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Enhanced field emission from vertically aligned carbon nanotubes on metal mesh electrode

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ABSTRACT

A vertically aligned carbon nanotube (CNT) mesh emitter array on metal mesh electrode has been fabricated with a low temperature growth process, from which a current density of up to 5 A/cm^2, and a threshold field of 0.9 V/μm for a current density 1 mA/cm^2 were obtained, which show much better performance than CNT mesh on a flat electrode. This result was attributed to the enhanced edge effect of CNT mesh on metal mesh electrode. The numerical calculation results proved that the electric field on top of CNT emitter on mesh electrode was enhanced compared to that on flat electrode.

1. Introduction

Application of carbon nanotubes (CNTs) for field emission has received much attention across the world. Since the first reports of field emission with these materials, a tremendous progress has been made in the applications in a wide range of field emission devices such as backlighting [1], flat panel displays [2] and [3], X-ray sources [4] and [5] and microwave amplifiers [6,7] and [8]. CNTs have been shown to be excellent emitters, providing very low turn-on voltage and very high current densities while being very robust and promising low fabrication costs compared with micro-machined field emitter arrays. This application, however, remains limited to fairly small markets of high value added products. The application of CNT field emitters in mass-produced systems still requires refinement of the cathode design and fabrication processes.

Among different CNT structures, CNT films have the larger potential for technical applications [9]. They combine good emission characteristics, relative ease of fabrication, and possibility to scale for production. The fabrication of CNT film emitter is divided into two fundamentally different approaches: deposition or layering of pre-grown tubes on a substrate [5], or in situ growth of the CNT. Direct growth of the CNT film on a cathode substrate using chemical vapor deposition (CVD) processes offers the advantage of scalability for production. Patterned films can be obtained by controlling the catalyst deposition. Vertically aligned CNT films are usually obtained with high densities with the CNT supporting each other in their vertical position, whereas low-density films tend to have randomly oriented tubes [9].

Many factors could determine whether a CNT film will have good emission characteristics. For a CNT film emitter, the most important factor affecting the field emission properties is field screening [10] and [11]. The environment of a CNT tip can be such that it is shielded from the macroscopic electric field, preventing it from emitting to the extent it would if placed alone in the field. In any case to obtain high current density at low electric field, it is crucial to optimize the design of CNT field emitters to enhance the local field around CNT tips. Most of the previous works were focusing on designing the structure of CNT film. However, the shape of under-electrode is also significant to the performance of the CNT emitters [12] and [13]. Actually, we have investigated the field emission from CNT mesh on flat electrode covering on a glass substrate [14]. Although that result is promising, further optimization is still needed. In this paper, we reported an enhanced field emission from vertically aligned CNT film on metal mesh electrode with a low driving electric field.

2. Experimental details

Fig. 1(a) shows the diagram of metal mesh on glass, while Fig. 1(b) shows that of CNT mesh on metal mesh electrode. The fabrication process is described as following. Glass substrates, were patterned by photolithography with 1 μm wide mesh lines, in which molybdenum (Mo) (100 nm)/Aluminum (Al) (10 nm)/Iron (Fe) (1 nm) multilayer metals were deposited by sputtering.

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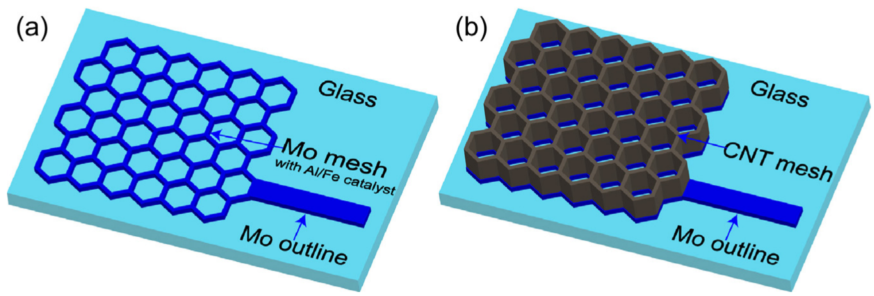

Fig. 1. (a) Shows the diagram of metal mesh on glass, while (b) shows that of CNT mesh on metal mesh electrode.

