

Area Effect of Patterned Carbon Nanotube Bundle on Electron Field Emission Characteristics

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ABSTRACT

This study shows the relationship between the property of electron field emission, the area of patterned carbon nanotube (CNT) bundles, and the density of CNT bundles. In this work, patterns of different diameter and pitch were fabricated on Si(100) substrates by photolithography. We synthesize carbon nanotubes using thermal chemical vapor deposition (CVD) at a growth temperature of 700°C and under a pressure of 533 Pa maintained by flowing C₂H₂ for 20 min. The lowest threshold electric field of 0.87 V/μm was obtained for the aligned CNT bundles with the number density of 9.42×10⁴ cm⁻². The result shows either the screening effect or the density of emission site affects the electron field emission properties and there is an optimal number density of CNT bundles for electron field emission.

Keywords: aligned carbon nanotubes, patterned growth, electron field emission property, thermal chemical vapor deposition, Fowler-Nordheim equation

1. Introduction

Electron field emission from nanostructure materials such as carbon nanotubes [1,2] (CNTs) is a wide and interesting field of research in science and technology. Related studies have focused on exploring highly efficient field emitting materials and their fabrications [3-6]. Although the electron field emitters reported to date require the threshold electric field (E_{th}) of 1.5–2.5 V/μm at

minimum to produce the technologically useful current density of 1 mA/cm² [7,8], it is indispensable to lower the E_{th} to achieve practically applicable electron field emitters that operate with low power consumption. Regarding an aligned CNT array as a field emitter, it has been reported that the electron field emission becomes maximum when the ratio of intertube distance to the height of each individual CNT is approximately 2 [9]. In practical, it is not easy to set the individual CNT and its neighboring CNT to be the optimal condition. In this work, the CNT bundles were substituted for the individual CNTs to form an architecture that satisfies the optimal condition. The CNT bundles were grown by thermal chemical vapor deposition (CVD). The lowest threshold electric field of 0.87 V/μm was obtained with 46% of patterned CNT bundles of total area which synthesized with the pitch of 10 μm and the diameter of 25 μm. Adjusting the patterned CNT bundles of total area to the optimal ratio of 46% can effectually enhance the field concentration, resulting in a highly efficient electron field emission. This provides a promising method of obtaining the optimal ratio of patterned CNT bundles of total area, which possesses the advantages of simplicity and inexpensiveness.

2. Experimental

In this work, patterns of different diameter and pitch were fabricated on Si(100) substrates by photolithography. The pitch between the CNT bundles is fixed of 10 μm and the diameters of the CNT bundle varied from 5 to 50 μm. Before the formation of CNT bundles, Al films (10 nm) as

