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UNCD electron emitters using Si nanostructure as a template

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A B S T R A C T

The electron field emission (EFE) properties of silicon nanostructures (SiNSs) coated with ultra-nanocrystalline diamond (UNCD) were characterized. The SiNS, comprising cauliflower-like grainy structure and nanorods, was generated by reaction of a Si substrate with an Au film at 1000 °C, and used as templates to grow UNCD. The UNCD films were deposited by microwave plasma-enhanced chemical vapour deposition (MPECVD) using methane and argon as reaction gases. The UNCD films can be grown on the SiNS with or without ultrasonication pretreatment with diamond particles. The EFE properties of the SiNS were improved by adding an UNCD film. The turn-on field (E_0) decreased from 17.6 V/μm for the SiNS to 15.2 V/μm for the UNCD/SiNS, and the emission current density increased from 0.095 to 3.8 mA/cm^2 at an electric field of 40 V/μm. Ultrasonication pretreatments of SiNS with diamond particles varied the structure and EFE properties of the UNCD/SiNS. It is shown that the ultrasonication pretreatment degraded the field emission properties of the UNCD/SiNS in this study.

1. Introduction

Diamond and related materials have been extensively studied for their novel mechanical, chemical and electrical properties. Particularly because of its low or negative electron affinity (NEA) diamond is an optimum candidate for electron field emission (EFE) that has potential applications in the areas of flat panel displays and vacuum microelectronic devices [1,2]. Cold cathode field emission has been demonstrated in chemical vapour deposited diamond films [3]. However, the EFE properties of these materials are inferior to those of carbon nanotubes (CNTs) [4] due to the large electric field required for turning on the EFE phenomenon [5]. Methods to reduce the turn-on field for diamond films have been extensively studied. Several techniques have been proposed to enhance the EFE properties of the diamond films, which include reducing the grain size of diamond films [6], doping semiconducting species to increase the conductivity of diamond [7], and using high-aspect-ratio tips as a template for fabricating diamond tips [8].

High EFE has been demonstrated from ultra-nanocrystalline diamond (UNCD)-coated Si microtips which were synthesized from catalyzed vapour deposition [9]. Aligned Si tip arrays generated by an electrochemical etch have also been used as templates for UNCD emitters [10,11]. In our previous study, Si nanowires (SiNWs) could be synthesized by reaction of thin metal films with a Si substrate at a high temperature [12]. In this study, UNCD electron emitters with improved EFE properties were investigated by depositing an UNCD film on templates of silicon nanostructures (SiNSs) that were generated by reaction of gold with the Si substrate.

2. Experimental

A p-type (100) silicon wafer was used as a substrate to grow SiNS. The silicon substrates were first cleaned ultrasonically in acetone and in ethanol in turn for 10 min each, and then leached in de-ionized water. Then the substrates were dried and transferred into a metal sputter-coater where a thin layer (10 nm) of gold catalyst was deposited. The silicon nanostructure (SiNS) was synthesized on the silicon substrates via a catalytic reaction in an N_2 atmosphere at 1000 °C for 30 min.

UNCD films were deposited in a microwave plasma-enhanced chemical vapour deposition (MPECVD, IPLAS) system. Before the UNCD deposition, the SiNS substrate was treated by ultrasonication in nano-sized diamond/titanium powder in methanol solution for 0, 20 and 45 min. The UNCD coatings were deposited with a microwave power of 1200 W, methane/argon flows of 1/99 sccm, total pressure of 1.6×10^4 Pa (120 Torr), deposition temperature of 300 °C and growth time of 3 h.

Topography of the as-grown SiNS was inspected by atomic force microscopy (AFM, Veeco CP-R). The UNCD coatings were characterized by Micro-Raman spectroscopy (Renishaw 2000) and field

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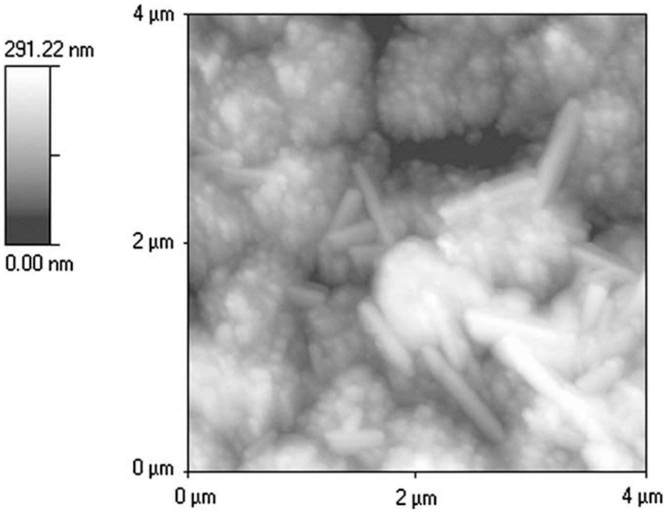

Fig. 1. AFM image for the as-grown SiNS.

emission scanning electron microscopy (FESEM, JEOL 6010). Micro-Raman measurements were performed at room temperature, using a 514.5-nm laser as the excitation source. The field emission properties of the NCD films were measured in a parallel plate set-up under a high vacuum environment of 1.33×10^{-4} Pa (1×10^{-6} Torr). The distance between the anode (ITO glass) and the cathode (UNCD films) was approximately 30 μm and the emission measurement area of NCD films was 10×2.5 mm^2. The current–voltage properties were measured by a Keithley 237 source measurement unit.