Actually, Mo layer is the under-electrode, while Al/Fe is catalyst layer. Subsequently, the vertically aligned CNT meshes were synthesized by thermal CVD in a cold wall CNT growth system. First, the sample was annealed in Argon at 420 °C for 40 s to form catalyst nanoparticles. Then, CVD was carried out at a growth temperature of 450 °C and pressure of 14 mbar with a flow rate of 200 SCCM of acetylene (C_2H_2). After growth, the samples were cooling to room temperature in Ar atmosphere. Fig. 2 (a) shows the top view scanning electron microscopy (SEM, Quanta 20 FEI, operating at 15 kV) image of as-grown CNT mesh on flat metal electrode, while Fig. 2(c) shows the SEM image of CNT mesh on metal mesh electrode. The height of CNT mesh is around 5 μm after 30 s growth. And the length of diagonal of the hexagon is 8 μm, while the width of the CNT mesh wall is 1 μm. Fig. 2(b) and (d) show the CNTs in the CNT mesh on flat metal electrode and metal mesh electrode, respectively, which are uniform, dense, well aligned and perpendicular to the substrate. It has previously been proved that the vertical self-alignment of CNTs results from van der Waals interaction between neighboring CNTs.[2]

Field emission measurements were performed using a custom-built turbo-molecular pumped chamber evacuated to

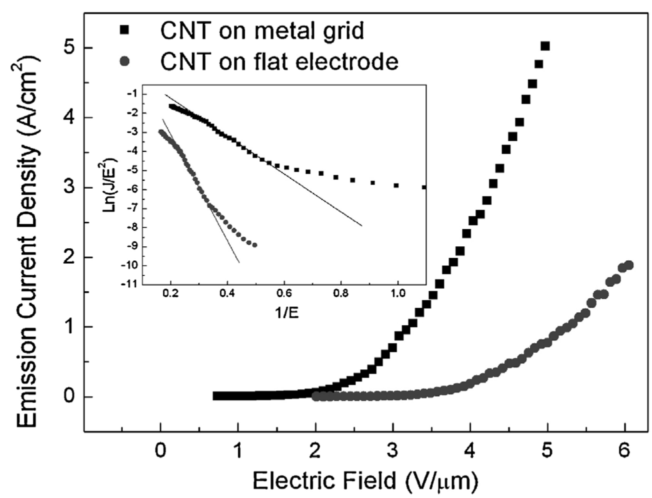

Fig. 3. The dependencies of FE current density on applied electric field for two samples. The corresponding Fowler–Nordheim (FN) plots are shown in the top-left inset.

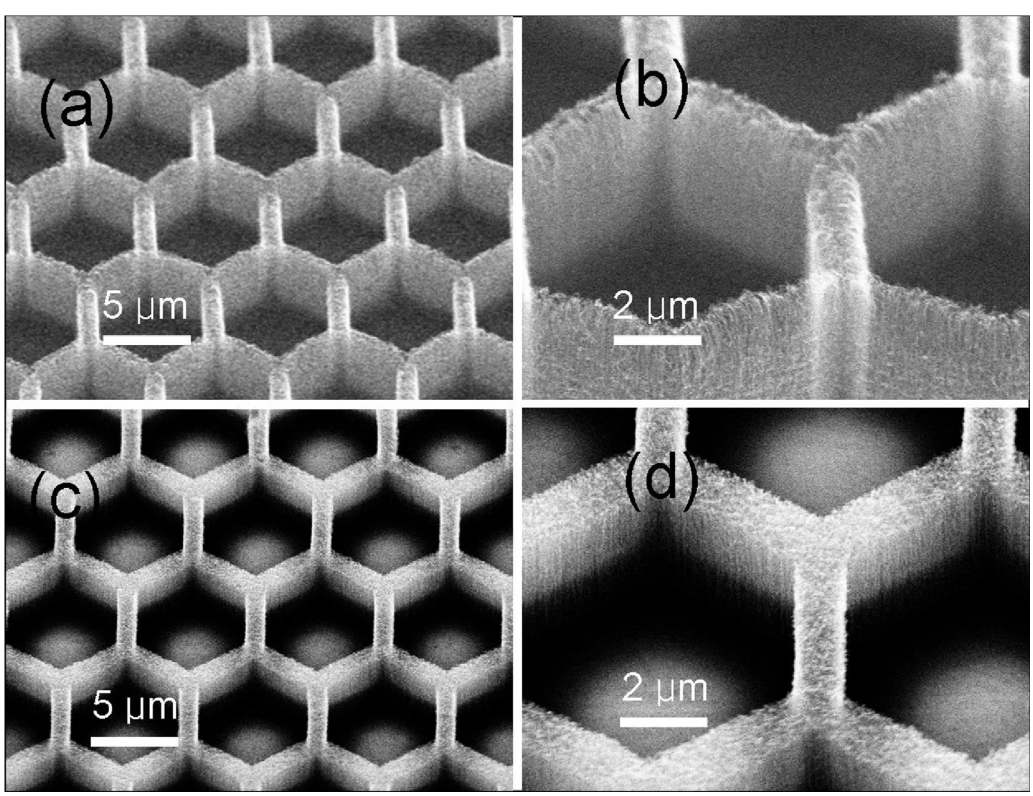

Fig. 2. (a) The top view SEM image of CNT mesh on flat metal electrode, while (b) shows the corresponding high magnification image. (c) The top view SEM image of CNT mesh on metal mesh electrode, while (d) shows the corresponding high magnification image.