P-7-9

Experimental and Theoretical Examination of Field Emission in Surface Conduction Electron-Emitter Displays

Hsiang-Yu Lo[1], Yiming Li[1,*], Chih-Hao Tsai[2], Hsueh-Yung Chao[1], Fu-Ming Pan[2], Mei-Chao Chiang[3], and Chi-Neng Mo[3]
[1]Department of Communication Engineering, National Chiao Tung University
[2]Department of Materials Science and Engineering, National Chiao Tung University
[3]Chunghwa Picture Tubes, Ltd., Taoyuan, Taiwan
[*]Corresponding author. Address: 1001 Ta Hsueh Rd., Hsinchu 300, Taiwan
TEL: +886-3-5712121 ext: 52974; FAX: +886-3-5726639; and E-mail: ymli@faculty.nctu.edu.tw

1. Introduction

Surface conduction electron-emitter display (SED) is one of new type flat panel displays based upon surface conduction electron-emitters (SCEs) [1-3]. Potentiality of SCEs as field emission sources is superior to conventional cathodes in many respects. These SEDs possess high luminance, good color, as well as low power consumption, where the emission efficiency is determined by the shape and material of SCE. Unfortunately, studies on SCE have not been clearly understood yet [4].

In this work, we employ the novel technique which we have developed lately to form the nanogaps by high pressure hydrogen absorption treatment and use 3D particle-in-cell (PIC) method [5-6] coupled with the Maxwell equations to explore the electron emission in SEDs. This new scheme has included the space charge effects automatically. We thus analyze the conducting mechanism, the emission efficiency, and the image of light spot with one field emission emitter in this work.

2. Experiments and Simulations

The schematic of the emitter structure and related experiment setup is shown in Fig 1. In the experiment, we perform a simple method to fabricate nanogaps in the palladium (Pd) thin film strips by high pressure hydrogen absorption treatment. Once Pd is exposed to hydrogen gas, the adsorbed hydrogen atoms can quickly diffuse into the Pd lattice and occupy the interstitial site due to a very small mass and size, and an accordingly large diffusion coefficient of hydrogen atoms. On the microscopic scale, fracture proceeds in a ductile manner and occurs more reactive at higher temperature. Therefore, the separation and edge roughness of the nanogap increase with the temperature. Figure 2 shows the plane-view SEM images of the nanogap formed on Pd electrodes at hydrogen absorption temperature 300℃. The emitter has an uneven structure with a palladium nanogap, where the width is approximately 90 nm.

A program has been developed to simulate the emission efficiency and the electron mechanisms of different emission structure. The 3D finite-difference time-domain code for self-consistent simulation of the electromagnetic fields and charged particles are performed in our simulation. The computational scheme and the related equations based on physical basis are shown in Fig. 3 and the PIC procedure is shown in Fig. 4.

3. Results and Discussion

According to our calibrated model [7] and the experimentally measured data, Fig. 5 shows the measured and simulated current-voltage (I-V) characteristics for the sample with 90-nm nanogap, where the Vg varies from 10 V to 300 V and Va = 0 V. The solid lines indicate the experimental data and the symbols are the simulation results. Two different turn-on voltages near 100 V and 200 V are observed in the 90-nm nanogap. This phenomenon is caused by the Pd-H system reacts vigorously when the temperature is higher such that the separation and edge roughness of the nanogap is increased. Hence, when the applied voltage is up to 100 V, the first turn-on voltage is found due to the conducting of nanogap with roughest surface, and full region will turn on until the applied voltage equals 200 V. Also, the corresponding Fowler-Nordheim (F-N) plot of the field emission of a Pd surface conduction electron-emitter, shown in the inset of Fig. 5, is further calculated. Assuming the work function φ = 5.12 eV for Pd, the linear relationship indicates that the electron conduction followed the F-N field emission mechanism. Figure 6 shows the contour plot of electric fields near the nanogap, where Va = 3 kV and Vg = 60 V. The electron trajectory is shown in Fig. 7. The electron beam emits toward the driver electrode and goes upwards to the anode. The zoom in plot of Fig. 7 around the emitter is shown in the inset. This is clearer to know the electron-emission mechanism. Figure 8 shows the current density distribution on the anode plate. The collected current is approximately 3 μA which is evaluated by integrating the current density to the area and its value is large enough to let the phosphor luminance. The light spot which is produced on the phosphor plate of spacer of 500 μm apart from the emitter is also shown in Fig. 8 when Va = 3 kV and Vg = 60 V. The achieved performance is coincided with the suppositions in [1-3].

