Carbon Nanotubes Cathode of Field Emission Lamp Prepared by Electrophoretic Deposition

Gang Chen\textsuperscript{a}, Lan Zhang\textsuperscript{b}, Huizhong Ma\textsuperscript{b}, Ning Yao\textsuperscript{a}, Binglin Zhang\textsuperscript{a,}\textsuperscript{a*}

\textsuperscript{a} Department of Physics, Zhengzhou University, Zhengzhou 450052, China
\textsuperscript{b} Department of Engineering Mechanics, Zhengzhou University, Zhengzhou 450001

Abstract

Field emission lamp is a kind of green and low energy loss light source. Carbon nanotube cathode of field emission lamp was prepared by electrophoretic deposition. Two types of solute salt were added in electrophoretic solution separately, which were used to prepare two types of carbon nanotubes films on identical aluminum sheets by electrophoretic deposition method. Scanning electron microscopy (SEM) were used to observe the surface morphology of the films. The field emission properties of the films were tested by using a diode structure. The turn-on field of the film deposited with CsNO\textsubscript{3} / Ca(NO\textsubscript{3})\textsubscript{2}·4H\textsubscript{2}O solution was 0.7V/\textmu m. The current density of the film was about 4000mA/cm\textsuperscript{2} at an electric field of 1.8V/\textmu m. While corresponding data by using Mg(NO\textsubscript{3})\textsubscript{2}·6H\textsubscript{2}O solution was 0.8V/\textmu m and 3800mA/cm\textsuperscript{2}. It is concluded that the field emission properties of the deposited film cathode by using CsNO\textsubscript{3} / Ca(NO\textsubscript{3})\textsubscript{2}·4H\textsubscript{2}O solution better than that using Mg(NO\textsubscript{3})\textsubscript{2}·6H\textsubscript{2}O solution.

Keywords: Field emission; Carbon Nanotubes; Electrophoretic Deposition

1. Introduction

Carbon nanotubes (CNTs) films have attracted much attention for their unique characteristics, such as nanometer scale, high aspect ratio, superior mechanical strength, good conductance and high chemical stability\cite{1,2}. All of these properties make them possess stable emission, long life times, and low emission threshold potentials suitable for field electron emission\cite{3,4}, and can be applied to field emission displays (FEDs)\cite{5,6}, and field emission lamp to be a cold cathode. Especially, the field emission lamp with green

* Corresponding author.
E-mail address: blzhang@zzu.edu.cn.
and low energy loss property have bright future, and the emission cold cathode is the most important part in the field emission lamp.

Electrophoretic deposition (EPD)\cite{6,7} is suitable for the formation of the cathode layer due to the advantages of short formation time, little restriction in the shape of substrates, simple deposition apparatus and low-cost manufacturing. With the method a large sized nanotube film can be fabricated at room temperature. In the EPD process, the presence of salts solution can play an important role in increasing the deposition rate and in improving the adhesion of CNTs to substrates. Thus select a type of suitable solution salt can improve the property of field emission. Mg(NO$_3$)$_2$·6H$_2$O was a traditional salt to be used in electrophoretic deposition \cite{6,8}. In this paper, CsNO$_3$ with Ca(NO$_3$)$_2$·4H$_2$O together were also used to be electrophoretic salts because cesium has low work function. It can probably lower the turn-on field of the emission for improving the field emission properties. The field electron emission properties of the prepared films by using the two types of salt solution prepared films were investigated, respectively.

2. Experiments

In this work, CNTs prepared by chemical vapor deposition technique were used. They tend to form aggregates due to their high van der Waals interactions and highly entangled structure. To form uniform emission sites, well-distributed CNTs film were required. CNTs aggregates were grinded into smaller units first, then dispersed in two beakers, each contains certain volume IPA solvent. After that salt Mg(NO$_3$)$_2$·6H$_2$O, CsNO$_3$ with Ca(NO$_3$)$_2$·4H$_2$O were added into each beaker, respectively, to charge the CNTs aggregates positively and to form adhesive material. Then stirred for 24h to form stabilized suspension. During the EPD process, carbon nanotubes were deposited onto an aluminium sheet cathode at room temperature. While a stainless steel was used as anode. The morphology of the two types of CNTs-deposited films were studied by scanning electron microscopy (SEM). Field electron emission properties were measured by a diode type structure in a vacuum chamber. The two electrodes were separated by a 500μm insulating sheet, and the measured field electron emission area was about 1.0 cm$^2$. The deposited CNTs films were used as cathode emitter, and a piece of indium tin oxide (ITO) glass coated with phosphor as anode. Phosphor screen images were taken by a CCD camera.

