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Improved field emission characteristic of carbon nanotubes by an Ag micro-particle intermediation layer

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Abstract

An efficient way to improve field emission characteristic of carbon nanotubes (CNTs) through an Ag micro-particle intermediation layer is presented. In this way, the intermediation layer is deposited on an indium tin oxide glass substrate by electrochemical method and then the CNTs are covered onto surface of the intermediation layer by electrophoretic method as CNT field emitters. The field emission characteristic of the CNT field emitters with the intermediation layer is significantly improved compared to the one without the intermediation layer, including decreased turn-on electric field from 4.2 to 3.1 V/μm and increased emission current density from 0.224 to 0.912 mA/cm^2 at an applied electric field of 6 V/μm. The improved field emission characteristic may be attributed to gibbous surface of the CNT field emitters. This efficient way is much simple, low cost, and suitable for production of large scale CNTs–based field emission cold cathode.

Keywords: Carbon nanotubes; Field emission; Ag micro-particle intermediation layer

1. Introduction

Carbon nanotube (CNT)is considered to be an ideal cold cathode material [1,2] because of its high geometric aspect ratio, small radius of curvature at the tip apex, high electrical conductivity, high mechanical strength, and chemical inertness. Various device applications using CNTs as field emitters have been demonstrated, such as field emission display (FED) [3], X-ray tubes [4], flat lamp [5]. For such device applications, CNT field emitters are required to have an excellent field emission characteristic. Up to now, many investigation focuses on how to improve field emission characteristic of CNT field emitters. Hideki Sato et al. [6] reported selective growth of CNTs on silicon protrusions as CNT field emitters by chemical vapor deposition (CVD). This approach is effective to improve the field emission characteristic of CNTs with an emission current density of 1 μA/cm^2 at low voltage of 180 V. The investigation also indicates that the field emission can be enhanced if the CNTs are assembled on a rough substrate. However, the approach has some imperfections for large area CNT field emitters, such as high complex processes and difficulties in scaling up.

In this paper, an efficient way to improve the field emission characteristic of CNTs is presented by introducing an Ag micro-particles intermediation layer between CNTs and substrate. In this way, the intermediation layer is deposited on an indium tin oxide glass substrate by electrochemical method and then the CNTs are covered onto surface of the intermediation layer by electrophoretic method. The intermediation layer makes a rough substrate surface and the field emission form CNTs assembled on this rough substrate is enhanced. The way is much simple, low cost, and suitable for production of large-scale CNTs-based field emission cold cathode.

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2. Experiment

In this study, the CNTs are assembled on two different substrates as CNT field emitters to compare their field emission characteristic. One of the substrates is Ag micro-particle layer on ITO glass. The Ag micro-particle layer is deposited on the ITO glass by electrochemical method. The ITO glass as working electrode and a graphite foil as the counter electrode are parallel immersed into electrolyte at room temperature. The electrolyte is 1 wt% $AgNO_3$ aqueous solution. An electrodeposition current of $10\,mA/cm^2$ is supplied by a DC power source for 1 min. The Ag micro-particle layer is prepared and attached to the ITO glass. The other one is Ag thin film on ITO glass.

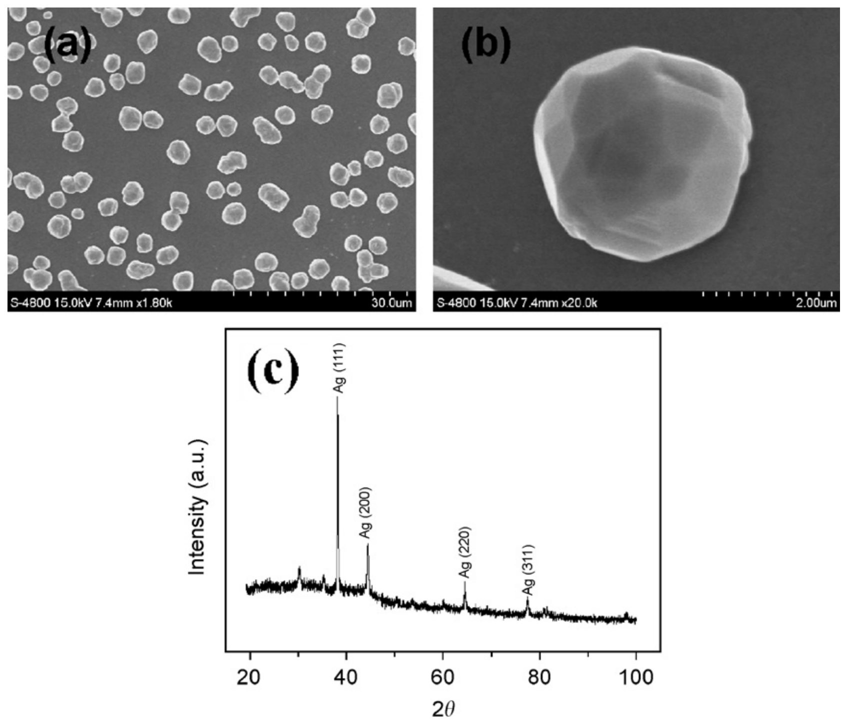

Fig. 1. SEM images and X-ray diffraction pattern of the Ag micro-particle intermediation layer: (a) SEM images of the Ag micro-particle intermediation layer, (b) morphology of single Ag particle, (c) X-ray diffraction pattern of the Ag micro-particle intermediation layer.

