

Research Article

Improvement of Lighting Uniformity and Phosphor Life in Field Emission Lamps Using Carbon Nanocoils

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The lighting performances and phosphor degradation in field emission lamps (FELs) with two different kinds of cathode materials—multiwalled carbon nanotubes (MWCNTs) and carbon nanocoils (CNCs)—were compared. The MWCNTs and CNCs were selectively synthesized on 304 stainless steel wire substrates dip-coated with nanosized Pd catalysts by controlling the growth temperature in thermal chemical vapor deposition, and the film uniformity can be optimized by adjusting the growth time. FELs were successfully fabricated by assembling these cathode filaments with a glass bulb-type anode. The FEL with the CNC cathode showed much higher lighting uniformity and light-spot density and a lower current at the same voltage than that with the MWCNT cathode filament, and its best luminous efficiency was as high as 75 lm/W at 8 kV. We also found that, for P22, the phosphor degradation can be effectively suppressed by replacing MWCNTs with CNCs in the cathode, due to the much larger total bright spot area and hence much lower current density loading on the anode.

1. Introduction

The phenomenon of field emission (FE) was proposed by Fowler and Nordheim in 1928 [1]. This phenomenon has been used in a variety of applications such as display panels [2–5], backlight in flat panel displays [6, 7], field emission lamps (FELs) [8–11], and X-ray tubes [12]. FEL devices have numerous advantages such as short switching times, low power consumption, high brightness, and low heat generation. In addition, they are also free of mercury. Compared with light-emitting diodes and cold cathode fluorescent lamps, FELs have an edge as a new-generation environment-friendly light source [13].

Carbon nanotubes (CNTs) have been widely used as the cathode material in most FELs that were recently developed because they are characterized by a high aspect ratio and a low turn-on electric field [14]. Hence, the voltage required

for operating these FELs is lower than those of conventional cathode materials. In 2001, Bonard et al. fabricated a prototype of cold illumination device with CNTs as the cathode material [15]. They directly grew CNTs on metal wires using thermal chemical vapor deposition (TCVD) and then used the CNT-coated wires as the cathode emitter set in the middle of a vacuum tube. The inner side of the vacuum tube was coated with an ITO film and phosphor and served as the anode of the tubular FEL, which has brightness higher than 1×10^4 cd/m² under an applied voltage of 5.4 kV. Huang et al. also successfully fabricated an FEL device in 2008 using a CNT wire cathode, which was also prepared by TCVD growth of CNTs on a stainless steel wire with a diameter of 0.7 mm and a length of 30 mm, and an anode coated with blue and green phosphors [16]. Fu et al. blended multiwalled CNTs (MWCNTs) and silver glue and then applied the mixture on a stainless ball with a diameter of 2 mm to fabricate a spherical

FE light bulb in 2008 [17]. The bulb they made can achieve an emission current density as high as 300 mA/cm^2 and a luminous efficiency of 26.4 lm/W .

However, compared to those commonly used lamps such as CCFLs, these CNT-FELs have not shown significantly higher luminous efficiency or brightness. To achieve high luminous efficiency or brightness, the characteristics of the cathode material are crucial. The choice of cathode material not only directly affects lighting uniformity and light-spot density, but also is very important for the anode performance and phosphor lifetime in FELs. This is because ZnS-based types of phosphors, P22, which have become the primary fluorescent material in FELs currently, suffer from many unsolved problems, including Coulombic damage (aging), charge accumulation, and thermal quenching, despite their high efficiency and brightness in high-voltage or high current operation [18].

In particular, in high current density operation with intense electron bombardment, the phenomenon of Columbic damage and charge accumulation were quite severe since for the P22 phosphors the maximum Columbic loading per stimulated phosphor area (C/cm^2) is limited to ~ 200 [19–21]. The luminescent brightness increases with the current density at low current density for a short term, but the lifetime of the phosphor rapidly decreases at high current density. Therefore, increasing the voltage (hence the kinetic energy of electrons) to improve the brightness of FELs is considered more suitable than increasing the current.

In addition, even at a moderate current level, poor lighting uniformity and low light-spot density, which are common in FEL devices, will result in excessive concentration of current density at local phosphor particles, easily causing phosphor degradation and brightness declination. Generally, to control the lighting uniformity and light-spot density is difficult because electron emission only occurs at the tip of CNTs. Many researchers have synthesized vertically aligned CNT arrays to enhance the uniformity of electron emission using various different methods, but they usually require complicated or expensive processes.

Carbon nanocoils (CNCs) were first synthesized by Motojima and coworkers [22] using TCVD. Pan et al. pointed out that CNCs can be a better candidate for an effective FEL material. Because of the special helical morphology of CNCs, they have sharp edges (graphene edge) all over the surface, which offer numerous electron emission sites on one single CNC [23], and this will significantly increase the light spots on the phosphor. In previous studies [24, 25], it has been demonstrated that the FELs with CNC cathodes exhibited much better light-spot density and uniformity than those with CNT counterparts. The emission from a carbon nanocoil occurs not only at its tip, but also on its top surface, where the electric field is concentrated [25]. These results indicated that CNCs are a great potential material for FEL cathodes.

In this study, we grew CNTs and CNCs separately on 304 stainless steel (304-SS) wires utilizing a poly(styrene-co-NIPAAm)/Pd catalyst (reported in our previous study [26, 27]) as the FEL cathode and compare their FE characteristics. Higher lighting uniformity and light-spot density at lower

current density, as well as greater luminescence efficiency and a longer anode phosphor life, were observed in the FEL with a CNC cathode.

