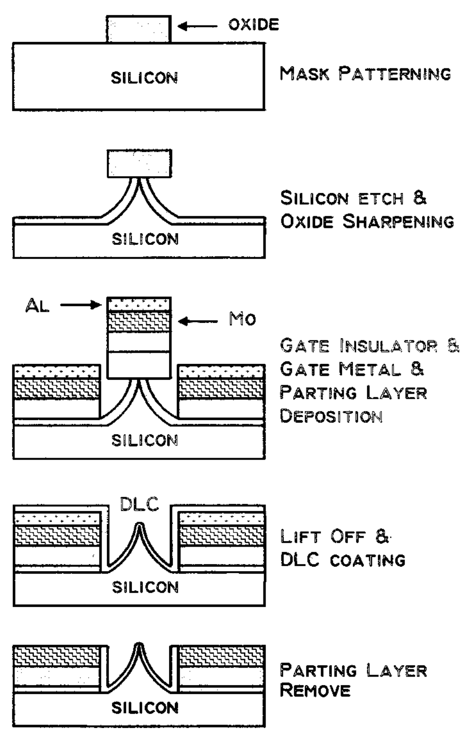

FIG. 1. A diagram for the fabrication of gated, DLC-coated silicon tips.

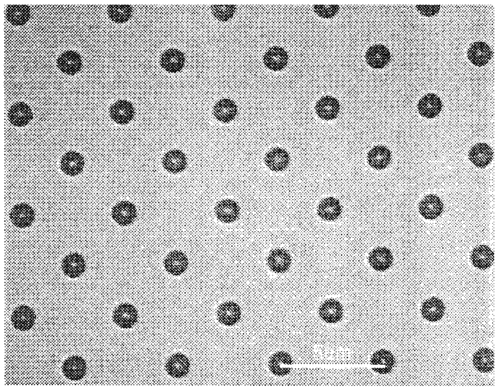

FIG. 2. SEM micrograph of the top view of the DLC-coated FEA.

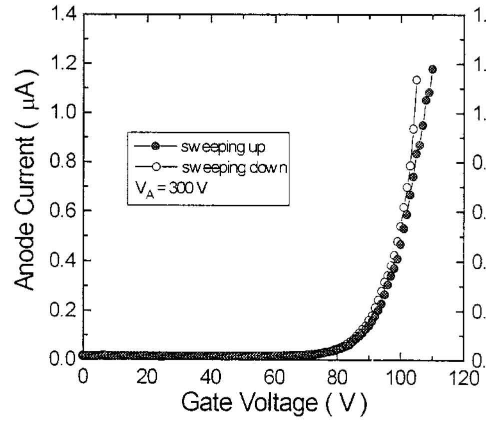

FIG. 4. Hysteresis of the emission current. The gate voltage sweeping speed was 40 V/s.

An obstacle in the application of the DLC or diamond to the practical vacuum microelectronics devices is the fact that its emission mechanism is not understood. This makes the control of the device performance difficult. Huang *et al.* proposed that electrons emit from the conduction band and the surface states from diamond,[2] and that the population of these states and the energy distribution of the emitted electrons depend on the strength of the field and film thickness.[3] Since all these factors contribute to the noise in the field emission current, knowing the emission mechanism is important to produce stable low-noise field emission devices. Although at the moment we cannot relate the experimental emission noise directly with the theory, we have measured the hysteresis and the current fluctuation of our gated DLC-coated silicon tips, and the results are shown in Figs. 4 and 5. The hysteresis of the emission current was measured by sweeping the gate voltage up and down at a speed of 40 V/s, and the result shown in Fig. 4 is the average of ten cycles. The hysteresis becomes prominent when the gate voltage exceeds 100 V, but at lower voltages it is almost negligible. However, the fluctuation in the emission current, especially at high voltages, is very large, as can be seen in Fig. 5. The large fluctuation can be due to several reasons, but the biggest question should arise from the electron transport at the complex Si–DLC interface and the DLC film.[3] The emission current was also measured as a function of anode voltage with the fixed gate voltage. The result, shown in Fig. 6, represents a typical $I-V$ characteristic of a field emitter transistor.

