



Comparison of Electron Emission Characteristics of W and CNT Field Emitter for Microcolumn

ANJLI SHARMA¹, SANJEEV K. KANTH¹, HO SEOB KIM¹, DAE-WOOK KIM¹, SEUNG JOON AHN¹, TAE-SIK OH¹ and YOUNG CHUL KIM^{2,*}

¹Department of Information Display, Sun Moon University, Asan-si, Chungnam-do 31460, Republic of Korea

²Department of Optometry, Eulji University, Seongnam-si, Gyeonggi-do 13135, Republic of Korea

*Corresponding author: E-mail: yckim@eulji.ac.kr

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In a microcolumn, a sharp tungsten tip fabricated through electrochemical etching process is usually used as an electron emitter. However, the process of alignment of the tungsten tip with the extractor aperture is a bottleneck in the assembly of a microcolumn. We have considered both tungsten tip and two dimensionally distributed carbon nanotube emitter as the electron emission source and compared their electron emission characteristics in a microcolumn by assembling test columns.

Keywords: Microcolumn, Field emission, W emitter, CNT emitter.

INTRODUCTION

Since microcolumn was developed in IBM, steady research and efforts have been devoted to improve its structure and performance. Basically a microcolumn is a tiny electron column having simple geometrical structure with the height of about 10 mm and nearly similar lateral size. Due to the small size of the column, the apertures for the electron beam path should be made very small without losing the high quality in its shape, which is compulsory requirement in order to reduce the optical aberrations and to maintain the high performance. The lens electrodes with small (μm size) and high quality apertures can be fabricated by using the MEMS technologies [1-3].

However, the assembly of a microcolumn is still complicated, which is a bottleneck in the production of multiple electron beam system. The most promising advantage of a microcolumn is that the multiple electron beam system can be developed by using it as a basis and the multiple electron beam system can be practically applied for high resolution lithography or inspection by overcoming the drawback of low throughput [4-8].

In a microcolumn, a tungsten (W) field emitter has been usually adopted as an electron emitter. However, the assembly of a microcolumn adopting tungsten emitter is not so easy because of either the long-term stability or the difficulty in the alignment procedure of a tungsten tip and the small source lens aperture. Even though carbon nanotube (CNT) is also used for an electron emitter because of the low turn-on voltage and higher beam current, there still remains the same alignment

problem. In this study, we investigated both tungsten and CNT field emitters and compared their emission characteristics for the application to a microcolumn system.

EXPERIMENTAL

We have fabricated two types of electron emitters; (i) conventional tungsten field emitter and (ii) two-dimensionally distributed carbon nanotube (2D-CNT) emitter. The tungsten field emitter was fabricated by following the electrochemical etching process [9]. In order to fabricate the 2D-CNT emitter, we have cut a Kovar wire (diameter = about 500 μm) and formed a CNT layer on the cross-sectional surface by printing CNT paste.

RESULTS AND DISCUSSION

The typical SEM images of fabricated field emitters are presented in Fig. 1. Fig. 1(a) is the SEM image of tungsten field emitter and (b) is that of a 2D CNT emitter. The white region in Fig. 1(b) corresponds to the cross-sectional area of the Kovar wire and the dark region 2D-CNT area.

At first, two sets of microcolumns have been assembled by adopting these two types of field emitters. We obtained emission current from each microcolumn. Fig. 2 presents the typical I-V curves; (a) tip current obtained from the microcolumn with tungsten field emitter and (b) with 2D-CNT emitter. According to our pre-experiment, a single CNT emitter shows higher than that from a tungsten emitter as expected and reaches a few μA at the same tip voltage, which is not shown here. The emission current from a 2D-CNT emitter is observed