2. Experimental

The substrates used for the FEL cathodes were 304-SS wires with a length of 6 cm and a diameter of 1 mm. The substrate was first cleaned with acetone and ultrasonicated for 30 min. The substrate surface was then roughened by sand blasting with 220-grit sands. Before TCVD, Pd catalyst was deposited on the wire substrates by dipping the wires into a poly(styrene-co-NIPAAm)/Pd solution (see [26, 27] for the details of preparation) and then drying at 80°C in air. Figure 1 shows a schematic of cathode preparation. The wires were placed at the center of a quartz tube, which was heated by a furnace and equipped with a gas-flow controlling system. Subsequently, 5 sccm of acetylene, 100 sccm of argon, and 20 sccm of hydrogen were introduced into the furnace as the carbon source, carrier gas, and reductive gas, respectively.

To fabricate separately the two different types of electron emitters, two process temperatures— 600 and 800°C —were used. A heating ramp lasting for 30–40 min was used to reach the desired process temperature, and acetylene was introduced into the reaction tube for 0–30 min. After cooling the reaction system to room temperature, CNC or MWCNT cathode filaments were obtained. The morphologies of the cathodes were examined using a field emission scanning electron microscope (FE-SEM) (model: JEOL JSM-7600F) and a transmission electron microscope (TEM) (model: FEI Tecnai F30).

The bulb-type FE anode adopted in this study is shown in Figure 1. The diameter of the glass bulb was 6 cm, and the lower hemisphere of the inner surface was coated with an aluminum film. 10 g of P22 phosphor, 9.8 g of butyl acetate, and 0.25 g of ethyl cellulose (EC) were mixed together to form the phosphor slurry, which was then coated on the aluminum film to act as the anode. Then the anode with the phosphor slurry was baked at 500°C to remove the butyl acetate and EC.

A cathode filament was fused with the glass bulb-type anode and pumped to a 3×10^{-6} Torr vacuum to form an FEL bulb. The FEL bulb was tested in a vacuum chamber at high voltages (0–8 kV). The characteristics for the FELs with two different cathode materials, including their current density versus applied voltage and emission uniformity, were investigated. Also, the performances of anode phosphor for the FELs with the two different cathode materials were also evaluated.

3. Results and Discussion

Figures 2 and 3 show the SEM images with various magnifications for the two distinct types of carbonaceous materials synthesized on Pd-nanoparticle-containing substrate wires at the two process temperatures. MWCNTs and CNCs were synthesized in the samples processed at 800 and 600°C , respectively. Figures 2(a)–2(c) show the MWCNTs grown on 304-SS for various growth times: 5, 8, and 10 min.

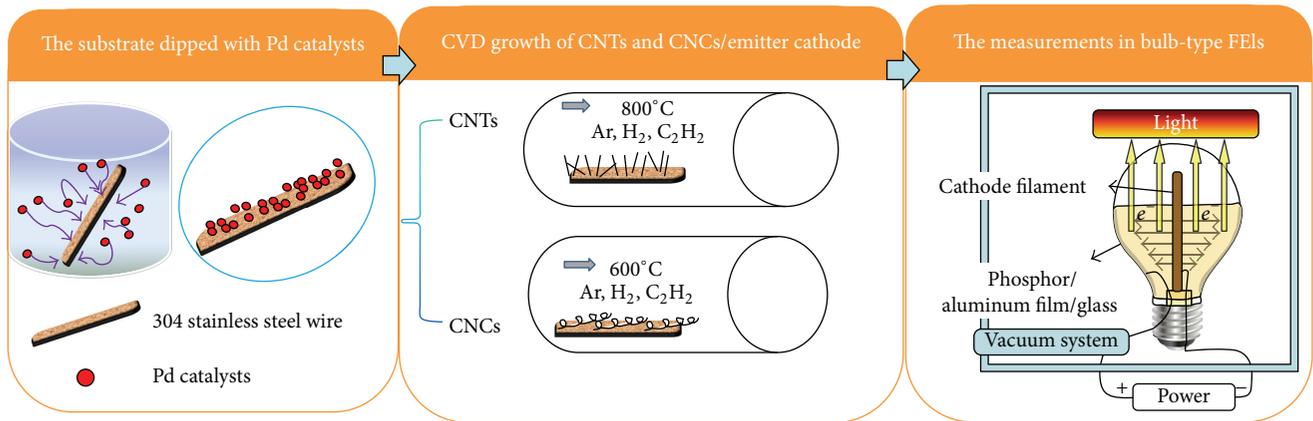


FIGURE 1: Schematic depicting the experimental process for FEL cathode preparation and device fabrication: dip coating of Pd catalysts; TCVD growth of MWCNTs and CNCs; the assembly of a bulb FEL and the FE measurements.