4. Conclusions

We have fabricated a single nanogap in the Pd strip electrode of a SCE structure and developed a 3D simulation scheme of the electron emission in SED applications. Thus, the electron-emission mechanisms, the current density distribution on the anode plate, and the high emission efficiency have been explored. To illustrate the potential of the SCE emitters for display applications, the image of a light spot was successfully produced on a phosphor plate. They promise the advantage of the SED for TV application.

Acknowledgement

This work was supported in part by Taiwan National Science Council (NSC) under Contract NSC-95-2221-E-009-336, Contract NSC-95-2220-E-009-030, Contract NSC-95-2752-E-009-003-PAE, by MoE ATU Program, Taiwan, under a 2006-2007 grant, and by the Chunghwa Picture Tubes under a 2006-2007 grant.

References

[1] K. Sakai *et al. Euro Display* '96, **18.3**, 569 (1996).
[2] A. Asai *et al. SID '97 DIGEST* **10.4**, 127 (1997).
[3] E. Yamaguchi *et al. SID '97 DIGEST*, **6.2**, 52 (1997).
[4] M. Okuda *et al. SID '98 DIGEST*, **14.1**, 185, (1998).
[5] C.-H. Tsai *et al. Appl. Phys. Lett.* **90**, 163115 (2007).
[6] C. K. Birdsall and A. B. Langdon, *Plasma Physics via Computer Simulation*, McGraw-Hill, New York (1985).
[7] H.-Y. Lo *et al. SID '07 DIGEST*, 102 (2007).

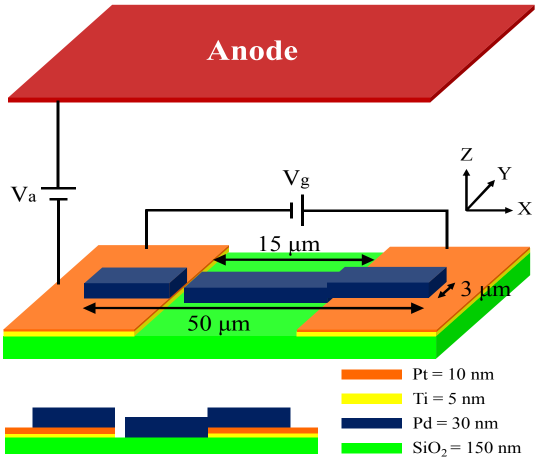

Fig. 1. A schematic plot of the SED structure and the cross section of the surface conduction electron-emitter on the *x*-*z* plane.

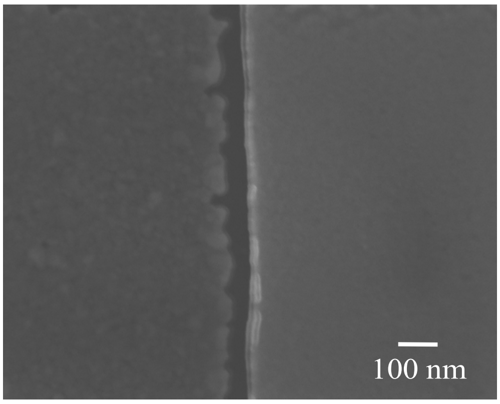

Fig. 2. A SEM image of the nanogap formed on the Pd strip in the SCE device. The width of nanogap is approximately 90 nm.

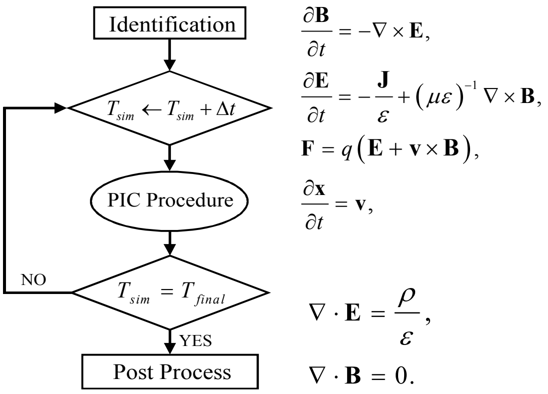

Fig. 3. The computational scheme and the corresponding equations for the 3D simulation.

