Field Emission from a Mixture of Amorphous Carbon and Carbon Nanotubes Films*

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Abstract: A mixture of amorphous carbon and carbon nanotubes films was synthesized on stainless steel plates by a microwave plasma enhanced chemical vapor deposition system. The source gases were hydrogen and methane with flow rates of 100 and 16sccm, respectively, with a total pressure of 5.0kPa. The surface morphology and the structure of the films were characterized by field emission scanning electron microscopy (SEM) and Raman scattering spectroscopy. Field emission properties of as-deposited film were measured in a vacuum room below 5×10^{-5} Pa. The experimental results show that the initial turn-on field is 0.9V/μm; The current density is 4.0mA/cm^2 and the emission sites are dense and uniform at an electric field of 3.7V/μm. These results indicate that such a mixture of amorphous carbon and carbon nanotubes films is a promising material for field emission applications.

Key words: amorphous carbon; carbon nanotubes film; field electron emission
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1 Introduction

Carbon nanotubes (CNTs) are very attractive as electron field emitters because of their nanometer scale, high aspect ratio[1,2], superior mechanical strength[3], good conductance, and high chemical stability. Several groups have reported electron field emission from CNTs[4~6]. Many efforts have been made to develop methods for making patterned carbon nanotubes[7,8]. At the same time, amorphous carbon film shows good properties for field electron emission[9~12]. However, there are only a few reports about the mixture of amorphous carbon and carbon nanotube films with a low turn-on field and high emission current density at low electric fields[13~16].

In this paper, we report that a mixture of amorphous carbon and carbon nanotubes were synthesized on stainless steel substrates by microwave plasma enhanced chemical vapor deposition (MPECVD). The surface morphology and the structure of the films were characterized by field emission scanning electron microscopy and Raman scattering spectroscopy. The field emission characteristics of the samples were measured using a diode structure.

2 Experiment

A stainless steel plate with a 6mm diameter was used as a substrate. The source gases were hydrogen and methane with flow rates of 100 and 16sccm and the growth pressure was 5.0×10^3 Pa. The substrate temperature was maintained at 700℃ and deposition time was 3 hours. Before deposition of the mixture film, the stainless steel plate was mechanically polished by SiC polishing powders with a diameter of 20μm. Scanning electron microscopy (SEM) was used to determine the morphology of the samples. Raman spectroscopy was used to analyze the structure of the samples.

The field emission characteristics of the samples were measured using a diode structure. The transparent anode was made by coating phosphor onto an ITO coated glass plate. The samples as the cathode were separated from the anode by a china sheet with a suitable hole as the emission area. The gap between the anode and the cathode was 270μm. The measurement was carried out in vacuum chamber under pressure of 5.0×10^{-5} Pa. The voltage was stepped up at the same time; the luminescence of the anode was recorded by a CCD device.

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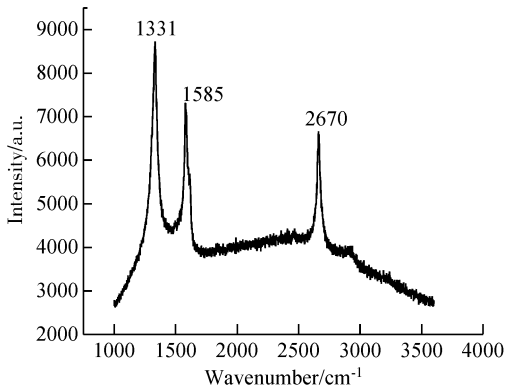

Fig. 1　Raman spectra of the sample

3　Results and discussion

Figure 1 is the Raman spectra of the deposited carbon film. There is a peak at approximately 1585cm^{-1} (G-band), which arises from the zone-center E_{2g} mode of highly oriented pyrolytic graphitic (HOPG). The D peak (the strongest peak of 1331cm^{-1}) is due to the disorder of the graphite grains and defects in the films. These two broad peaks are the typical spectra for amorphous carbon film. The peak of 2670cm^{-1} is the secondary peak of the D band.

An SEM picture (Fig. 2) of the sample indicates that the film is composed of the carbon grains and carbon nanotubes. The sizes of the amorphous carbon grains are not identical, but range from 20 to 200nm. The carbon nanotubes are distributed on the surface of the film-like nets. The diameter of the carbon nanotubes is 50～100nm, a length on the micron level. The reason for the composition of the amorphous carbon and carbon nanotubes in the deposited films is that Ni is a catalyst for the carbon nanotube growth, while the larger flow rate of methane (16sccm) produces the amorphous carbon at the same time.

The field emission properties are shown in Fig. 3. The electric field required for extracting a current density of 1μA/cm^2 was defined as the turn-on field.