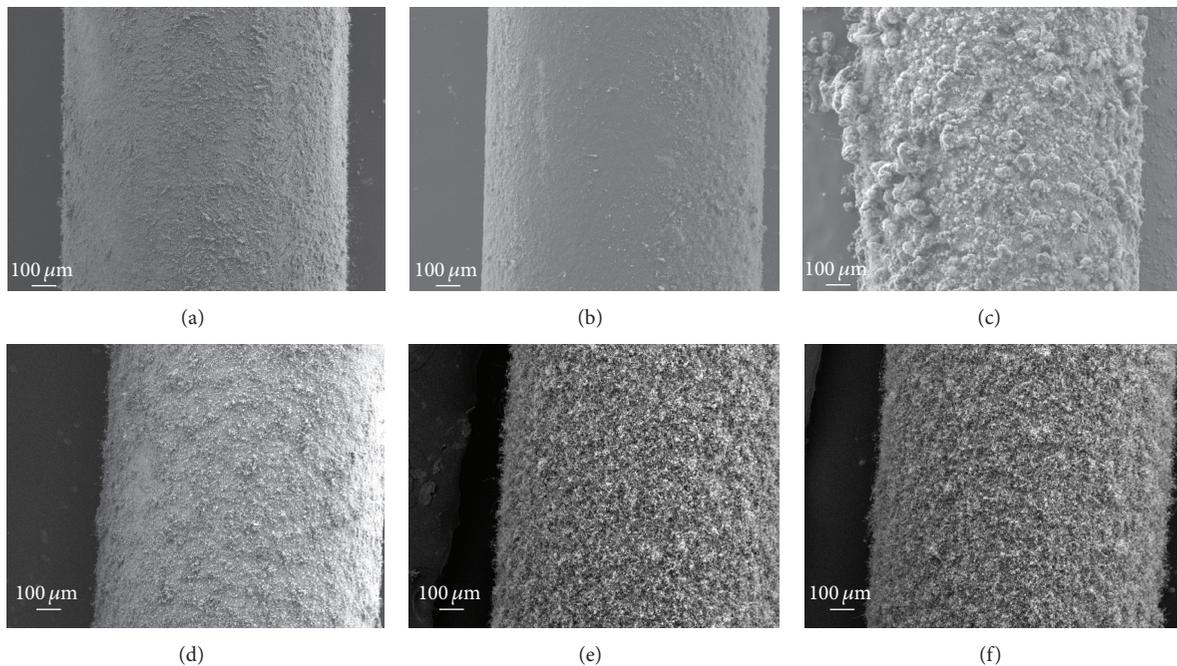


FIGURE 2: SEM images of MWCNT cathode filaments grown for various periods of time: (a) 5, (b) 8, and (c) 10 min and CNC cathode filaments grown for various periods of time: (d) 10, (e) 20, and (f) 30 min.

Figures 2(d), 2(e), and 2(f) show the CNCs grown on 304-SS for 10, 20, and 30 min, respectively. The reason we grew CNTs and CNCs with different periods is that the growth rates of CNTs and CNCs are quite different. Proper lengths of CNTs or CNCs are needed to achieve good field emission efficiency, so the ranges for their synthesis time for a better field emission effect are different. For example, as shown in Figures 2(a) and 2(c), an uneven CNT film was obtained for growth times of 5 and 10 min. The optimum growth time for MWCNTs was about 8 min at 800°C. In contrast, the optimum growth time for the CNCs prepared at 600°C was about 20 min, as revealed in Figures 2(d)–2(f). So, for the subsequent research including the FE measurements and material analysis, the growth times of MWCNT and CNC cathode filaments were fixed at 8 and 20 min, respectively.

According to Baker's hypothesis [28], the decomposition of the carbon source and the diffusion of carbon atoms in the catalyst involve thermally activated reactions that obey the Arrhenius equation, so they are very sensitive to the reaction temperature. In Figures 3(a) and 3(c), acetylene decomposed quickly at 800°C and the fast diffusion and high deposition rate of these carbon atoms resulted in the formation of MWCNTs. The reason is that, at higher diffusion rates, the diffusion of carbon atoms became increasingly isotropic, and their precipitation rates on various catalyst planes were almost identical, leading to the uniform growth of CNTs. In contrast, at 600°C acetylene decomposed slowly and the diffusion of carbon atoms was not only slow but also anisotropic, resulting in the formation of a coiled or helical structure in Figures 3(b) and 3(d). In our previous work [29], carbonaceous materials

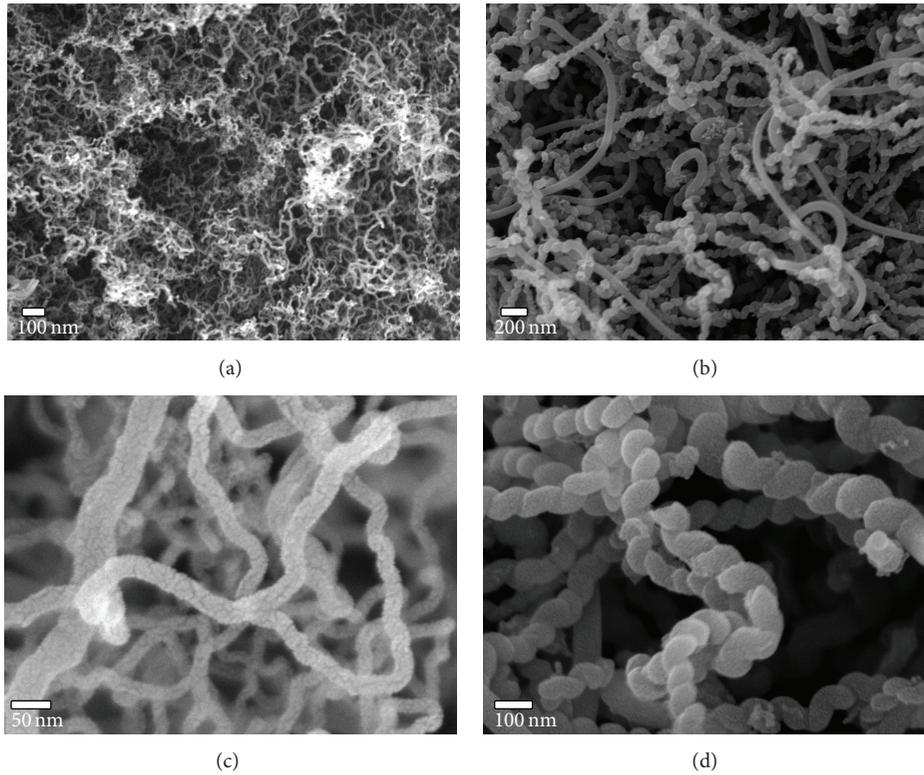


FIGURE 3: SEM images of carbon nanomaterials grown at different temperatures in low magnification, (a) 800°C and (b) 600°C, and in high magnification, (c) 800°C and (d) 600°C.