3. Results and discussion

![Fig.1 SEM image of CNTs films deposited on Al substrate](image)

(a) Mg(NO$_3$)$_2$·6H$_2$O   (b) CsNO$_3$ +Ca(NO$_3$)$_2$·4H$_2$O
Fig. 1 shows scanning electron microscope (SEM) of two cathodes films deposited uniformly on 2×2.5 cm² of Al substrate. Both cathodes with randomly oriented CNTs, identical morphology exist as aggregates and a single nanotube diameter about 10nm.

Then field electron emission measurement were carried out when base pressure of vacuum chamber were maintained at 1×10⁻⁵Pa. Fig.2(a) presents the current density versus electric field (J–E curve) characteristics of the CNTs cathodes. The turn-on field of the sample with Mg(NO₃)₂·6H₂O was 0.8V/μm and the current density of 3800μA/cm² was obtained at 1.8V/μm. While corresponding data of the sample with CsNO₃ and Ca(NO₃)₂·4H₂O was 0.7V/μm and 4000μA/cm² at 1.8V/μm, and the current density was increased to 8000μA/cm² at 2.0V/μm. This meant that CsNO₃ and Ca(NO₃)₂·4H₂O had lower turn-on field and higher current density than that with Mg(NO₃)₂·6H₂O solution.

![Fig.2](a) J–E characteristics and (b) F–N plot of CNTs film on Al substrates

Fig. 2 shows J–E characteristics and the corresponding Fowler–Nordheim (F–N) plot of two types films. The plotting ln(I/E²) vs. 1/E yields a straight line in both samples, which indicates that the emission follows Fowler–Nordheim model. The linearity of the F–N plots, suggests that the measured emission current came from field emission by electron tunneling behavior.

![Fig.3](a) Mg(NO₃)₂·6H₂O (b) CsNO₃ +Ca(NO₃)₂·4H₂O at 1.8V/μm
Fig. 3 shows the corresponding emission performance of two types cathodes under a phosphor anode screen at an applied field of 1.8 V/μm. The field emission luminescence images results reveal that CsNO$_3$ +Ca(NO$_3$)$_2$·4H$_2$O cathode have better light uniformity and higher emission dot density.

When increasing the electric field, it disclosed that there were scarcely any carbon nanotubes on the substrate at electric field exceeded 1.9V/μm for Mg(NO$_3$)$_2$·6H$_2$O samples, and field emission failure. For CsNO$_3$ with Ca(NO$_3$)$_2$·4H$_2$O samples, when electric field higher than 2.2V/μm still have CNTs on the substrate, and field emission occurred. This means that the deposited carbon nanotubes film by using CsNO$_3$/Ca(NO$_3$)$_2$·4H$_2$O solution had larger adhesive force on the substrate, improved the adhesion of CNTs to substrate.

These results indicate that the CsNO$_3$ +Ca(NO$_3$)$_2$·4H$_2$O cathode exhibited excellent field emission properties, i.e. low turn-on emission field, high emission current density, and high emission light spot density and well distributed over the whole CNT cathode. It can be a good cold cathode for field emission lamp.

4. Conclusions

In summary, two types of carbon nanotubes-deposited films were prepared on identical aluminium sheets by electrophoretic deposition method. The turn-on field of the deposited film with CsNO$_3$/Ca(NO$_3$)$_2$·4H$_2$O salt solution was 0.7V/μm. The current density of the film was about 4000mA/cm$^2$ at an electric field of 1.8V/μm. While corresponding data of the sample deposited with Mg(NO$_3$)$_2$·6H$_2$O salt solution were 0.8V/μm and 3800mA/cm$^2$. The experimental results indicate that the deposited CNTs film by using CsNO$_3$/Ca(NO$_3$)$_2$·4H$_2$O solution had low turn on field, could endure higher electric field and improved the adhesion of CNTs to substrate under the same conditions. It can be a good cold cathode for field emission lamp.

Acknowledgements

This work was supported by Excellent Youth Foundation of He’an Scientific Committee (104100510023) and by Henan province university innovation talents of science and technology support program (2009HASTIT013)

References