

FIELD EMISSION CHARACTERISTIC OF SILICON CATHODES COATED WITH GaN NANOPARTICLES

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ABSTRACT

Arrays of p-type silicon micro-emitters have been formed using a subtractive tip fabrication technique. Following fabrication, the emitter surface was coated with GaN nanoparticles and nanocrystalline diamond by a dielectrophoresis deposition technique. The emitters were evaluated and compared before and after the surface treatment using I-V measurements in the diode configuration. The phosphor screen, used as the anode, was spaced nominally about 70 μm from the cathode. The field emission characteristics were measured in a high vacuum chamber at a pressure range between 10^{-5} and 10^{-8} Torr. The results suggest that the emitters benefit from coating the surface with nanocrystalline diamond in terms of reduction in the turn on voltage, GaN coating increase the turn on voltage. Both diamond and GaN improved the emission uniformity in the region of the low voltage operation.

INTRODUCTION

In recent years, the attention has been drawn towards post-fabrication conditioning processes aimed to improve the performance of the field emitters. The desirable cathode surface is one that is chemically inert and has low workfunction. Investigation of overcoating metal emitter tips (Mo) with Cs whose workfunction is $\sim 1.8\text{eV}$ has been conducted [1]. Low workfunction results in a chemically active surface; they rapidly degrade in their emission characteristics because of the increasing workfunction caused by the formation of chemical compounds such as oxides or hydrides on the emitter-tip surfaces. Hence potentially chemically inert emitter-tip overcoating with wide band gap materials is preferred for field emission system and is presently under investigation.

Cathodes coated with diamond [2], [3], [4], have been evaluated by many researchers in recent years. The Semiconductor III-V nitrides (GaN, AlN [5], InN) and their solid solutions also show a great promise for applications in coating of field emission tips since their wide band gap encompass a broad range of energies (up to 6.2 eV). Recently nanocrystalline GaN clusters were successfully synthesized at using reactive laser ablation of gallium metal in a nitrogenating ambient [6]. The method uses a pulsed Nd: YAG (266 nm) laser beam focused on the target through UV grade quartz windows. Products of the synthesis are deposited on the selected target. As a result, hexagonal GaN crystallites as small as 12nm mean diameter (with log-normal size distribution) have been formed.

These nanoparticles can be deposited on other substrates using dielectrophoresis [7]. In this paper we investigate the performance of the ungated emitters when coated by dielectrophoresis of gallium nitride (GaN) nanoparticles (NP) and nanocrystalline diamond.

FABRICATION

The device configuration considered for the surface treatment of the emitters is the “bed of nails” which is an array of un-gated single crystal Si emitters placed in an area of 4cm^2 with a tip-to-tip spacing of $6\mu\text{m}$. The emitters were formed from p-type ($1\text{-}10\Omega\text{cm}$) Si (100) substrate by the subtractive tip fabrication process. Firstly, thermal grown oxide of 2000 \AA thick and a 1000 \AA thick chromium layer on the Si were patterned into a 3.0 \mu m -diameter disk. Using the chromium and the SiO_2 cap as a mask, the outline of the emitter tip was formed by means of reactive ion etching with SF_6 . The tips were then sharpened using the method of oxidation sharpening as we have previously described elsewhere [8]. Tip caps were subsequently removed by wet etching of the silicon dioxide. The final silicon emission tip is shown in Fig.1e. The typical tip curvature radius is estimated using SEM microscopy, to be on the order of 15 nm .