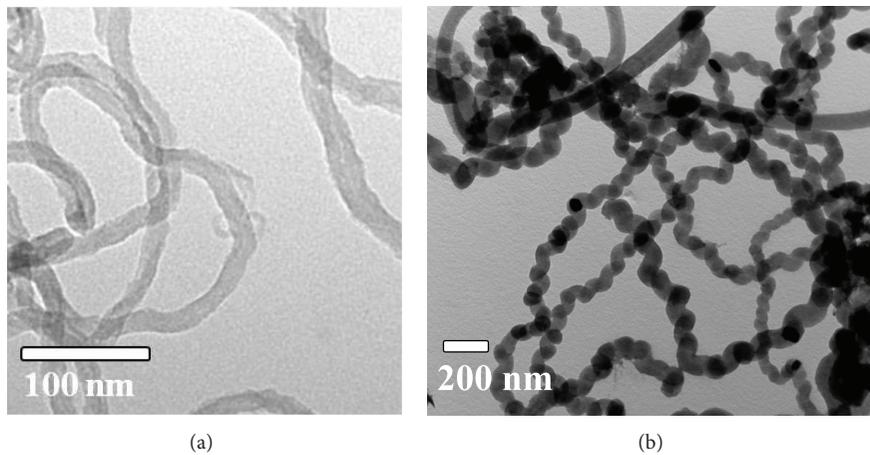


FIGURE 4: TEM images of the (a) MWCNTs and (b) CNCs.

synthesized on Pd-nanoparticle-containing substrate wires at various temperatures (500–800°C) have been studied. The results showed that CNCs and MWCNTs were the major synthesized carbonaceous products at 600 and 800°C, respectively, using our Pd catalysts. Similar carbon products were synthesized using Pd catalysts by Nitze et al. [30] and Segura et al. [31]. These observations indicated that the growth temperature determines the morphology of carbon nanostructures. So the growth temperatures of MWCNT and CNC cathode filaments were fixed at 800°C and 600°C, respectively, in this research.

The TEM images of the MWCNTs and CNCs synthesized in this study are shown in Figure 4. The MWCNTs grown at 800°C had a hollow structure and smaller diameters of 20–50 nm as shown in Figure 4(a). By contrast, in Figure 4(b) the CNCs grown at 600°C showed a solid amorphous helical structure and had considerably larger diameters of 80–150 nm.

Figure 5 shows the I - V curves for the FELs with (a) MWCNT and (b) CNC cathode filaments. The FE I - V curves were measured in a vacuum chamber using a bulb-type anode and a CNC or MWCNT filament cathode. The FE currents

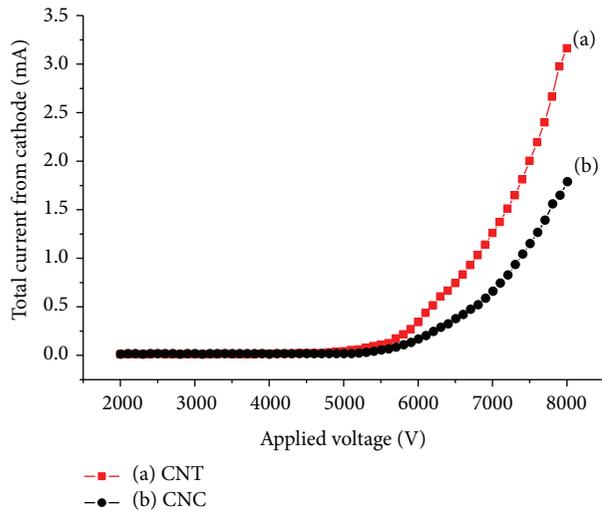


FIGURE 5: I - V curves for the FELs with (a) MWCNT and (b) CNC cathodes.

at a voltage of 8 kV with MWCNT and CNC cathodes were 3.2 and 1.7 mA, respectively. The current emitted from the MWCNT cathode filament was considerably higher than that from the CNC counterpart. This is reasonable because MWCNTs have a higher aspect ratio and hence a lower turn-on electric field than CNCs.

Furthermore, Figures 6(a) and 6(b) show the photos of FELs in operation (operated at dc 8 kV) using the same (a) MWCNT and (b) CNC cathode filaments in Figure 5 ((a) and (b)), respectively. It reveals that the MWCNT cathode FEL had much poorer lighting uniformity (see Figure 6(a)) despite its higher FE current. In contrast, Figure 6(b) shows that the CNC cathode FEL was brighter and had excellent bright spot density and uniformity, which can be attributed to the numerous emission sites on a single CNC, as opposed to the only emission site at the tip of a MWCNT.

