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Calculation of the emission performance of the carbon nanotube array

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Abstract

Because of the excellent field emission performances, the carbon nanotube array has already been used as the cold electron source in the field emission display, the vacuum microwave tube, and the electron microscopy, etc. It is necessary to estimate the emission performance of the carbon nanotube array in the design of these devices. The emission current density of a single carbon nanotube can be estimated with the Fowler–Nordheim formula approximately. Thus, the emission performance of the whole array is obtained by the sum of the current emitted from all carbon nanotubes in the array. However, this calculation is very complex and time consuming due to the large number of carbon nanotubes in the array. This paper proposes a simple model to predict the emission performance of the whole CNT array. The total emission current can be deduced easily with this model if we know the geometrical parameters of the CNT array. A few experiments have been performed to verify this model. With this model, the influences of geometric dimensions of the CNT array on the emission performance are also discussed.

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Keywords: Emission performance; CNT array; Geometrical dimension

1. Introduction

It is well known that the carbon nanotube has very excellent field emission characteristics. It has already been used as the cold electron cathode in the field emission display, the microwave power tube and the electron microscopy, etc. [1–3]. To obtain good emission performances with the CNT cathode, highly oriented and well-distributed CNT array is needed [4–6]. A lot of ways have been proposed for the fabrication of the CNT cathode. It is reported that the alignment, precise position, orientation, height, and diameter can all be well controlled [7–10].

In the design of the device with CNT cathode, it is necessary to estimate the emission performance of the whole CNT array. Usually, Fowler–Nordheim formula

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can be used to calculate current density from a single carbon tube. In principle, the emission performance of the whole CNT array can be obtained from the sum of the currents emitted from all carbon nanotubes in the array. Because there are too many nanotubes in a CNT array, this calculation is very complex and expensive. This paper proposes a simple model to predict the emission performance of the whole CNT array. This model can describe the influences of the geometric dimensions of the carbon nanotube on the emission performance of the CNT array. Therefore, the total emission current of the CNT array can be predicted easily with this model after we know the geometrical parameters of the CNT array.

Some experiments have been performed to verify the model proposed in this paper. The influences of the geometrical dimensions of the CNT array on the total emission current are also discussed.

2. Simulation model

In order to simplify the calculation, the carbon nanotube is regarded as a cylinder with a dome cap. Fig. 1 shows the structure of a CNT array.

When a voltage is applied on the anode, the current can be emitted from the carbon nanotubes in the array. Fig. 2 shows the potential distribution in the CNT array.

It is very important to study the emission performance of the CNT array in the design of the device with CNT cathode. After the calculation of the electric field distribution in the CNT array, the emission performance of the CNT array can be obtained with Fowler–Nordheim formula directly. However, this calculation is complicated, so the long calculation time is needed. This paper proposed a simple model to estimate the emission performance of the CNT array quickly.

2.1. Direct calculation with FN formula

It is well known that the emission characteristic of a single carbon nanotube can be estimated with Fowler–Nordheim formula approximately. The current density, which is emitted from a single tip, can be expressed as [1,11–14]

$$J_{\text{tip}}\,(\text{A/cm}^2) = 1.54 \times 10^{-6}(E_{\text{tip}}^2/\phi t^2(y))\exp(-6.87 \times 10^7(\phi^{3/2}v(y)/E_{\text{tip}})) \quad (1)$$

where J_{tip} is the current density emitted from the tip of a carbon nanotube, E_{tip} the electric field at the tip in V/cm, $v(y)$ and $t^2(y)$ are electric field-dependent elliptical functions, ϕ the work function of the emitter material in eV, and y the image charge lowering contribution to the work function, is given by $y = 3.79 \times 10^{-4}E^{1/2}/\phi$. With an approximation over the operating range of most cathodes, it is generally assumed that $t^2(y) = 11$ and $v(y) = 0.95 - y^2$.

After the calculation of the emission current from a single carbon nanotube, the total emission current of the carbon nanotube array can be obtained with the following equation

$$I_{\text{total\_array}} = \sum_{k\_\text{cnt}=1}^{n} I_{k\_\text{cnt}} \quad (2)$$

where $I_{\text{total\_array}}$ is the total emission current from the CNT array, I_{k_cnt} is the current emitted from the kth carbon nanotube in the array. It is assumed that there are n carbon nanotubes in the array.

From Eqs. (1) and (2), it can be seen that the direct calculation of the emission performance of a carbon

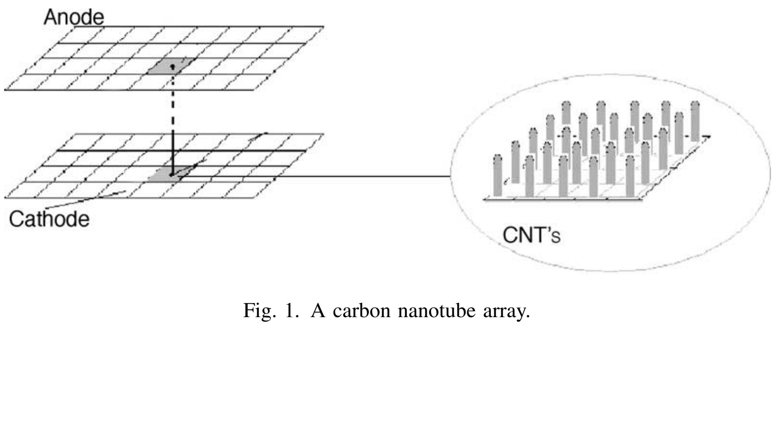

Fig. 1. A carbon nanotube array.