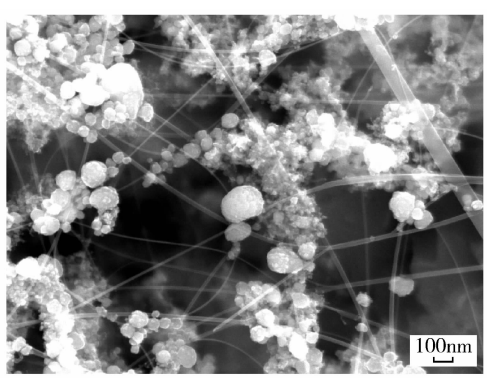

Fig. 2　SEM of the film

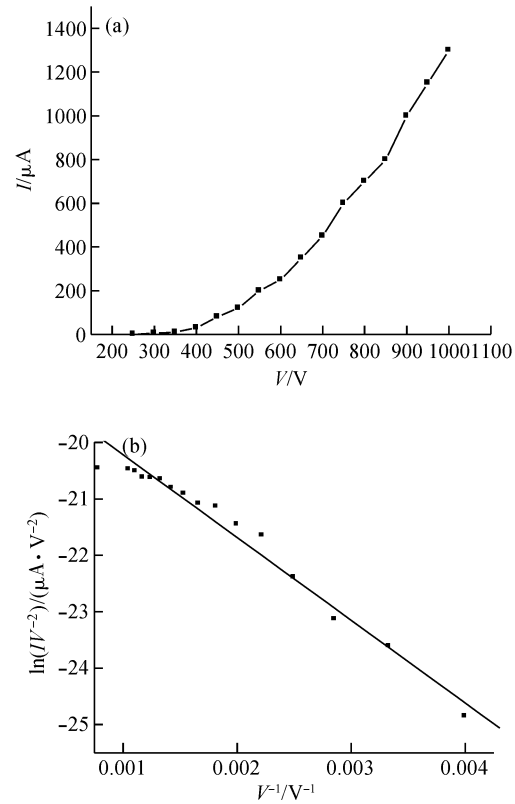

Fig. 3　(a) Current versus voltage (*I*-*V*) curve; (b) Fowler-Nordheim (F-N) plots of sample

By using such definition, a very low turn-on field of 0.9V/μm was obtained for the first time. After several operation circles with the voltage applied up and down, *I*-*V* curves gradually became stable and then a turn-on field of 1.7V/μm was maintained. Figure 3 (a) shows that the emission current density increased with applied voltage and it reached 4.0mA/cm^2 at an electric field of 3.7V/μm. Corresponding Fowler-Nordheim plots for the final stable operation are shown in Fig. 3 (b). This curve was well fitted by the straight line, indicating that the field emission property could be explained by the tunneling mechanism.

Figure 4 shows luminous spot images on an ITO anode impacted by electrons from a cathode at four different applied fields. The emission site density is a function of the applied field, and the emission site density reached 10^{5}cm^{-2} at an electric field of 3.7V/μm.

4　Conclusion

In summary, we have synthesized a mixture film of the amorphous carbon and carbon nanotubes on stainless steel plates by a microwave plasma enhanced chemical vapor deposition system. SEM and Raman spectroscopy were used to characterize the surface morphology and composition.

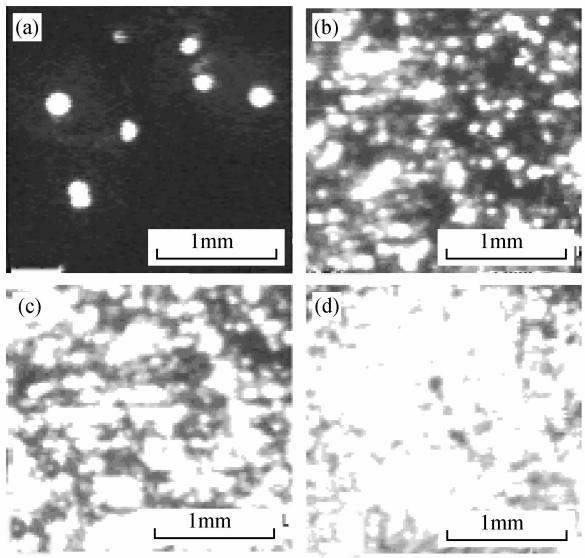

Fig. 4 Images of emission spots on the surface of ITO anode for different electron fields (a) 1.85V/μm; (b) 2.41V/μm; (c) 2.96V/μm; (d) 3.70V/μm

Field emission results show this film possesses better properties, i.e., a low emission threshold field, higher emission current, and emission site density. The emission sites are dense and uniform. These results indicate that such a mixture of the amorphous carbon and carbon nanotubes films is a promising material for field emission applications.

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非晶碳和碳纳米管混合薄膜的场发射性能*

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摘要： 利用微波等离子体化学气相沉积法在不锈钢衬底上直接合成非晶碳和碳纳米管混合薄膜. 采用氢气和甲烷作为反应气体，流量分别为 100 和 16sccm. 沉积室内的压强为 5.0kPa. 利用场发射扫描电镜(SEM)和喇曼谱(Raman)对制备的薄膜的结构和形貌进行了分析. 场发射实验在 5×10^{-5} Pa 的真空下进行. 实验结果表明：制备的非晶碳和碳纳米管混合薄膜开启电场较低，仅有 0.9V/μm；在电场为 3.7V/μm 时电流密度达到 4.0mA/cm^2，发射点密集，分布均匀. 表明此种材料是一种优良的场发射冷阴极材料.

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