In addition, Pan et al. [23] have pointed out that 5-ring or 7-ring carbon bond defects in the nanocoil-structure can serve as the FE sites (electrons are emitted from these points). Compared with a CNT of the same length, a CNC has considerably more FE sites and efficiency [24, 32]. In accordance with Pan's study, our study showed that the CNC cathode FEL was brighter than the CNT one and had excellent lighting-spot density and uniformity, which can be attributed to the numerous emission sites on the single CNC, as opposed to the only one emission site at the tip of a MWCNT. According to the measurements with an integrating sphere, the best luminous efficiency from our CNC cathode filament was as high as 75 lm/W.

For P22, a higher electron kinetic energy and hence a higher working voltage are needed to achieve a high CL efficiency, but this will be detrimental for exceedingly high emission current density. In high current density operation with intense electron bombardment, the phenomenon of Coulombic damage and charge accumulation were quite severe since for the P22 phosphors the maximum Coulombic loading per stimulated phosphor area (C/cm^2) is limited to

$\sim 200 C/cm^2$ [19–21]. Thus if we raise the current to improve the brightness, the phosphor would be damaged more quickly and so the number of bright spots and the luminous efficiency would decay faster.

Moreover, after 1 h of operation the FEL with the MWCNT cathode showed evident yellowing of the phosphor (Figure 6(c)) due to the much higher FE current. To make the situation even worse, this higher current converged on the much smaller area of the sparse bright spots on the phosphor, as shown in Figure 6(a). The high-density electric bombardment on the anode caused fast degradation of the P22 phosphor, which was evidenced by the yellowing. The CNC cathode FEL, in contrast, showed no clear sign of phosphor degradation (Figure 6(d)).

Because the MWCNTs have lower turn-on and threshold voltages than our CNCs, MWCNTs tend to emit higher current density than CNCs at the same operation voltage. In addition, the total bright spot areas on the anode for the CNC FEL were much larger due to the numerous emission sites per CNC. Therefore the Coulombic loading (C/cm^2) on the phosphor can be significantly lower in the CNC FEL. To quantitatively estimate this effect, the actual loading current density on the anode versus the applied voltage (J - V curve) was calculated by dividing the current by the total bright spot area, and the result is shown in Figure 7. The total bright spot areas calculated by the software ImageJ were 49.6 and 93.7% of the anode area for Figures 6(a) and 6(b), respectively. Evidently, the loading current density can be significantly reduced—from 0.23 to 0.03 mA/cm^2 at 8 kV—by replacing the MWCNTs with CNCs. In this work, for P22, the phosphor life estimated from the current density can reach about 810 h for the CNC cathode FEL, while for the MWCNT cathode FEL it is only about 115 h. Therefore, an operation regime at low emission current density, rather than high emission current density, is preferred because it leads to higher lighting efficiency and longer life of the anode phosphors.

To reveal the damage on the phosphors, the SEM morphologies of the phosphor for the FELs with (a) the MWCNT cathode (high current density) and (b) the CNC cathode (low current density) after 1 h of operation were displayed in Figure 8. The phosphor particle in Figure 8(a) (the MWCNT cathode FEL) had a severely roughened surface morphology due to the numerous eroded defects. In comparison, the phosphor in Figure 8(b) (the CNC cathode FEL) showed no sign of morphological changes. We think the eroded defects came from the electron bombardment at high current density. High-energy electron bombardment can produce changes in the surface chemical composition on the ZnS phosphors [18, 33] and may also create a nonluminescent layer on the surface of the phosphor.

The changes in the surface chemical composition on the ZnS phosphors can be analyzed with electron spectroscopy for chemical analysis (ESCA). Figure 9 shows the $S_{2p_{3/2}}$ (Figure 9(a)) and $Zn_{2p_{3/2}}$ (Figure 9(b)) photoelectron spectra for the FELs with (A) the MWCNT cathode (high current density) and (B) the CNC cathode (low current density) after 1 h of FE operation. After the high current density electron bombardment (curve (A)), the sulfur signals (at about 152 eV)