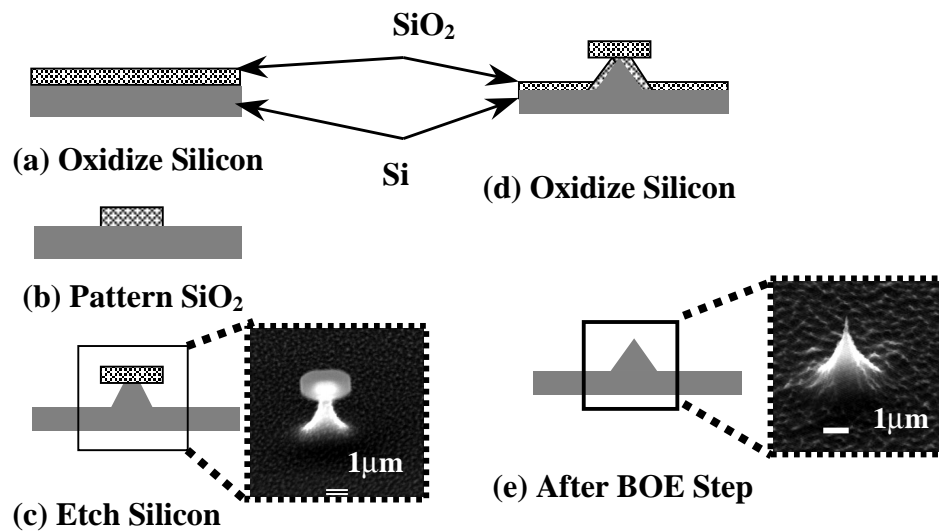


Fig.1. Subtractive tip fabrication process

The emitters were coated using dielectrophoresis of GaN nanoparticles and nanocrystalline diamond from an ethanol suspension [7]. This technique of deposition is desired due to its low temperature, minimal processing time, and low cost. Deposition on any conductive substrate of almost any shape and size may be achieved. Coatings are readily deposited on sharp emitter tips. The field enhancement at the tip apex favors deposition since the deposition rate is controlled by the local field distribution. Thus it may be possible to optimize the conditions to coat only the emitter tips. A TEM image of the initial attempt to deposit GaN nanoparticles on the surface of the Mo emitter is shown in Fig.2.

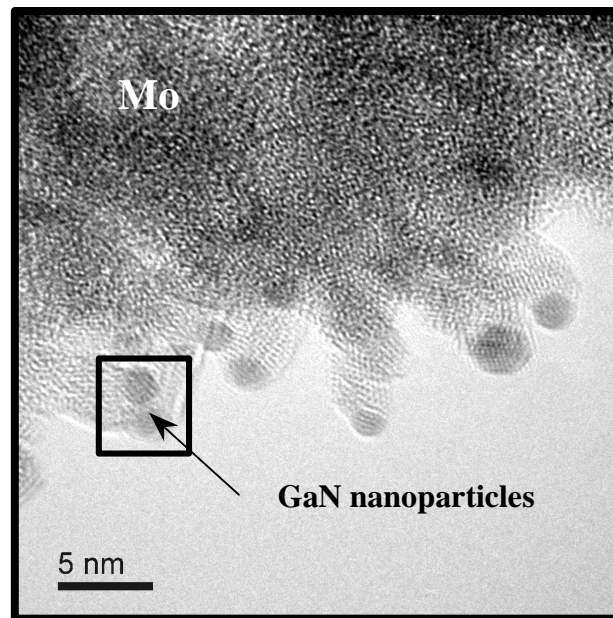


Fig.2. TEM of Molybdenum Tip Coated with GaN Nanoparticles

We studied the field emission characteristics before and after the surface coating of the emitters with GaN nanoparticles and nanocrystalline diamond.

RESULTS AND DISCUSSION

We tested the emission properties of the cathodes in a diode configuration. The packaging of the cathodes containing the array of ungated Si-tips for testing in a high vacuum environment is done by placing quartz spacers, 60 – 70 μm thick between the cathode and the phosphor screen, which acts as an anode, as seen in Fig.3.

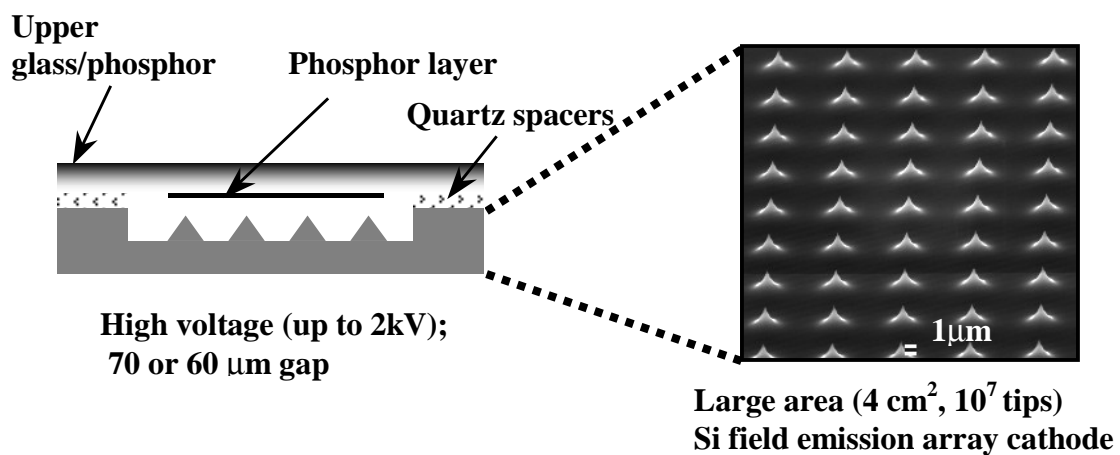


Fig.3. Test structure: Diode design for Si-tip array testing

The whole assembly is then held together on both sides by a spring. This arrangement helps us to remove the sample after the measurements, maintain the same measuring set up before and after the surface treatment and also allows us to compare the emission characteristic before and after treatment of the arrays. A medium voltage green-color phosphor (Osram Sylvania 9620) was deposited on patterned ITO glass by electrophoresis. The advantage of this process was that the deposition was carried out in room temperature with a very uniform thin layer of small particle phosphor being deposited. The phosphor screen helps us to visually investigate the distribution of the emitting tips.

