SOURCE 2D Simulation for High Resolution Carbon Nanotube Cold Cathode Fabrication

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ABSTRACT

High-resolution electron microscopy requires an electron source with high brightness and resolution. We simulated and fabricated the carbon nanotube (CNT) cold cathode with high resolution. For the simulation, we used SOURCE 2D simulator and fabricated self-focused CNT based electron beam. The beam shows micron scale resolution with optimized self-focused CNT beam design. The beam spot size depends on the various parameters, such as depth, width and driving conditions.

1 INTRODUCTION

Cold cathode electron beam with CNT emitter has robust electrical and mechanical properties. This type of electron beam has recently been applied in electron microscopy. Many groups studied on the source of electrons for high resolution imaging. For the high resolution imaging, electron source requires some parameters such as high current and current density, small beam divergence and small source size. CNTs could be applied as electron source for high-resolution electron microscopy that requires high brightness electron source. [1]

In this study, we fabricate direct grown single free standing CNT emitter which shows superior electron emission properties. The electron emission characteristics compared with SOURCE 2D simulation results for beam design. The software SOURCE for electron sources simulates electron guns, crossover size and location, beam divergence, brightness, current density distribution and electric field distribution. [2] The SOURCE simulation computes the potential distribution and space charge distribution. It computes the potential distribution using the second-order finite element method and uses the Incomplete Choleski Conjugate Gradient (ICCG) method to solve the second-order finite element matrix equation. Optimization of electron beam resolution obtained by the simulation and fabricate high resolution self-focused electron beam with CNT emitters.

2 EXPERIMENT

We fabricated the direct grown single CNT emitter using direct-current plasma-enhanced chemical vapor deposition (DC-PECVD) system and conventional photolithography process. [3] Nickel (Ni) catalytic was sputtered on the Si wafer. After sputtering of Ni, a single dot pattern of 5 μm diameter size was formed on Si wafer through UV photolithography process. Growth of the CNT was proceeded with the gas flow of C_2H_2/NH_3=16/160 sccm and pressure was kept at 1.8 Torr for 90 minutes at 700 ℃. For vertically well-aligned CNT growth, cathode and mesh electrode were biased -600 V and 300 V. The CNT emitter we fabricated is a cone shape with an emitter height of 50 μm, dot diameter of 5 μm. Fig. 1 shows the image of single free standing CNT emitter taken using scanning electron microscope (SEM; Hitachi S-4700).