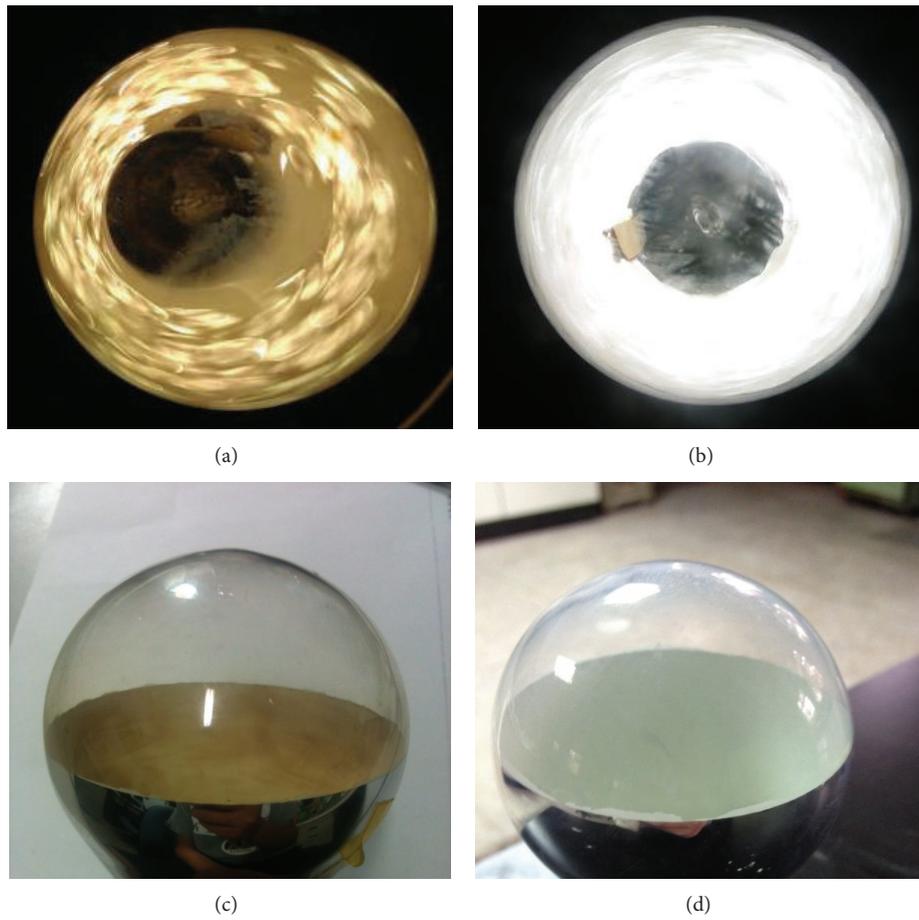


FIGURE 6: Top: FELs with (a) MWCNT and (b) CNC cathodes in operation. Bottom: phosphor on the anodes after 1 h of FE measurement for FELs with (c) MWCNT and (d) CNC cathodes.

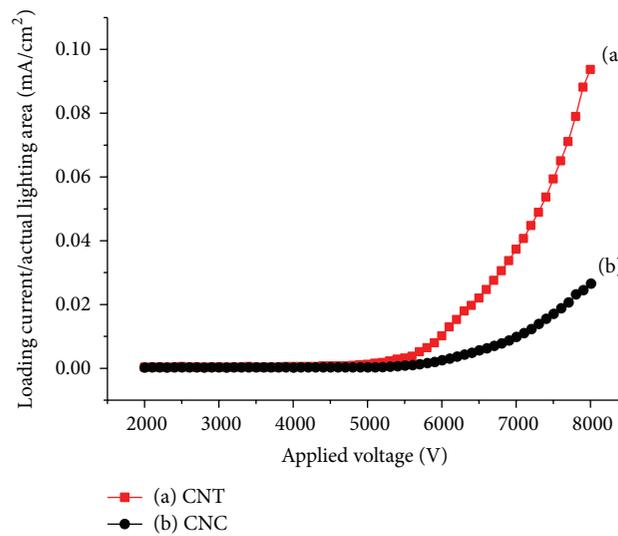


FIGURE 7: J - V curves for FELs with (a) MWCNT and (b) CNC cathodes, where J is the averaged loading current density on the anode.

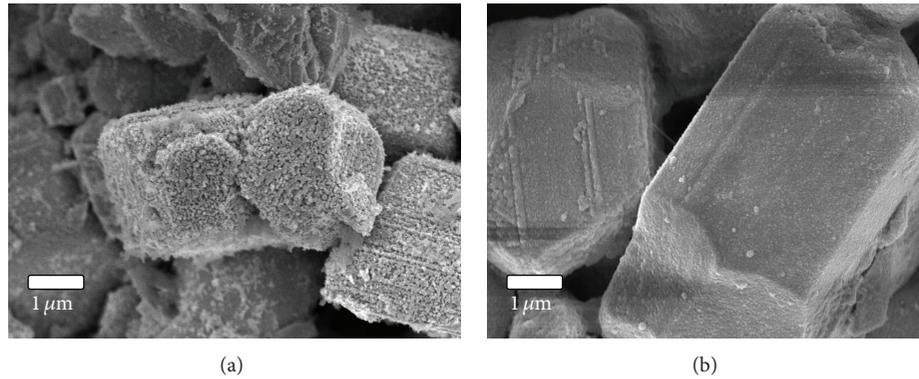


FIGURE 8: SEM morphologies of phosphor for the FELs with (a) MWCNT and (b) CNC cathodes after 1 h of FE operation.

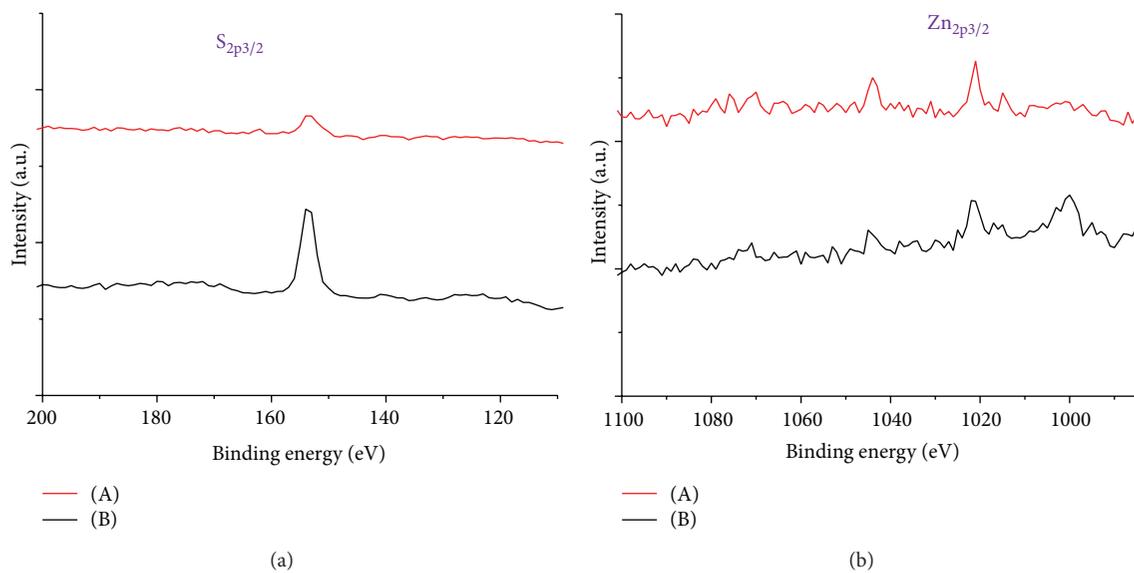


FIGURE 9: ESCA $S_{2p_{3/2}}$ (a) and $Zn_{2p_{3/2}}$ (b) photoelectron spectra of P22 phosphor for FELs with (A) MWCNT and (B) CNC cathodes after 1 h of FE operation.