Field emission properties of the cathodes were measured in a vacuum chamber under a residual gas pressure of 10^{-8} Torr. The Hewlett-Packard 4142B modular DC source/monitor was used to acquire the emission data. A positive potential (to 1000 volts) was applied to the anode, and the cathode had a negative bias. The field emission properties of the cathodes were measured after the tips were conditioned for 3 days under a constant DC bias.

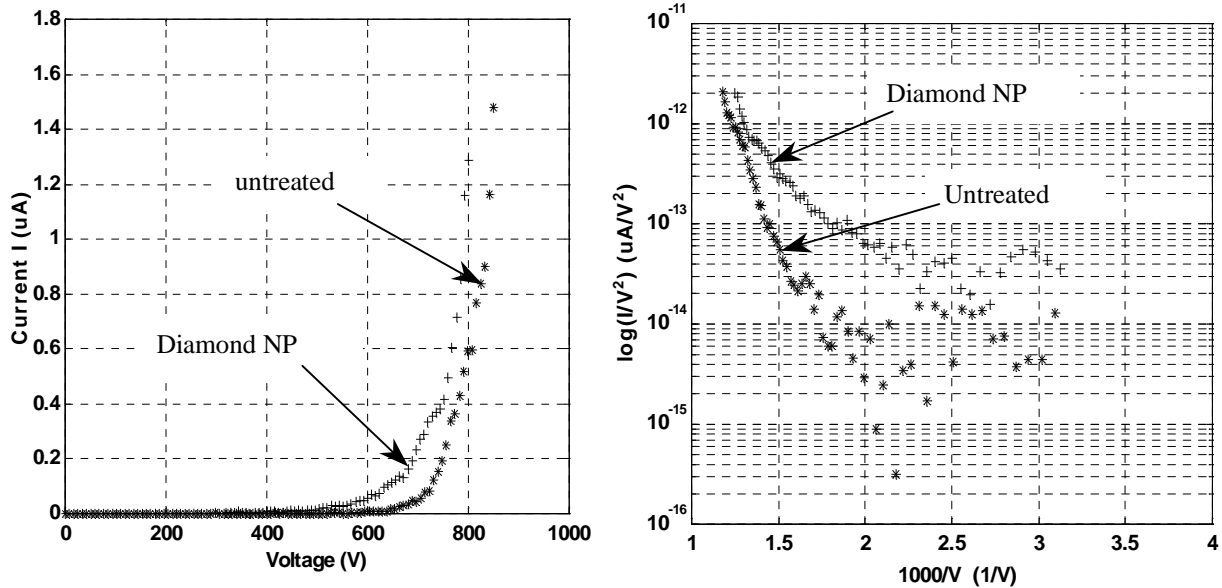


Fig.4 (a) I-V characteristic and (b) the F-N characteristic of the before and after the emitter surface was coated with nanocrystalline diamond

The I-V characteristics, as seen in Fig.4a, correspond to the two curves measured before and after the surface of the emitter was coated with nanocrystalline diamond (particle size about 5-10nm). It is seen from the graph that there is a considerable reduction in the turn on voltage and there is no degradation of the maximum extracted emission current. The results suggest that the reduction in the turn on voltage is due to the decrease in the effective workfunction of the emitter. Fig.4b is a Fowler-Nordheim plot of these data. It is seen from the graph that the emission characteristics shows a straight line behavior in both the treated and untreated case. It is also observed that the uniformity in emission from the array is increased in the region of low voltage operation when the surface of the emitters is coated with nanocrystalline diamond.