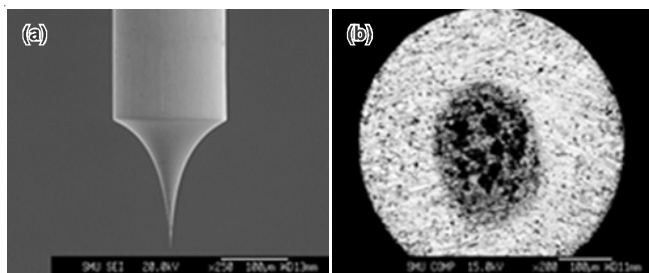


Fig. 1. SEM images of the three types of field emitters. (a) tungsten (W) field emitter, (b) two-dimensionally distributed CNT (2D-CNT) field emitter

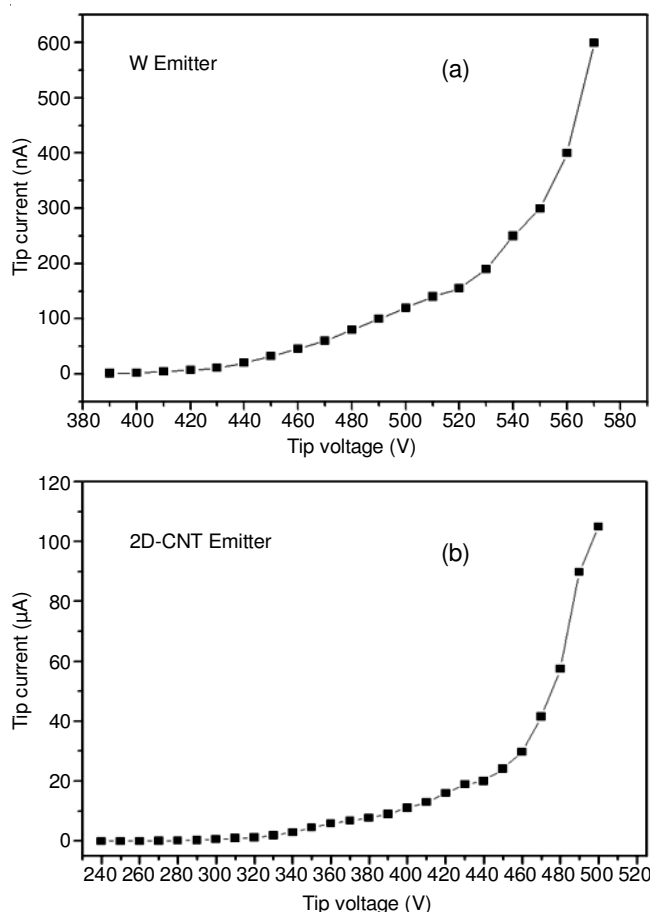


Fig. 2. Comparison of electron current emitted from the field emitters. (a) tungsten field emitter, (b) two-dimensionally distributed CNT field emitter

to be very high current since lots of emitters are activated simultaneously. Normally, the tip current is measured to be several hundred nA in case of tungsten field emitter when tip voltage is about 550 V, while that of 2D-CNT reaches order of about 100 μ A when the potential difference between the emitter and extractor of source lens is about 500 V. The variation of tip current was observed depending on the detailed features of individual tips such as sharpness, tip treatment process, etc.

Though the tip current of single CNT emitter is higher than that of tungsten emitter, the fabrication process of single CNT field emitter is very delicate and the alignment process is difficult also. The advantage of the 2D-CNT emitter is that it can reduce the difficulty in the column assembly procedure. The alignment of field emitter and the source lens aperture is

very easy when we adopt 2D-CNT emitter since the area which 2D-CNT covers is much larger than that of the source lens aperture. However, we cannot ignore the concern that large portion of the electrons emitted from 2D-CNT may not pass through the extractor aperture due to the geometrical structure of this emitter in spite of the higher tip current. Therefore, we did further experiments to check whether we can get enough probe current with this emitter.

