MEET8-3
Invited

Carbon Nanotube Based Cold Cathode Electron Beam (C-beam) for Lithography Application

Kyu Chang Park[1] and Sung Tae Yoo[1]

kyupark@khu.ac.kr
[1]Department of Information Display, Kyung Hee University,
Dongdaemun-gu, Seoul, 02447, Korea
Keywords: Carbon Nanotube, Electron emission, Ultraviolet, Lighting

ABSTRACT

Here, ultraviolet (UV) light in various wavelength ranges was developed with a carbon nanotube (CNT)-based cold cathode electron beam (C-beam). The UV properties are related to the electron emission properties of C-beam and the wide bandgap anode materials. The generation of various UV light from UVA to UVC was confirmed. With the UV light, we applied for photo-lithography process to manufacture displays. We confirmed that C-beam technology would be an alternative source of UV lighting.

1 Introduction

Cold cathode electron beams with a variety of electron emitters are being investigated for the next generation of vacuum nano-electronic applications. Among them, ultraviolet (UV) generation using a carbon nanotube (CNT) based cold cathode electron beam (C-beam) will be used in various industries. UV light, which is classified as UVA (400-315 nm), UVB (315-280 nm), UVC (280-200 nm), VUV (200-100 nm), and EUV (100-10 nm), is used for various purposes depending on the photon energy. UV light is mostly used for curing, sterilization and photo-lithography for display and semiconductor manufacturing. Currently, it can be applied to selective sterilization in situations where humanity around the world is threatened by virus infection caused by COVID-19. UVC light below 230 nm wavelength cannot penetrate mammalian cells, but can penetrate much smaller microorganisms (<1 μm) such as viruses and bacteria [1]. Using this UVC light, it is possible to selectively sterilize airborne infectious diseases without damaging the mammalian skin. In addition, the application of UV light as an exposure technology makes a large-area display, and EUV light is leading the development of the latest semiconductors.

We developed the UV lighting with various wavelengths by irradiating C-beam on various bandgap energy materials such as SrB_4O_7:Eu phosphor, Zn_2SiO_4, sapphire, and AlGaN multi-quantum wells [2]-[5].

UV light with various peak wavelengths in a wide wavelength range from 363 nm to 208 nm was created with C-beam irradiation technology. We will discuss the fabrication of the anode materials, the performance of UV light according to the C-beam irradiation conditions, the C-beam structure, electron emission characteristics, and C-beam for lithography.

2 Experiment

C-beam has CNT emitters as core components as electron sources and consists of a mesh gate for electron extraction and ceramic insulation between gate and cathode. CNT emitters grown on a silicon wafer using DC-PECVD feeding acetylene and ammonia gas and DC bias are shown in Fig. 1. SEM image of a CNT emitter with a perfectly vertically aligned structure, Fig. 1(a) is a representation of one island, and Fig. 1(b) is an enlarged image. Since the CNT emitters were fabricated through a photo-lithography process, they were selectively grown where desired.

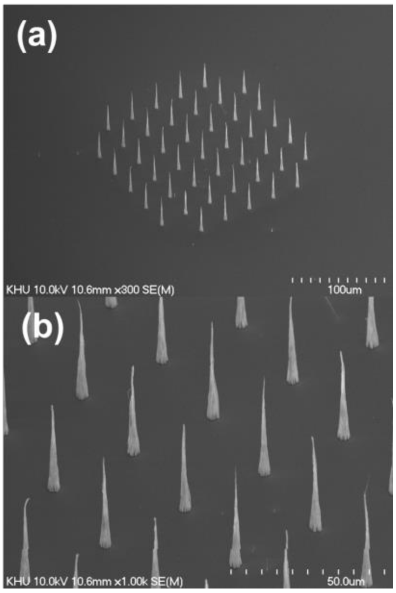

Fig. 1. SEM image of CNT emitters for UV lighting. (a) One island and (b) magnified photo of CNT emitters.

Schematic of UV generation is depicted in Fig. 2. As the anode material, various wide bandgap materials have been used to generate UV light. For the anode electrode, an aluminum electrode was fabricated using a thermal evaporation technique. The current and electrons emitted from the CNT emitter are controlled by the gate bias voltage, and the high anode voltage causes electrons to collide with the anode material and generate

UV light by excitation and relaxation. Electron emission characteristics of CNTs depend on the island design and number of island arrays. Also, density of CNTs strongly related on the electron emission current density and threshold voltage.