decreased very obviously. The work in [21] and [33] indicated that sulfur was severely depleted from ZnS on the phosphor surface. The phenomenon is not observed in the low current density CNC cathode FEL. It suggests that using CNC as the cathode can effectively decelerate the degradation of P22 phosphors.

4. Conclusions

In this paper, MWCNTs and CNCs were separately synthesized by TCVD at growth temperatures of 800 and 600°C, respectively, using nanosized Pd catalysts. The film uniformity can be optimized by adjusting the growth time. We successfully fabricated high-uniformity bulb-type FELs using CNCs on a 304-SS wire as field emitters. The P22 phosphor prefers high-voltage and low current density operation. Our results showed that the best luminous efficiency from our FEL with the CNC cathode can reach 75 lm/W at an applied DC voltage of 8 kV and low loading current density (on the anode) of 0.03 mA/cm². For P22, the phosphor life estimated from the current density can reach about 810 h for the CNC

cathode FEL, as opposed to 115 h for the MWCNT cathode counterpart. Our results showed that using CNC as the FE cathode material can effectively decelerate the degradation of P22 phosphors.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Authors' Contribution

Nen-Wen Pu and Kun-Ju Chung contributed equally to this work.

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References

- [1] R. H. Fowler and L. Nordheim, "Electron emission in intense electric fields," *Proceedings of the Royal Society of London Series A*, vol. 119, no. 781, pp. 173–181, 1928.
- [2] N. S. Lee, D. S. Chung, I. T. Han et al., "Application of carbon nanotubes to field emission displays," *Diamond and Related Materials*, vol. 10, no. 2, pp. 265–270, 2001.
- [3] J. E. Jung, Y. W. Jin, J. H. Choi et al., "Fabrication of triode-type field emission displays with high-density carbon-nanotube emitter arrays," *Physica B*, vol. 323, no. 1–4, pp. 71–77, 2002.
- [4] F. G. Zeng, C. C. Zhu, W. Liu, and X. Liu, "The fabrication and operation of fully printed Carbon nanotube field emission displays," *Microelectronics Journal*, vol. 37, no. 6, pp. 495–499, 2006.
- [5] A. A. Kuznetsov, S. B. Lee, M. Zhang, R. H. Baughman, and A. A. Zakhidov, "Electron field emission from transparent multiwalled carbon nanotube sheets for inverted field emission displays," *Carbon*, vol. 48, no. 1, pp. 41–46, 2010.
- [6] Y. C. Choi, J. W. Lee, S. K. Lee et al., "The high contrast ratio and fast response time of a liquid crystal display lit by a carbon nanotube field emission backlight unit," *Nanotechnology*, vol. 19, no. 23, Article ID 235306, 2008.
- [7] Y. Zhang, S. Z. Deng, N. S. Xu, and J. Chen, "Fully sealed carbon nanotube flat-panel light source and its application as thin film transistor-liquid-crystal display backlight," *Journal of Vacuum Science and Technology B: Microelectronics and Nanometer Structures*, vol. 26, no. 3, pp. 1033–1037, 2008.
- [8] N. Y. Bae, W. M. Bae, A. N. Ha, M. Nakamoto, J. Jang, and K. C. Park, "Low-voltage driven carbon nanotube field emission lamp," *Current Applied Physics*, vol. 11, no. 4, pp. S86–S89, 2011.
- [9] H. S. Yoo, W. Y. Sung, S. J. Yoon, Y. H. Kim, and S. K. Joo, "Novel triode-type field emission arrays and appropriate driving method for flat lamp using carbon nanofibers grown by plasma enhanced chemical vapor deposition," *Japanese Journal of Applied Physics*, vol. 26, no. 7, p. 4381, 2007.
- [10] L. Wei, X. Zhang, B. Wang et al., "A stable field-emission light source with ZnO nanoemitters," *IEEE Electron Device Letters*, vol. 29, no. 5, pp. 452–455, 2008.
- [11] X.-X. Zhang and C.-C. Zhu, "Field-emission lighting tube with CNT film cathode," *Microelectronics Journal*, vol. 37, no. 11, pp. 1358–1360, 2006.
- [12] S. Wang, X. Calderon, R. Peng, E. C. Schreiber, O. Zhou, and S. Chang, "A carbon nanotube field emission multipixel X-ray array source for microradiotherapy application," *Applied Physics Letters*, vol. 98, no. 21, Article ID 213701, 2011.
- [13] H.-C. Wu, M.-J. Youh, W.-H. Lin et al., "Fabrication of double-sided field-emission light source using a mixture of carbon nanotubes and phosphor sandwiched between two electrode layers," *Carbon*, vol. 50, no. 13, pp. 4781–4786, 2012.
- [14] Y. Saito, K. Hamaguchi, R. Mizushima et al., "Field emission from carbon nanotubes and its application to cathode ray tube lighting elements," *Applied Surface Science*, vol. 146, no. 1, pp. 305–311, 1999.
