Developments of high brightness cold field emission source for TEM and SEM applications

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1. INTRODUCTION

Cold field emission gun are the brightest electron sources available for transmission and scanning electron microscopes. Due to this very important property in electron microscopy, this technology, which remains almost unchanged since 40 years, could be a suitable choice when using methods which requires a high spatial or temporal coherence of the electron beam, like for EELS, STEM or electron interferometry.

However, some several drawbacks are inherent to CFEG like the stability of the emitted current which, in the most favorable case, decreases by some 10%/hours, the beam noise (standard deviation around 1%), … To tackle these problems, the use of ultra high vacuum, careful high voltage conditioning and flash cleaning of the tip are mandatory.

By using a new carbon cone nanotip (CCnT), we have succeeded to improve considerably the stability of the electron beam with almost no decay during 8 hours, and a standard deviation of the noise lower than 0.5%, which avoids the use of intensive flash cleaning technology. An increase by a factor of 3 to 5 has been also observed in the reduced brightness. Results have been obtained both with high voltage TEM and Butler type low voltage SEM gun.

2. RESULTS

The synthesis of CCnTs was first reported by Jacobsen and Monthioux [1] in 1997. The CCnTs were produced using a catalytic method to create multiwall carbon nanotubes with a diameter of around 5 nm. This was followed by the deposition of pyrolytic carbon onto them, using chemical vapor deposition from a methane carbon source at a temperature of ~1300 °C . The resulting CCnTs exhibit a unique shape with a "large" microfiber segment of few µm in diameter consisting of graphene stacks coarsely concentrically displayed, ended by two smooth carbon cones on each side of the microfiber segment. In order to mount the CCnT onto a FE tip which can be used as a cathode for SEM and TEM sources, we used a FIB-SEM method to select and manipulate them [2,3].

CCnT tips have been first tested as FE cathodes using a standard Butler field emission gun in a commercial FEG Scanning Electron Microscope (Hitachi SU8200) working at 30 kV and equipped with NEG (Non Evaporate Getter) pumping system. The Butler optic is made by an extracting anode with a voltage V1 and the accelerating anode with voltage V0 [4].The tip-anode distance was 10mm. The results presented in the Fig. 1, shows the evolution of the emission current before and after a flash cleaning. After flash cleaning, the emission current appears to be very stable and the noise very small. No decay has been observed during one hour with an emission noise standard deviation less than 0.5% which are good values compare to state of the art CFEG using [310] oriented Tungsten (W) tips for which the decay can be around 15% for one hour with an emission noise standard deviation of 1%.

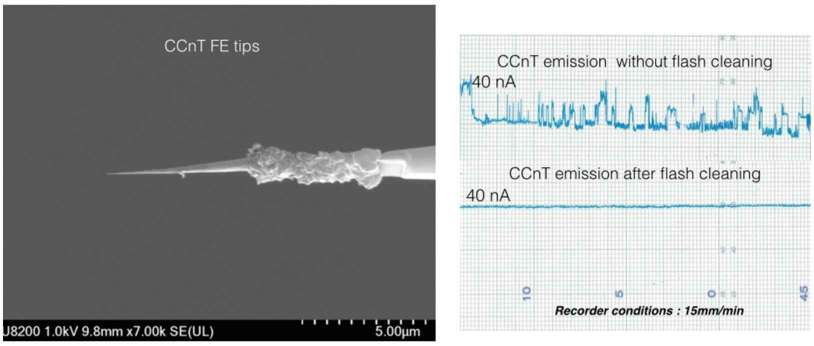

Figure 1. CCnT FE tip used as FE cathode in Hitachi SU8200 with associated emission current

A Hitachi HF-2000 200 kV FE source has been also modified in order to test the CCnT tips capabilities under high voltage environment. We have adjusts the electron optics conditions to maximize the ratio between the probe current on the TEM sample and the emission current of the source [2]. As for the 30 kV SU8200 source, the tip-anode V1 distance was adjusted around 10 mm.

In order to maximize the probe current, the ratio V2/V1 between the Focusing lens voltage V2 and the extracting anode has been adjusted with the help of ray tracing simulations done using the electrostatic simulation software Simion (see Fig. 2) [5]. The simulation reported shows the position of the cross over inside the accelerating tube when setting the standard ratio at 7, as used with regular W FE tips, and an extraction voltage of 380 V. The best illumination condition for CCnT was found tuning the ratio down to 4.5 for which the electron beam was almost parallel at the exit of the gun. Using this condition the first cross-over inside the column, is formed close the back focal plane of the first condensor lens (C1), which maximizes the probe current and minimize the effect of C1 aberrations and therefore optimizes the probe brightness.

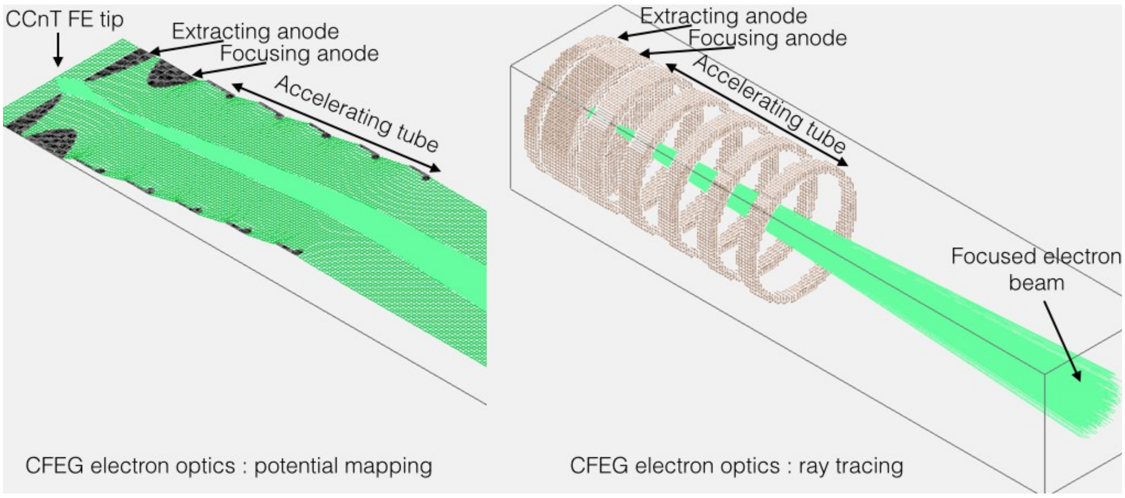

Figure 2. Electron optics simulations of CCnT based CFEG using SIMION

3. CONCLUSION

We aim at developing CCnT FE tips as new sources for TEM and SEM applications. Regarding TEM applications, the performances of the CCnT source need to be investigated more deeply for electron holography and high-resolution purposes to better understand the effect of the tip regarding the spatial coherence of the beam. Current experiments are under progress to determine the coherent current Ic as defined by Krivanek *et al.* [6] and a new measurement of the absolute brightness is also a work in progress.

For SEM applications, the good stability of the CCnT tip with no decay of current during one hour can be a very good advantage for practical applications. The main concern will be to find the correct optical conditions using the standard and simple Butler geometry, which have to be used to maximize the beam brightness. This work is also under progress.

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