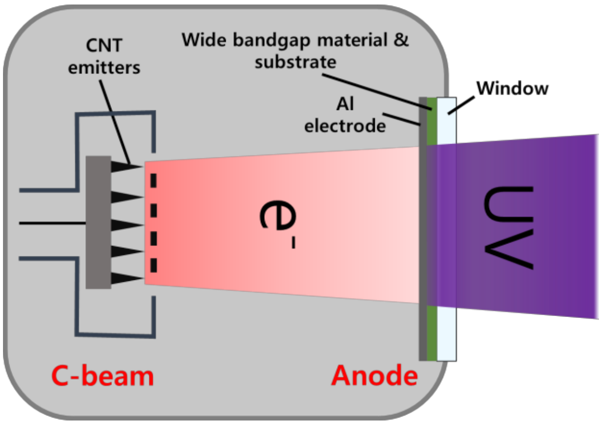

Fig. 2. Schematic of UV lighting with carbon nanotube-based cold cathode electron beam (C-beam) irradiation.

3 Results

UV lighting characteristics depend on the C-beam irradiation conditions and anode materials. When electrons were irradiated to wide bandgap materials such as SrB_4O_7:Eu phosphor, Zn_2SiO_4, Sapphire, and AlGaN MQWs, it was reported that the wavelength from UVA to UVC was changed [2]-[5]. In addition, changes in UV intensity and characteristics were confirmed with C-beam irradiation conditions.

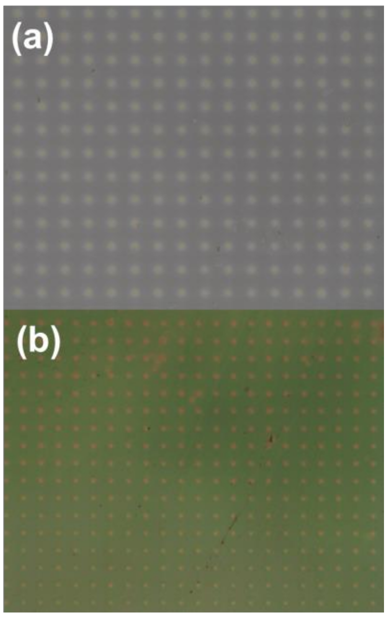

Fig. 3. Optical images after lithography using UVC light with C-beam. (a) 10 μm and (b) 3 μm-sized dot photographs.

Fig. 3 shows photo-lithography images with the UVC light. Peak wavelength of UVC light is 251 nm and used anode with sapphire wafer. The irradiation condition on anode with is voltage of 10 kV, and current of 0.6 mA. The optical images show after lithography of (a) a 10 μm-sized dot and (b) a 3 μm-sized dot. The irradiance of UV light depends on the anode bias and current. Detail of lithography with the UV light would be presented.

4 Conclusions

In summary, we developed UV lighting of various wavelengths using CNT emitters as field emitters. The wide bandgap anode is irradiated with C-beam to successfully generate UV light from UVA to UVC, and its characteristics depend on the anode materials and C-beam irradiation conditions. In addition, the lithography using UVC with C-beam was confirmed, and based on this, the flat UV light source produced by C-beam irradiation is expected to be applied to many applications in optical cleaning, sterilization, medical fields, and advanced lithography.

References

[1] M. Buonanno, D. Welch, I. Shuryak, and D. J. Brenner, “Far-UVC light (222 nm) efficiently and safely inactivates airborne human coronaviruses,” Sci Rep, Vol. 10, pp. 10285 (2020).

[2] S. T. Yoo, H. I. Lee, and K. C. Park, “363 nm UVA light generation with carbon nanotube electron emitters,” Microelectronic Eng., Vol. 218, pp. 111142 (2019).

[3] S. T. Yoo, H. I. Lee, and K. C. Park, “Optimization of Zn_2SiO_4 Anode Structure for Deep Ultraviolet Generation With Carbon Nanotube Emitters,” IEEE J. Electron Devices Soc., Vol. 7, pp. 735–739 (2019).

[4] S. T. Yoo and K. C. Park, “Sapphire Wafer for 226 nm Far UVC Generation with Carbon Nanotube-Based Cold Cathode Electron Beam (C-Beam) Irradiation,” ACS Omega, Vol. 5, No. 25, pp. 15601–15605 (2020).

[5] S. T. Yoo, B. So, H. I. Lee, O. Nam, and K. C. Park, “Large area deep ultraviolet light of $Al_{0.47}Ga_{0.53}N/Al_{0.56}Ga_{0.44}N$ multi quantum well with carbon nanotube electron beam pumping,” AIP Adv., Vol. 9, No. 7, pp. 075104 (2019).