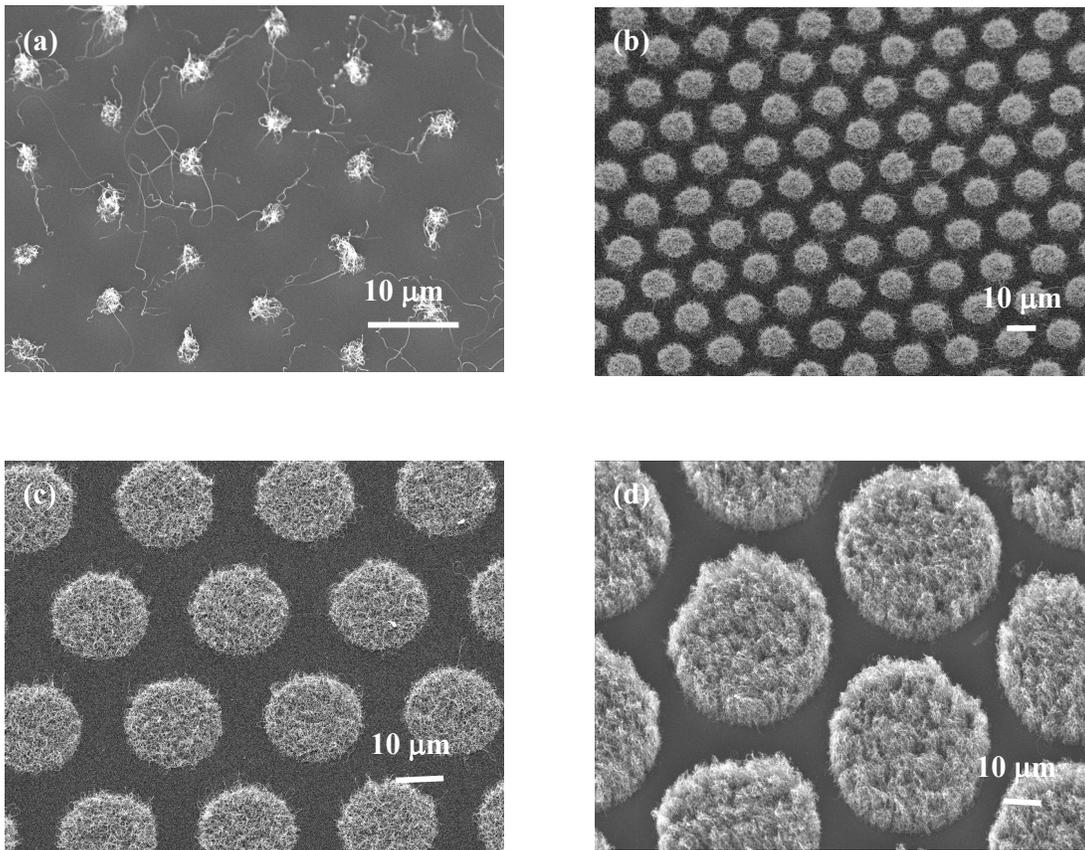


Figure 1: SEM images of CNT bundles grown by thermal chemical vapor deposition with pitch of 10 μm and diameters of (a) 5, (b) 10, (c) 25 and (d) 50 μm .

buffer layers were deposited on Si substrates and then Fe thin films (5 nm) as a catalyst were deposited on the Al thin films at room temperature by thermal evaporation deposition at a pressure of less than 1.0×10^{-4} Pa. Annealing was carried out at 700°C for 60 min to form Fe catalyst nanoparticles. Subsequent, the thermal CVD was carried out at a growth temperature of 700°C and under a pressure of 533 Pa maintained by flowing C_2H_2 . The growth of carbon nanotubes was carried out for 20 min.

The synthesized CNT bundles were characterized by using a high-resolution scanning electron microscope (SEM, JEOL JSM-6500F). The electron field emission measurement apparatus equipped with a high-vacuum system (10^{-7} Pa) consists of parallel plates which are separated by 250 μm .

3. Results and discussion

Figure 1 shows the titled (30°) SEM images of CNT bundles grown on patterned Fe/Al/Si substrates at 700°C . The pitch of CNT bundles is fixed of 10 μm with different diameters of 5, 10, 25, and 50 μm , respectively (Fig. 2(a), 2(b), 2(c) and 2(d)). Patterned growth of the CNT bundles on Si substrates are clearly seen from these low magnification images (Figure 2(a) ~ 2(d)). The CNTs were grown selectively on the Fe/Al/Si substrates, and no carbonaceous materials were formed elsewhere. The number density of the patterned CNT bundles are $5.13 \times 10^5 \text{ cm}^{-2}$, $2.88 \times 10^5 \text{ cm}^{-2}$, $9.42 \times 10^4 \text{ cm}^{-2}$, and $3.2 \times 10^4 \text{ cm}^{-2}$, respectively. The ratios of the Patterned CNT bundles to the total area (substrate area) are 10%, 23%, 46%, and 63%, respectively. Figure 2 shows the number density of CNT bundles as a function of patterned CNTs of total area.

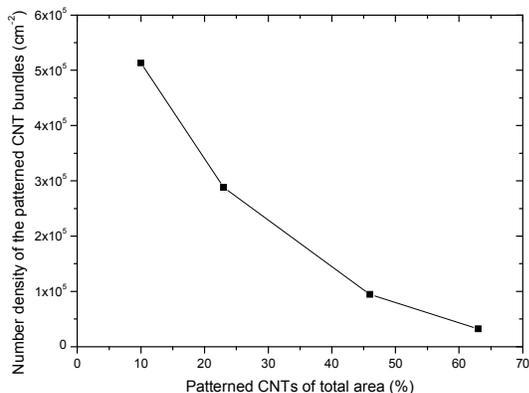


Figure 2: The number density of CNT bundles as a function of patterned CNTs of total area.