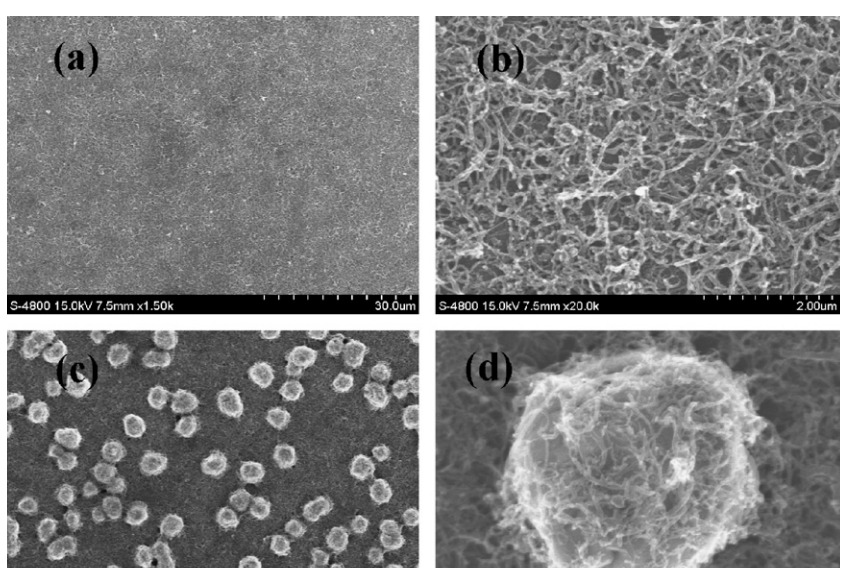

Fig. 2. SEM images of CNTs layer: (a) CNTs on Ag thin film, (b) magnified view of (a), (c) CNTs on the Ag micro-particle intermediation layer, (d) the morphology of CNTs covered on the single Ag particle.

The Ag thin film is deposited on the ITO glass by electron beam evaporation. The thickness of Ag thin film is about 100 nm.

The CNTs are deposited on the surface of as-prepared substrates using electrophoretic method as proposed elsewhere [7]. The as-prepared substrates as electrophoretic cathode and graphite panel as electrophoretic anode are parallel immersed into the CNTs electrophoresis suspension, the electrodes kept at a constant gap of 2 cm, the applied voltage is 60 V, and the deposition time is 3 min.

The scanning electron microscope (SEM) has been used to inspect the morphology of Ag micro-particle layer and the nanotube layer. Compositional of the Ag micro-particle layer is confirmed by an X-ray diffraction (XRD). The field emission measurements are carried out in a vacuum chamber with a base pressure 9×10^{-5} Pa. The distance between the sample surface and the anode is about 300 μm.

3. Result and discussion

Fig. 1(a) is the SEM image of the Ag micro-particle layer and Fig. 1(b) shows the morphology of single particle. It can be seen the particles of several micrometer size are formed on the ITO glass substrate. A typical XRD pattern of the Ag micro-particle layer is shown in Fig. 1(c). The sharp diffraction peaks in the pattern are indexed to pure silver of cubic structure. Fig. 2(a) is SEM image of CNTs on Ag thin film and corresponding magnified view shows in Fig. 2(b). The CNTs are deposited uniformly on the Ag thin film. Fig. 2(c) is the SEM image of CNTs on the Ag micro-particle layer. A lot of protrusions are shaped, which are Ag particles covered with CNTs. The surface is rougher than surface of CNTs on Ag thin film. Fig. 2(d) shows the morphology of CNTs covered on single Ag particle. The surface of Ag particle is fully covered with CNTs. The CNTs are randomly oriented and many CNTs protrude from surface of the Ag particle.

The emission current density versus applied electric field curves for the samples are shown in Fig. 3(a). It is found that the turn-on electric field, at which the emission current density reaches 10 μA/cm^2, is decreased from 4.2 to 3.1 V/μm and the emission current density at an applied electric field of 6 V/μm increased from 0.224 to 0.912 mA/cm^2 for CNTs on Ag thin film and CNTs on Ag micro-particle layer, respectively. By the Ag micro-particle layer, the field emission characteristic of CNTs is significantly improved. The corresponding F-N plot shows in Fig. 3(b). Each plot can be well fitted by using a straight line with different slopes. The field enhancement factor β of the CNT field emitters is evaluated from the F–N plot [8]. The slopes of the F–N plot of a linear correlation is given by $B\Phi^{1.5}/\beta$. Taking the work function $\Phi = 5$ eV [9] (the same as graphited) and constant $B = 6.83\times10^3$ V eV$^{-1.5}$ μm^{-1}, the field enhancement factors of the CNT field emitters for CNTs on Ag thin film and CNTs on Ag micro-particle layer are calculated to be 2253 and 3641, respectively.