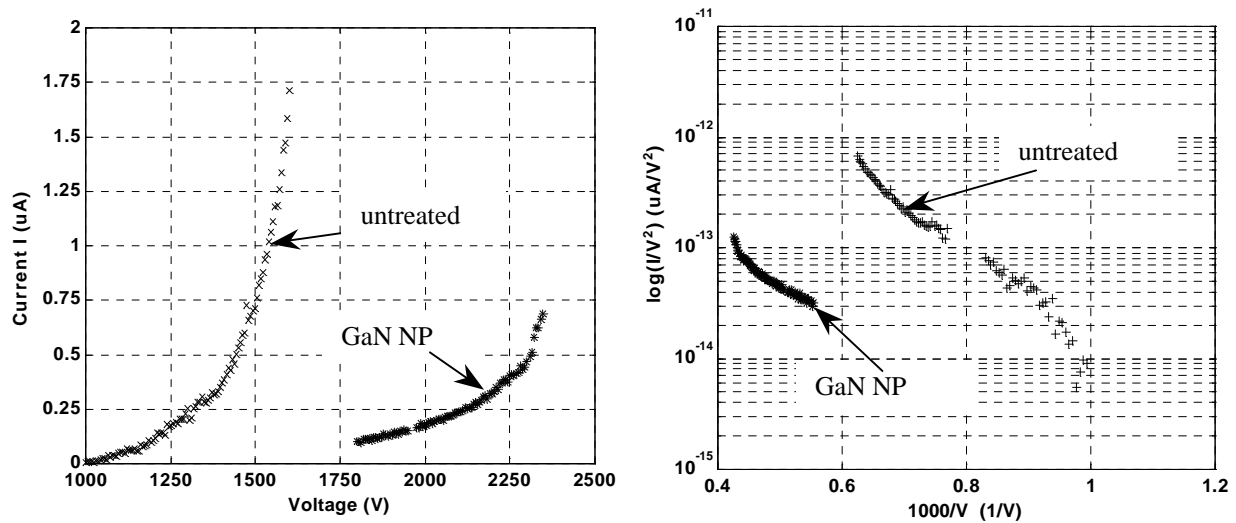


Fig.5. (a) I-V characteristic and (b) the F-N characteristic of the before and after the emitter surface was coated with GaN nanoparticles (NP)

The I-V characteristics as seen in Fig.5a correspond to the two curves measured before and after the surface of the emitter was coated with GaN nanoparticles (particles size about 2-20nm). It is seen from the two curves that there is an increase in the turn on voltage and there is considerable degradation in the emission current. Fig.5b is a Fowler Nordheim plot. Again, both the treated and untreated case have straight F-N behavior.

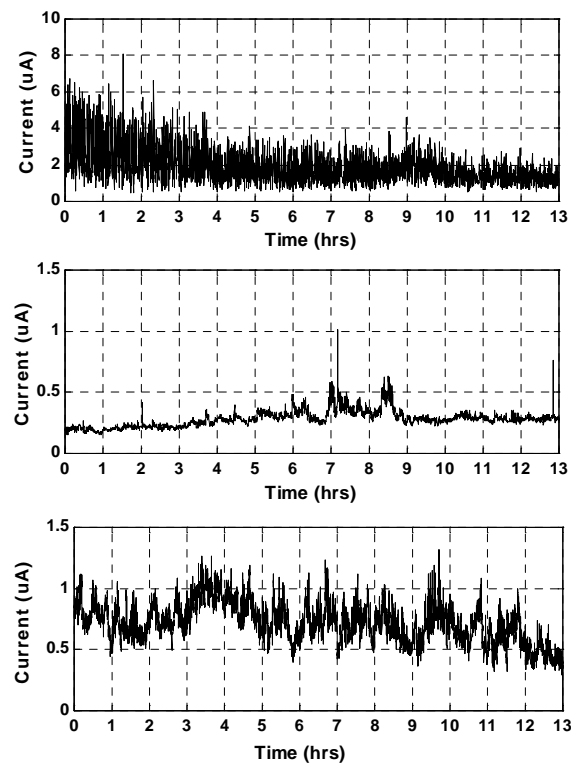


Fig.6. Current versus Time characteristics of an array of silicon emitter: (a) untreated; (b) coated with GaN nanoparticles; (c) coated with nanocrystalline diamond

The current versus time characteristics as seen in Fig.6 shows the emission current stability of an untreated (a), coated with GaN nanoparticles (b) and coated with nanocrystalline diamond (c) emitter array over an operating cycle of thirteen hours. In case of untreated silicon as seen in Fig.6a, the standard deviation of current fluctuation was about 49% of the average current value (1.91 μ A). The emitter surface coated with GaN nanoparticles and nanocrystalline diamond as seen in Fig.6b and 6c show a significant improvement in the current stability. The standard deviation of current fluctuation was about 24% of the average current value 0.28 μ A and 0.72 μ A respectively. The improvement in the current stability is due to the chemically inert intrinsic behavior of diamond and gallium nitride. It acts as a protective layer for the sharp conductive core from ion bombardment.

CONCLUSION

The presence of absorbed species on the surface of the field-emitter tip can remarkably influence the behavior of electron emission based devices. The presence of the surface contaminants leads to unstable cathode operation. The desirable cathode surface is one that is chemically inert and has low workfunction. Hence potentially chemically inert emitter-tip overcoatings with wide band gap materials are preferred for field emission system. In our investigation we have seen that when the emitter surface is coated with nanocrystalline diamond, there is a decrease in the turn on voltage and increase in the uniformity of the emission from the array in the region of low voltage operation. There is a significant increase in the current stability with surfaces coated with GaN nanoparticles and nanocrystalline diamond. Further investigation is being carried out to study the behavior of the emission current from the above two type of coating on the emitter surface over a long period of time in detail.

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