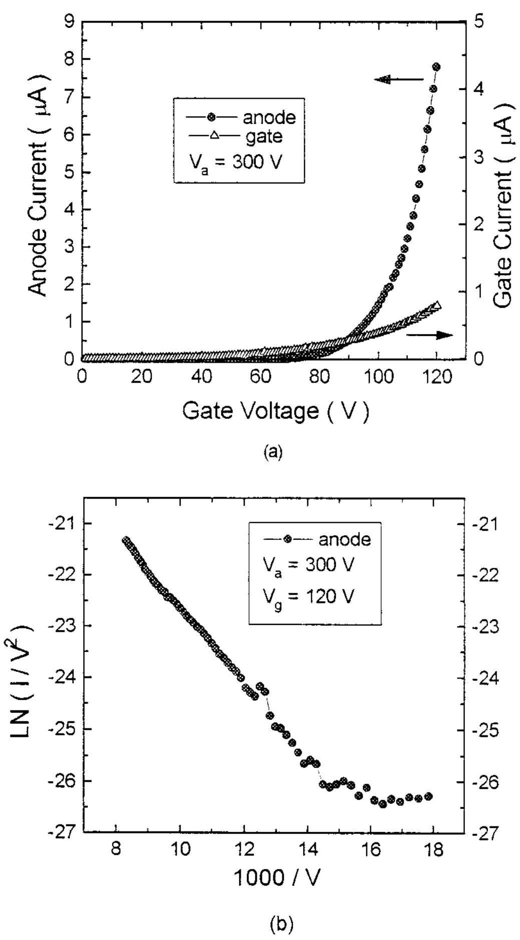

FIG. 3. (a) $I-V$ curve of the gated DLC-coated silicon FEA. 3600 tips. The anode–gate distance was 1 mm. (b) Fowler–Nordheim plot of the $I-V$ curve shown in (a).

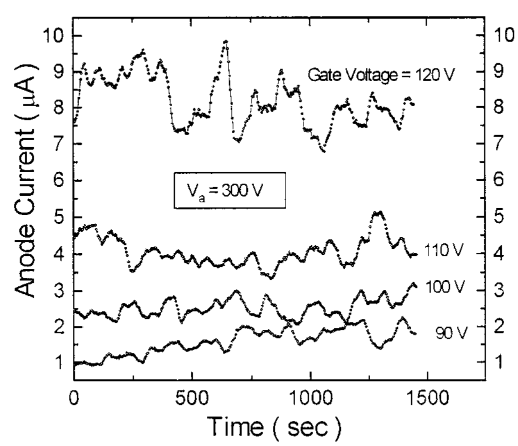

FIG. 5. Emission current fluctuation as a function of time.

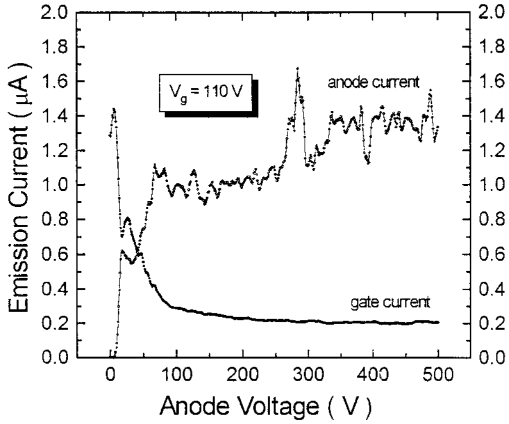

FIG. 6. Emission current as a function of anode voltage.

In conclusion, we have fabricated a gated, DLC-coated silicon FEA. The onset gate voltage for the emission was 70 V and the emission reached 8 μA at 120 V out of 3600 tips, but the current fluctuation was very large.

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