We have fabricated four 2D-CNT emitters and assembled 4 different microcolumns by using the emitters and measured both tip emission current and sample current. For simplicity, we designed the microcolumn with relatively larger aperture diameter in source lens system. Usually, in a microcolumn, the aperture diameter of extractor, accelerating electrode and limiting electrode is 2.5, 100 and 2.5 μ m, respectively. Sometimes, the microcolumns designed with three source lens electrodes having relatively larger aperture diameter of 100 μ m have been reported and showed good results in the SEM mode operation [10]. Therefore, we assembled microcolumns based on this design for the simpler assembly of test microcolumns.

Tip current measured from the four microcolumns adopting 2D-CNT emitters are presented in Fig. 3. In this figure, the squares, circles, up-triangles and down-triangles represent the data obtained from microcolumn 1, 2, 3 and 4, respectively. There is no difference in the design of each microcolumn and the variation of the data is thought to be originated from the variation in the components such as lens electrodes, emitter and other geometrical variation occurred during the assemble process. Though some variations are observed, large tip current of 50-100 μ A can be obtained below 1 kV of tip voltage for all the microcolumns by simply replacing the tungsten emitter with 2D-CNT emitters.

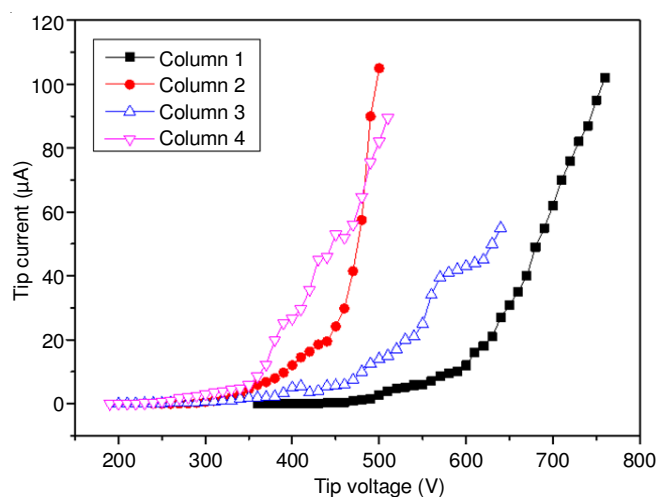


Fig. 3. Tip current measured from the four microcolumns adopting 2D-CNT emitters. The squares, circles, up-triangles and down-triangles are tip current measured from microcolumn 1, 2, 3 and 4, respectively

Probe beam current is more important in the operation of an electron equipment rather than the tip current and the experimentally measured probe beam current (that is, the sample current which was measured at the standard Cu grid sample) is shown in Fig. 4. Sample current of over about 100 nA was

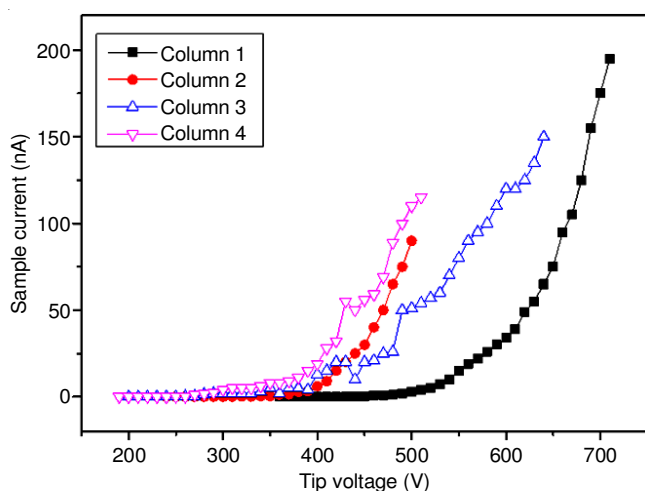


Fig. 4. Sample current measured from the four microcolumns. The squares, circles, up-triangles and down-triangles are sample current measured from microcolumn 1, 2, 3 and 4, respectively

observed for all the four microcolumns at the tip voltage below 1 kV. Even if considering the relatively larger aperture diameters in the source lens, the result of high sample current means that it is worthy of investigating the microcolumn with 2D-CNT emitter.