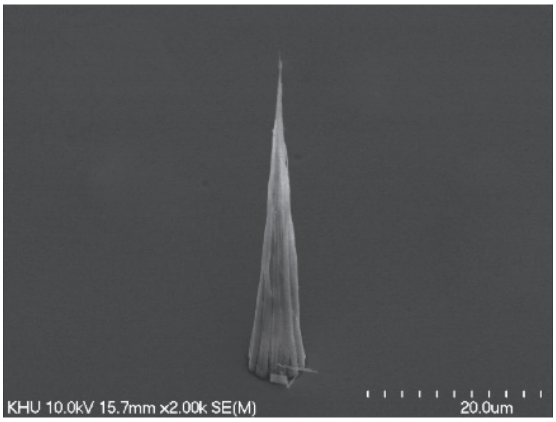

Fig. 1. SEM image of single CNT emitter

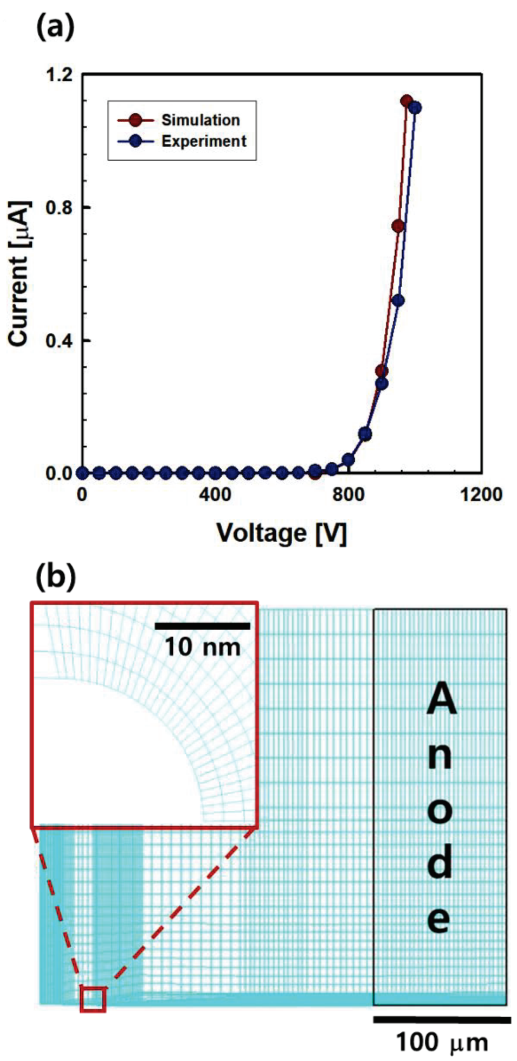

Fig. 2. Simulation results (a) Comparison of the I-V characteristics (b) SOURCE simulation of CNT emitter

3 RESULTS AND DISCUSSION

We fabricated the single free standing CNT emitter and confirmed the emission characteristics of emitter. The experimental result obtained a maximum current of 1.1 μA at 975 V. Fig. 2(a) shows the comparison of the I-V characteristics between the experimental result and simulation. It indicates that experimental and simulation results have similar tendencies. Fig. 2(b) represents the modelling of our CNT emitter. This program can plot the mesh layout. We simulated the same shape of the single CNT emitter we fabricated. The gap between cathode and anode is 250 μm. The inset image is the enlarged view of mesh layout near the CNT cold cathode emitter tip. The radius of CNT emitter tip is 15 nm.

With the SOURCE simulation, we could obtain the cathode current density distribution, the electron beam trajectory, effective electron beam divergence diameter and the beam brightness for electron sources. This simulation computes the potential at each mesh-point, taking space charge effects into account, using the second order finite element method.

We simulated that the single CNT emitter was located at the depth of the hole in a silicon substrate with tens of micrometer. In this structure, the CNT emitter shows focusing effect. In order to get a high resolution beam, the beam trajectory was simulated. Fig. 3 indicates the beam trajectory of electron beam with single CNT emitter in trench structure. The deeper the depth and the larger the hole width, the emitter has the smaller beam divergence diameter. If the depth is greater than 80 μm, the emitter has a sub-micrometer beam divergence diameter, based on simulation. This allows us to obtain the focused beam divergence with trench structure and adjust the diameter of it. High resolution CNT based electron beam made with optimized depth and width of self-focusing holes around CNT emitters.

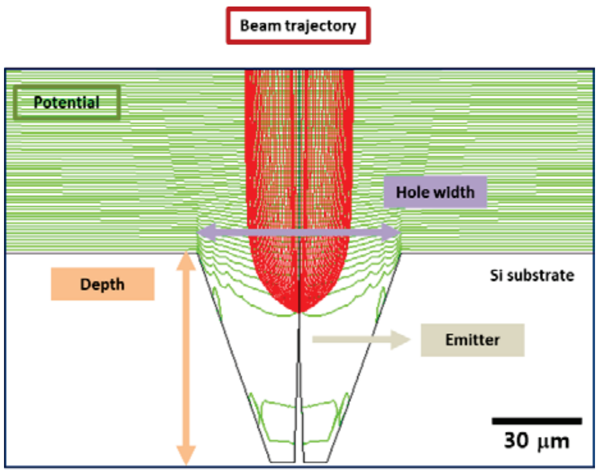

Fig. 3. Self-focused SOURCE simulation of electron sample structure

4 CONCLUSIONS

We fabricated direct grown single free standing CNT emitter using DC-PECVD system. We confirmed the electron beam trajectory using SOURCE 2D simulation. We expect that the CNT cold cathode with hole structure shows micro-focused electron beam without any electrical lens system. High resolution electron beam with easy fabrication process strongly required for many electron beam systems.

Especially, electron microscopy society require high brightness and high resolution electron source. In this study, we developed novel structure of electron beam with CNT emitters for high resolution electron source. The electron source structure would be applied for the next generation electron microscopy system.

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