The highest (63%) and lowest (10%) patterned CNT bundles of total area were obtained with pitch of 10 μm , diameter of 50 μm and pitch of 10 μm , diameter of 5 μm , respectively, which exhibited about an 6.3-fold difference. Figure 3(a) shows the electron field emission current density vs. electric field characteristics of the CNT bundles with different patterned CNT bundles of total area. We define the threshold electric field as that which corresponds to the current density of 1.0 mA/cm^2 ; the threshold electric fields, as a function of patterned CNT bundles of total area, are shown in Fig. 3(b). It shows that the lowest threshold electric field of $0.87 \text{ V}/\mu\text{m}$ was obtained with 46% of patterned CNT bundles of total area which synthesized with the pitch of 10 μm and the diameter of 25 μm . When the patterned CNT bundles of total area was greater than 46% or smaller than 46%, the electron field emission property became worse. In this research, it can be thought when the patterned CNT bundles of total area was greater than 46%; the field

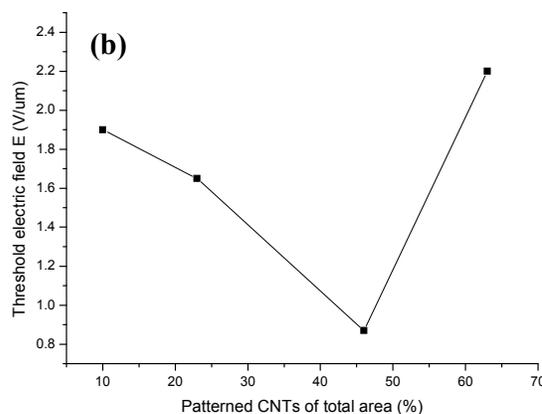
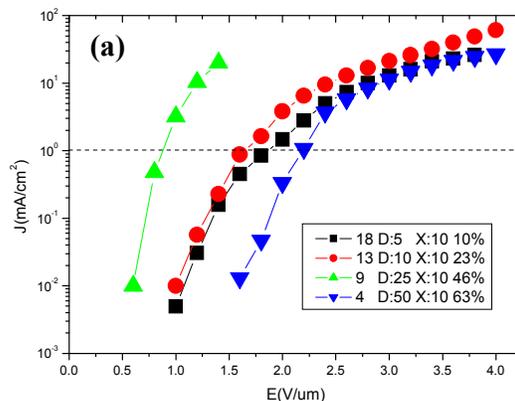


Figure 3: (a) Field electron emission property of CNT bundles. (b) Variation of threshold electric field with area of patterned CNTs.

emission property became poor due to the screening effect [9]. However, when the patterned CNT bundles of total area was smaller than 46%, the threshold electric field increased with decrease of patterned CNT bundles of total area. In this case, when the number density of aligned CNTs is low, the sum of the individual emission sites is the main influence on electron field emission property. Therefore, the low density with few emission sites presents poor electron field emission property.

4. Conclusion

Patterns of different diameter and pitch were fabricated on Si(100) substrates by photolithography. The pitch is fixed of 10 μm and diameters varied from 5 to 50 μm . The CNTs bundles were grown selectively on the Fe/Al/Si substrates at 700⁰C by flowing C₂H₂ for 20 min. We show the electron field emission current density vs. electric field characteristics of the CNT bundles with different patterned CNT bundles of total area. The electron field emission property could be controlled by adjusting the ratio of patterned CNT bundles of total area. According to the different number density of CNT bundles, either the screening effect or the density of emission site affects the electron field emission properties. In the experiment results, the lowest threshold electric field of 0.87 V/ μm was obtained with 46% of patterned CNT bundles of total area which synthesized with the pitch of 10 μm and the diameter of 25 μm .

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