The field enhancement factor of CNT field emitters depends on the length, diameter and density of CNTs and morphology of substrate surface [10,11]. For CNT field emitters of CNTs on Ag micro-particle layer, the field enhancement factor is related to both the macro-geometry of the Ag particles and the morphology of CNTs. The local electric field is enhanced at the vertexes of the Ag particles. By the two-grade enhancement effect [12], the field enhancement of each emission site can be understood by a coupling of field enhancement of Ag particle and intrinsic field enhancement of each CNT. Compared to the CNTs on Ag thin film, the CNTs at the vertexes of the Ag particles have a larger field enhancement factor, resulting in emission enhancement. Therefore, the improved field emission characteristic may be attributed to gibbous surface of the CNT field emitters.

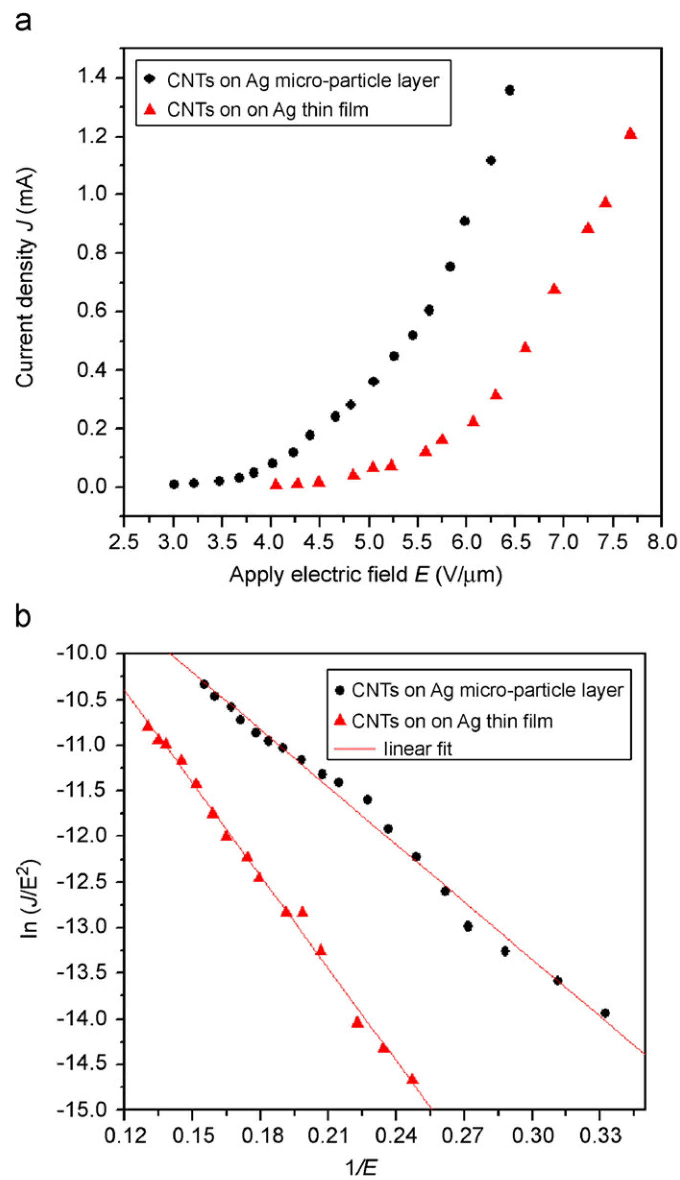

Fig. 3. Field emission characteristics of the CNT field emitters for CNTs on Ag thin film and CNTs on Ag micro-particle layer, respectively. (a) The emission current density versus applied electric field curves, (b) the corresponding F–N plot, showing linear $\ln(j/E_2)$ vs $1/E$ relation.

These results provided a way to fabricate the CNT field emitters with some advantages such as high throughput, low cost, easily manipulation, room-temperature and easy process. It has no intrinsic limit on the device size and easily scaling up. Therefore, the efficient way can serve as a promising candidate for production of large area CNT-based field emission cathode for many practical vacuum microelectron devices.

4. Conclusion

In conclusion, we have demonstrated an efficient way to improve field emission characteristic of CNTs through an Ag micro-particle intermediation layer. By the introducing intermediation layer, the field emission characteristic of CNTs is significantly improved, including decreased turn-on electric field from 4.2 to 3.1 V/μm and increased emission current density from 0.224 to 0.912 mA/cm^2 at an applied electric field of 6 V/μm. This efficient way is much simple, low cost, and suitable for production of large-scale CNTs-based field emission cold cathode.

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