- [15] J.-M. Bonard, T. Stöckli, O. Noury, and A. Châtelain, "Field emission from cylindrical carbon nanotube cathodes: possibilities for luminescent tubes," *Applied Physics Letters*, vol. 78, no. 18, pp. 2775–2777, 2001.
- [16] J. X. Huang, J. Chen, S. Z. Deng, J. C. She, and N. S. Xu, "Field-emission fluorescent lamp using carbon nanotubes on a wire-type cold cathode and a reflecting anode," *Journal of Vacuum Science and Technology B: Microelectronics and Nanometer Structures*, vol. 26, no. 5, pp. 1700–1704, 2008.
- [17] W. Fu, P. Liu, J. Tang, L. Liu, and S. Fan, "Spherical field emission cathode based on carbon nanotube paste and its application in luminescent bulbs," *Journal of Vacuum Science and Technology B*, vol. 26, no. 4, pp. 1404–1406, 2008.
- [18] J. S. Sebastian, H. C. Swart, T. A. Trottier, S. L. Jones, and P. H. Holloway, "Degradation of ZnS field-emission display phosphors during electron-beam bombardment," *Journal of Vacuum Science and Technology A: Vacuum, Surfaces and Films*, vol. 15, no. 4, pp. 2349–2353, 1997.
- [19] L. E. Tannas, *Flat-Panel Displays and CRT's*, Van Nostrand Reinhold, New York, NY, USA, 1982.
- [20] T. Hase, T. Kano, E. Nakazawa, and H. Yamamoto, "Phosphor materials for cathode-ray tubes," *Advances in Electronics and Electron Physics*, vol. 79, pp. 1819–1823, 1990.
- [21] S. Itoh, T. Kimizuka, and T. Tonegawa, "Degradation mechanism for low voltage cathodoluminescence of sulfide phosphors," *Journal of the Electrochemical Society*, vol. 136, no. 6, pp. 1819–1823, 1989.
- [22] S. Motojima, M. Kawaguchi, K. Nozaki, and H. Iwanaga, "Growth of regularly coiled carbon filaments by Ni catalyzed pyrolysis of acetylene, and their morphology and extension characteristics," *Applied Physics Letters*, vol. 56, no. 4, pp. 321–323, 1990.
- [23] L. Pan, T. Hayashida, M. Zhang, and Y. Nakayama, "Field emission properties of carbon tubule nanocoils," *Japanese Journal of Applied Physics*, vol. 40, no. 3B, pp. L235–L237, 2001.
- [24] Z. Zhang, P. He, Z. Sun et al., "Growth and field emission property of coiled carbon nanostructure using copper as catalyst," *Applied Surface Science*, vol. 256, no. 14, pp. 4417–4422, 2010.
- [25] S. Hokushin, L. Pan, Y. Konishi, H. Tanaka, and Y. Nakayama, "Field emission properties and structural changes of a stand-alone carbon nanocoil," *Japanese Journal of Applied Physics*, vol. 46, no. 23, pp. L565–L567, 2007.
- [26] W.-D. Chen, Y. Sung, C.-P. Chang, Y.-C. Chen, and M.-D. Ger, "The preparation of thermo-responsive palladium catalyst with high activity for electroless nickel deposition," *Surface and Coatings Technology*, vol. 204, no. 14, pp. 2130–2135, 2010.
- [27] Y. M. Liu, N. W. Pu, W. D. Chen et al., "Low temperature fabrication of Ni-P metallic patterns on ITO substrates utilizing inkjet printing," *Microelectronics Reliability*, vol. 52, no. 2, pp. 398–404, 2012.
- [28] R. T. K. Baker, M. A. Barber, P. S. Harris, F. S. Feates, and R. J. Waite, "Nucleation and growth of carbon deposits from the nickel catalyzed decomposition of acetylene," *Journal of Catalysis*, vol. 26, no. 1, pp. 51–62, 1972.
- [29] K. J. Chung, N. W. Pu, M. Y. Youh et al., "Improvement of field-emission-lamp characteristics using nitrogen-doped carbon nanocoils," *Diamond & Related Materials*, vol. 53, pp. 1–10, 2015.
- [30] F. Nitze, E. Abou-Hamad, and T. Wgberg, "Carbon nanotubes and helical carbon nanofibers grown by chemical vapour deposition on C60 fullerene supported Pd nanoparticles," *Carbon*, vol. 49, no. 4, pp. 1101–1107, 2011.
- [31] R. Segura, A. Tello, G. Cardenas, and P. Häberle, "Synthesis of carbon nanotubes and nanofibers by decomposition of acetylene over a SMAD palladium catalyst," *Physica Status Solidi A*, vol. 204, no. 2, pp. 513–517, 2007.

- [32] S. Hokushin, L. Pan, Y. Konishi, H. Tanaka, and Y. Nakayama, "Field emission properties and structural changes of a stand-alone carbon nanocoil," *Japanese Journal of Applied Physics, Part 2: Letters*, vol. 46, no. 20-24, pp. L565–L567, 2007.
- [33] H. C. Swart, J. S. Sebastian, T. A. Trottier, S. L. Jones, and P. H. Holloway, "Degradation of zinc sulfide phosphors under electron bombardment," *Journal of Vacuum Science and Technology A*, vol. 14, no. 3, pp. 1697–1703, 1996.



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