3. Results and discussion

Silicon nanostructure (SiNS) was produced on the surface of p-type Si substrate after annealing the Au-coated Si substrate. Fig. 1 displays the surface morphology of the annealed Si substrate. The substrate surface is composed of a cauliflower-like grainy structure and some randomly distributed nanorods of 0.3–1.1 μm in length and 90–160 nm in width. FESEM images for the annealed Si substrates in the as-grown state and after ultrasonication treatment for 45 min are shown in Fig. 2(a) and (b). It is indicated that both the cauliflower-like grainy structure and the nanorods were worn away after the ultrasonication treatment. The surface roughnesses for the annealed Si substrates before and after ultrasonication treatment for 45 min were 43.7 and 10.4 nm,

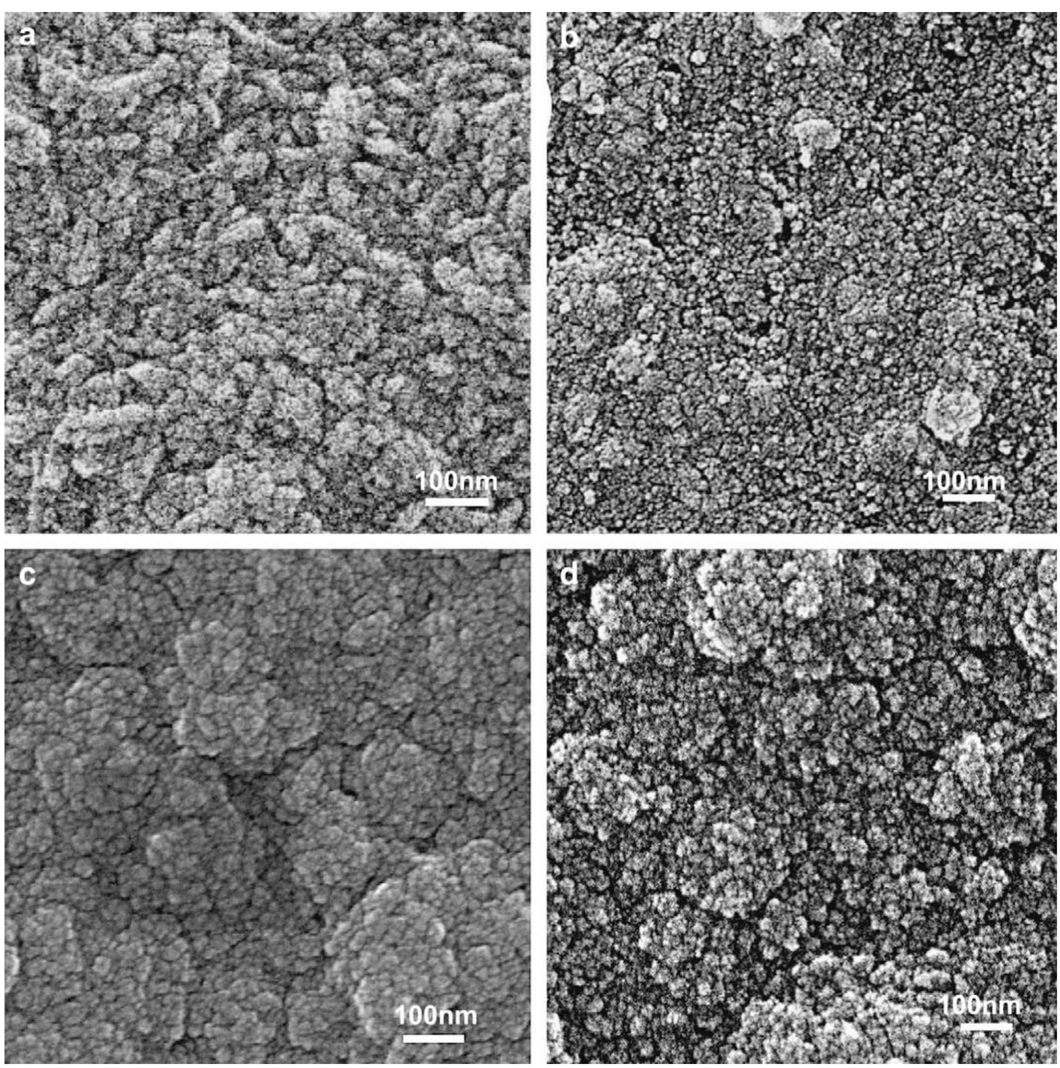

Fig. 2. FESEM images for (a) the as-grown SiNS, (b) the SiNS with ultrasonication treatment of 45 min, (c) UNCD on the as-grown SiNS and (d) UNCD on the SiNS with ultrasonication treatment of 45 min.