Field emission digital display tube with nano-graphite film cathode

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The field emission digital display tube with a nano-crystalline graphite cold cathode is designed and fabricated. Under the control of the driving circuits, a dynamic digital display with uniform luminance distribution is realized. The luminance of the character segments is 190 cd/m^2 at the operating voltage of 900 V. And the stable emission is attained with a fluctuation of about 3% at an average segment current of 75 μA. The results demonstrate that nano-crystalline graphite film is a promising material for cold cathode.

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Carbon-based materials have attracted considerable attention as promising candidates for field electron emitters due to the relative ease in the extraction of electrons at low applied electric fields[1−4]. Nano-crystalline graphite has sp^2 hybridized bonding and quasi two-dimensional (2D) structures with sharp edges, which means that it has good conductivity and high field enhancement factor. These characteristics are helpful to electron field emission (FE). Recently, it has been reported that nano-crystalline graphite could be prepared by using various types of chemical vapor deposition (CVD)[5−9]. Wang *et al.* prepared nano-graphite sheets by means of CVD, which yields high FE current of larger than 20 mA/cm^2 at an electric field of 10 V/μm[10]. Wang *et al.* reported that nano-graphite sheets, grown by using radio-frequency plasma-enhanced CVD system, have high FE reproducibility and stability[9]. The above studies indicate that nano-graphite can be a promising candidate for field electron emitters. However, nano-graphite film has not received much attention. So far no electronic device using nano-graphite film as cold cathode has been reported. At present, digital display is widely used and the digital display tube is very useful in electronic design. In this letter, the digital display tube with a nano-graphite film cold cathode is designed and prepared, and its display performance is measured.

Nano-graphite film was prepared directly on ceramic substrates by using microwave plasma CVD. Before deposition, a ~ 200-nm-thick Fe-Ni-Cr layer was deposited on the Ti-coated ceramic substrates as the combined catalyst. Then the catalyst-coated substrate was placed in a CVD reaction chamber with a base pressure of 10^{-3} Pa. The mixture gas of methane (CH_4) and hydrogen was introduced into the chamber. The flow rates of CH_4 and H_2 were controlled at 8 and 100 SCCM by mass flowline, respectively. The total pressure in the chamber was kept at 6.0 kPa during the deposition. The growth time was maintained for 10 min with substrate temperature of ~ 700 °C measured by using a thermocouple contacted with a substrate holder. The microwave power of 1600 W was applied during the deposition.

Figure 1(a) shows a scanning electron microscope (SEM) micrograph of the as-deposited carbon films. The deposited film is mainly composed of clusters like nano-structured slices with the lateral size of about $100-250$ nm. These nano-structured slices possess sharp edges less than 10 nm in thickness, as marked by arrows. Figure 1(b) shows a typical transmission electron microscopy (TEM) image of a slice. It could be seen that the slice has layered structure and the edges of the nano-structured slice are about several nanometers.

Figure 2 shows the Raman spectrum of the film. Two strong peaks at ~ 1328 and 1579 cm^{-1} are typical D and G bands of the microcrystalline graphite[11]. An

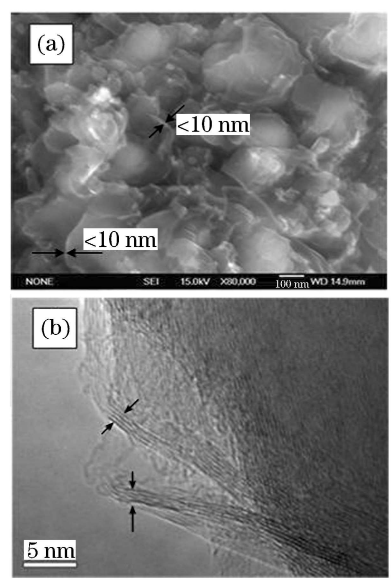

Fig. 1. SEM and TEM images of nano-crystalline graphite films.

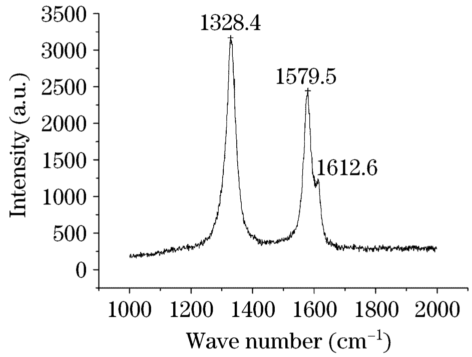

Fig. 2. Typical Raman spectrum of the film.

