Novel field emission from graphene sheets supported by CNTs arrays

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Abstract: *A good quality graphene is transferred onto honeycomb-like CNTs arrays with inner supporting CNTs. The efficient field emission is demonstrated due to a high aspect ratio protrusions and graphene crack edges. A high efficient current density about 1.2 mA/cm^2 at threshold electric field of 7.8 V/μm with a turn-on electric field of 1.8 V/μm at the current density of 10 μA/cm^2 is observed due to high localized electric field. Stable field emission is tested in a vacuum chamber. The results are of significance to the development of Graphene based field emitters.*

Keywords: graphene, carbon nanotubes, field emission

Introduction

Field emission of variety materials has been widely studied due to the potential applications such as electronic devices, field-effect transistors, field-emitter arrays, x-ray sources, and microwave amplifiers.[1-2] Among these materials, carbon-based materials have been studied for many years as the candidates for field emission display (FED).

Graphene, with a two dimensional carbon based material, has attracted wide attention from both academic and commercial organizations since its first discover in 2004.[3] field emission form graphene is challenging because chemical vapor deposition methods leads to the sheets lay flat on the substrate surface, which limits the field enhancement. We demonstrate an efficient method for field emission from large scale uniform single-layer graphene supported on vertical-aligned network honeycomb-like CNT arrays.

Experiment

In our structure, the most important method is the honeycomb-like CNT arrays used as supporting materials. We introduced two steps of electron beam lithography (EBL), metal sputtering to make the supporting materials catalyst. Then thermal CVD was carried out at a growth temperature of 520 • and pressure of 10mbar with a flow rate of 200 SCCM of acetylene (C_2H_2) which gave a CNT length of 2-3 μm after 80s growth, displayed in figure 1b.

Graphene film was synthesized by CVD of hydrocarbon on copper foil at temperatures up to 800°C using a mixture of methane and hydrogen. We introduce the "stick stamp" method to transfer the CVD-derived graphene films to the CNTs arrays, as show in figure 1.

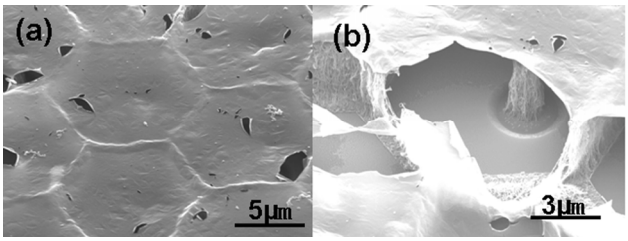

Figure 1. (a) Low magnification of as-fabricated Graphene/CNT cathode. (b) High magnification of as-fabricated Graphene/CNT cathode, CNTs and Graphene can be clearly seen.

Figure 2 shows a symmetric and sharp with a ~2 2D/G peak ratio, indicating high quality is maintained after transfer. But the D peak indicates some defect in our graphene which maybe general in the process of growing and transfering.

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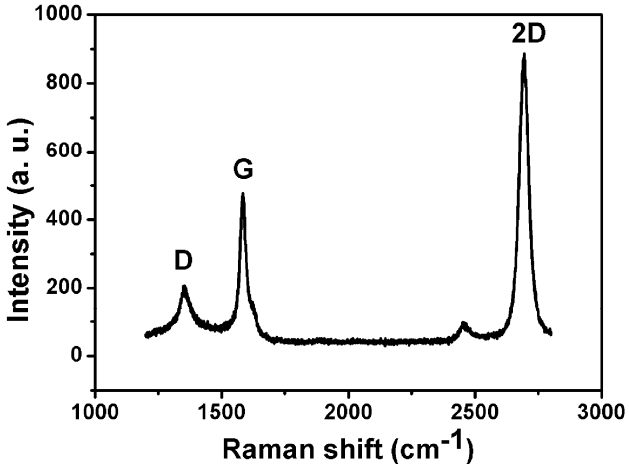

Figure 2. Raman of as-fabricated Graphene.

Result and discuss

Field emission testing is performed in a vacuum chamber at a pressure of ~10^{-6} Pa, displayed in figure 4a. The sample is fixed on the cathode panel while anode is applied from 0-4300V. The space between anode and cathode is controlled by a 550μm spacer. To remove the absorbed chemicals and gases, electrical annealing (a few hundred of volts) was applied on anode before real testing, shown in figure 3a.

From figure 3b, when we introduce Graphene with the inner supporting CNTs, there is a significant enhancement field emission, producing a current density of 10μA/cm^2 at an electric field of 1.8 V/μm and a high efficient current density of 1.2 mA/cm^2 at threshold electric field of 7.8 V/μm. The corresponding Fowler–Nordheim (FN) plots are shown in figure 4c, which exhibit linear behavior in the low-field measurement range. The emission current-voltage characteristics can be analyzed by the FN equation for FE,

$$J = \left(A\beta^2 E^2 / \varphi\right)\exp\left(-B\varphi^{3/2} / \beta E\right)$$

where J is the current density, A =1.56×10^{-10} （$AV^{-2}eV$ ）, B=6.83 × 10^3 （$VeV^{-3/2}\mu m^{-1}$ ）,[20] β is a field enhancement factor, φ is the work function, E=V/d is the applied field, d is the distance between the anode and the cathode, and V is the applied voltage. Here, the effective field enhancement factor β can be calculated from the slope of the FN plot if the work function of the emitter is known. Using 5.0 eV as the work functions of Grephene, the average field enhancement factors of the Grephene with inner supporting CNTs is calculated to 5780.figure 3d shows a stability of Graphene/CNTs cathode.

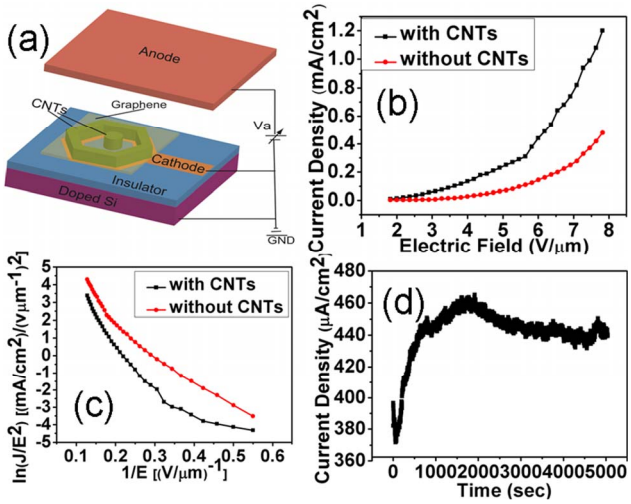

Figure 3. (a) Field emission structure. (b) I-V characteristic. (c) F-N characteristic. (d) Stability of graphene/CNTs field emission cathode.

The graphene froms sharp protrusions at the tip of CNT arrays. These protrusions improve the local field enhancement allowing the electron tunnel the tips with a low electrical field and dramatically increase the field emission. Meanwhile, there is a large electron emission from the edge of the graphene cracks since the graphene is suspended between the CNT arrays, which we could not get additional electron emission when the graphene sheets lay flat on the substrate surface.

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