Fig. 5 shows the ratio of sample current to tip current presented in Fig. 3 and 4. The ratio is in the range of 1×10^{-3} to 3×10^{-3} when the tip voltage is over 450 V and shows similar behaviour for all the columns. The ratio calculated from column 3 and 4 shows rather large fluctuation when the tip voltage is lower than about 550 V and about 400 V for column 3 and 4, respectively and we did not include the data corresponding to this voltage range. The I-V curve features for these two columns do not show the typical behaviour of I-V characteristics of field emission compared with the data obtained from the other two columns. This behaviour is thought to be originated from the uneven distribution of the emitting CNTs at the cross-sectional surface of Kovar wire.

Since the sample current is high and the ratio is typically order of 10^{-3} , the ultimate probe current is expected to exceed

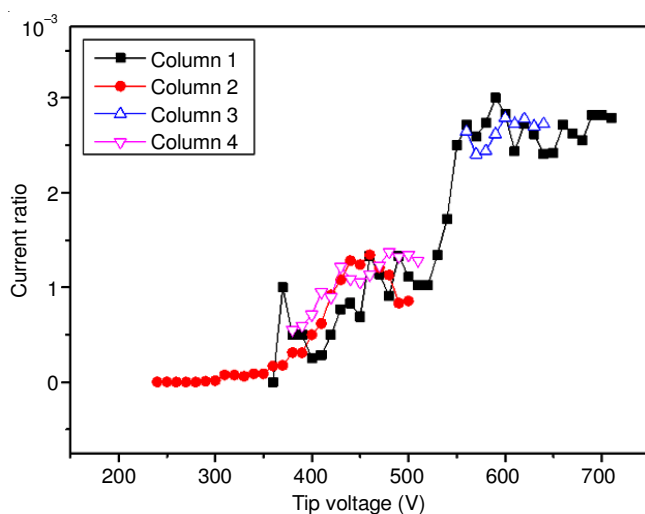


Fig. 5. Ratio of sample current to tip current. The ratio is in the range of 1×10^{-3} to 3×10^{-3} when tip voltage is over 450 V and the trend is similar for all the columns

about 1 nA even though we reduce the electrode diameters. Thus, we tried to obtain SEM images using standard Cu grid sample (1,000 mesh) with microcolumn 2 and the preliminary results are shown in Fig. 6. The images shown in this figure indicate that 2D-CNT can be used as an electron emitter for a microcolumn, which means that we can overcome the complicated alignment problem during the microcolumn assembly process.

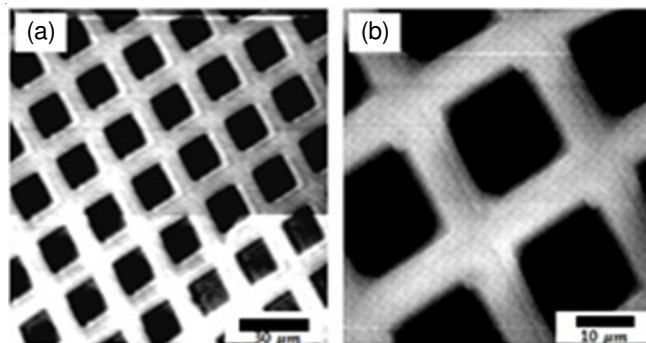


Fig. 6. Typical results of sample current images obtained with 2D-CNT microcolumn using a standard 1,000 mesh Cu grid

Conclusion

We have fabricated both tungsten and 2D-CNT electron emitters and studied their electron emission characteristics in several microcolumns. The emission current of 2D-CNT is observed to be much higher than that of tungsten emitter and the sample current is also measured to be very high. The preliminary results on the electron emission characteristics with four test microcolumns adopting 2D-CNT show that it can be used as a field emitter for a microcolumn, which is expected to reduce the difficulties in the assembly process of a microcolumn.

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