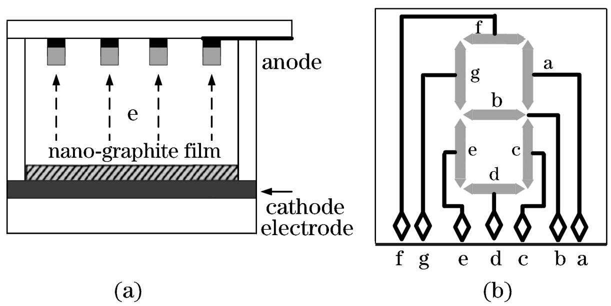

Fig. 3. (a) Structure schematic and (b) seven-segment character of the digital display tube with nano-graphite cathode.

additional peak at ~ 1612 cm^{-1} called as D$'$ is also observed, which also reveals a disorder-induced behavior similar to that of the D peak[5]. These Raman peaks indicate that nano-structured carbon slice has a crystalline but defective graphite structure.

The FE characteristics of the film were investigated by using a diode structure in a vacuum chamber. It was found that the nano-crystalline graphite has good FE properties[12] and can serve as a good field emitting material for field emission display (FED) applications.

Based on the above study, the field emission digital display tube with a nano-graphite cold cathode was prepared. Figure 3(a) shows the structure schematic of the display tube. To simplify sealing process, the digital display tube is a common-cathode structure. The transparent anode, made of phosphor/indium tin oxide (ITO) coated glass plate, was patterned to be seven-segment numeric character by laser writing technology, as shown in Fig. 3(b). The nano-crystalline graphite cathode was separated from the anode electrode by a 270-μm-thick insulating sheet. After sealing the vacuum tube, getter material was flashed to attain a high vacuum of the order of 10^{-6} Pa.

Figure 4 shows the dynamic driving circuit of the digital display tube. The cathode was connected to a negative voltage, and the anode character segments were under the control of the output stage, which consists of seven high voltage conversion circuits. When one segment was selected to display, the corresponding driving circuit output a positive voltage to the segment, which rendered enough electric field on the nano-crystalline graphite cathode to extract electrons by tunneling. For non-selected segment, the corresponding output voltage is 0 V, so no electron emission occurs. Figure 5 shows the current versus voltage plots of every segment. The corresponding typical FE parameters are summarized in Table 1. The measured results indicate that the average turn-on voltage is 430 V (current density of 10 μA/cm^2). When the voltage between anode and cathode is 900 V, the segment current attains 103 ± 7 μA. The mean deviation of the segment current is about $\pm 6.7\%$.

Figure 6 shows the typical luminance image of the tube. The measured luminance of the character segments is

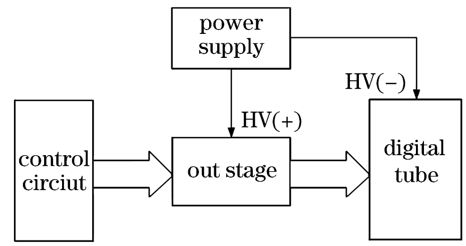

Fig. 4. Driving circuit schematic of the digital display tube.

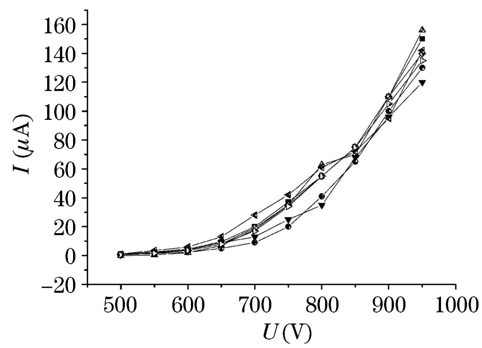

Fig. 5. Current versus voltage for every segment.

Table 1. Typical Field Emission Parameters of the Digital Display Tube

Segment	a	b	c	d	e	f	g
Turn-on Voltage (V)	435	410	440	415	420	440	425
Current (μA) (at 900 V)	100	110	95	110	105	96	110

Fig. 6. Luminance image of the digital display tube.

190 cd/m^2 at the operating voltage of 900 V. It can be seen that segments have relatively uniform luminance distribution. The lifetime test of the tube was carried out at a fixed operating voltage of 850 V over a period of about 3 h. The results exhibits a stable emission with a fluctuation of about 3% at an average segment current of 75 μA. It has been shown that the emission is stable and uniform, so nano-graphite can be a promising material for field electron emitters.

In summary, the digital display tube with a nano-graphite cold cathode is designed and sealed. A dynamic digital display is realized under the control of the driving circuits. Stable electron emission and relatively uniform luminance distribution demonstrate that nano-crystalline graphitic film is a promising material for cold cathode. This work will be a beneficial attempt for the application of FED.

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