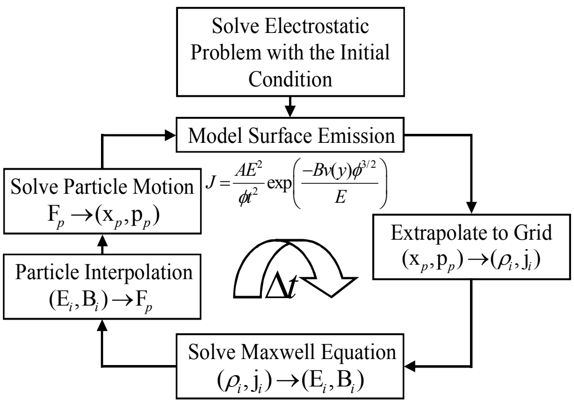

Fig. 4. A computational flowchart for PIC procedure.

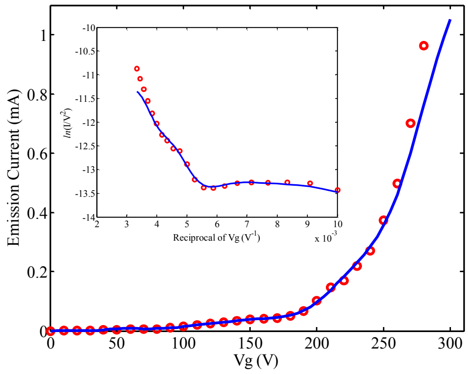

Fig. 5. The I-V characteristics of the SCE device with approximate 90-nm nanogap. The corresponding F-N plot is shown in the inset. The solid lines are experiment and the symbols are the simulation by the calibration model.

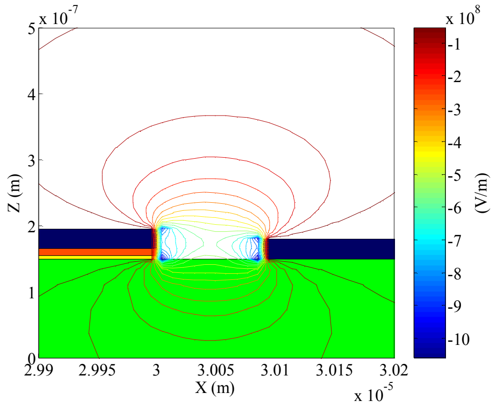

Fig. 6. The contour plot of electric fields in 90-nm nanogap, where Vg and Va are equal to 60 V and 3 kV.

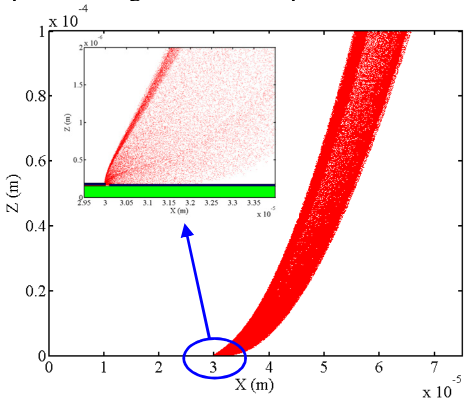

Fig. 7. The electron beam ejected from the SCE on the *x*-*z* plane with the Vg of 60 V and Va of 3 kV. The zoom in plot around the emitter is shown in the inset.

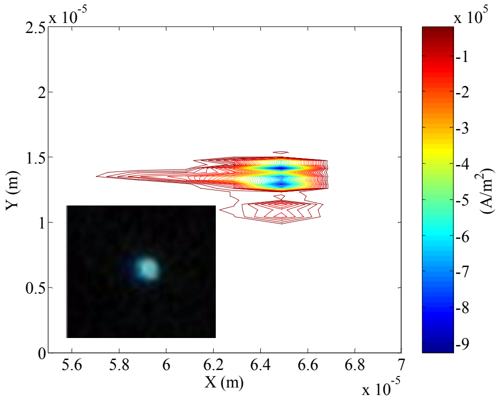

Fig. 8. The simulated current density distribution on the anode plate and the image of a light spot was produced on the phosphor plate.