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Optimal Configuration of Palladium Hydrogenation Nanogaps for Surface Conduction Electron Emission

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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, the studies on optimal field emission properties of SCE have not been clearly understood yet.

Extending the previous work [4-5], we employ the novel technique which we have developed recently to form the nanogaps by high pressure hydrogen absorption treatment and use 3D particle-in-cell method coupling with the finite-difference time domain scheme to explore the electron emission in SEDs. This new scheme has included the space charge effects automatically. We thus analyze the effect of configuration on the conducting mechanism and the optimal emission efficiency of the palladium hydrogenation nanogap field emission emitter. The geometry including tilted angle and separation of gap can bring significant influence on properties of field emission. For better efficiency, we obtain the range of the gap could be from 57 nm to 117 nm and the tilted angle is within 30^o - 60^o, in this work.

2. Simulation Methodology

In this work, we analyze the effect of tilted angle and separation width of the hydrogen embrittlement fabricated nanogap on the field emission properties of the designed SCE device. The 3D numerical solution technique performs a time integration of Faraday's law, Ampere's law, and the particle force equation. The electric field is evaluated by solving a set of Maxwell's equations, and then the field affects the movement of particles tunneling from the electrode into the vacuum via the Fowler-Nordheim equation. The attracted particles are then moved by the electric field which is modeled by the Lorentz equation. Furthermore, the moved particles are treated as a new electric source, and then the electric field is modified by Maxwell's equations. The self-consistent solution of the electromagnetic fields and charged particles is repeated till the requested time is achieved [6-7].

3. Results and Discussion

Figure 1(a) shows the SED structure and a cross-section plot of the SCEs on the *x-z* plane. The range of gap and tilted angle are illustrated, as shown in Fig. 1(b), due to the process variation. We first test few cases to investigate the filed emission due to the process variation. It a testing structure is with 10^o tilted angle and 147 nm gap; we find that it implies the worst case. From the view of electric field, the emitted electrons will be limited by the geometry, as shown in Figs 2(a) and 2(b). The gap distance between electrodes due to the smaller angle will reduce the electric field. Therefore, we decrease the gap and increase tilted angle. With the 0 nm gap and 80^o tilted angle, the result shows that electric field will be increased and emitted a large number of electrons. But the stronger electric field will attract electrons. Comparing both of them and from the view of electron trajectory, there is a relationship between the separation of gap and tilted angle, as shown in Figs. 4(a) and 4(b).

Extreme separations of gap will limit the strength of electric field. The more spread the electric field is, the more electrons can be scattered out the space. With lower electric field, the fewer emitted electrons will be attracted by the tip. It will lead to the high efficiency due to the smaller emitted current and higher collected current. We decrease the tilted angle and increase the gap to reduce the electric field, where the tilted angle is 20^o and gap is 27 nm. The result shows the electric field is reduced and more electrons can be collected by the anode, as shown in Figs. 5(a) and 5(b). It is found that some electrons will be captured due to the narrow gap. Therefore, we increase the gap which electrons will have space to move upward. But the electric field will be decreased. By increasing the tilted angle, emitted electrons will be easy and directly move upward due to the driving voltage increasing, as shown in Figs. 6(a) and 6(b). The range of electric field is thus wide and extends upward. When the electrons are emitted, most of them will be conducted by the electric lines and move toward the anode. There is a trade-off between the gap and tilted angle. After summarizing the results, the emitted current and collected current by the anode are illustrated in Figs. 7(a) and 7(b). Let the efficiency be the collected current divided by the emitted current. Ideal values for both the collected and emitted currents are as higher as possible. We here consider the emitted current which is greater than 1 μA for the following efficiency calculation. Depending on the definition of emission efficiency, the estimated efficiency is shown in Fig. 8. In the view of gaps of 57 nm and 117 nm, it shows the electric filed will be increased by increasing tilted angle, as shown in Tab. I. A larger angle can emit more electrons. But the electrons will be attracted by a strong electric field. A wider gap can provide enough space that benefits the formulation as well as the strength of electric field, and it thus is easy for emission and movement of electrons. The results show that the explored structure with a range of the gap from 57 nm to 117 nm and the tilted angle within 30^o - 60^o possesses promising emission efficiency. Nevertheless, the emitted and collected currents are sensitivity to structural configuration; we can find better emission efficiency by adjusting the tilted angle and separation of gap.

4. Conclusions

For a fixed separation of gap, a large angle may result in high emitted current, but the collected current on the anode is suppressed due to the strong electric field around the tip. A wide separation of gap weakens electric field around the tip and reduces the emitted electrons. We thus find a trade-off between tilted angle and separation of gap. For better filed emission efficiency, the gap could be from 57 nm to 117 nm and the tilted angle could be within 30^o - 60^o.

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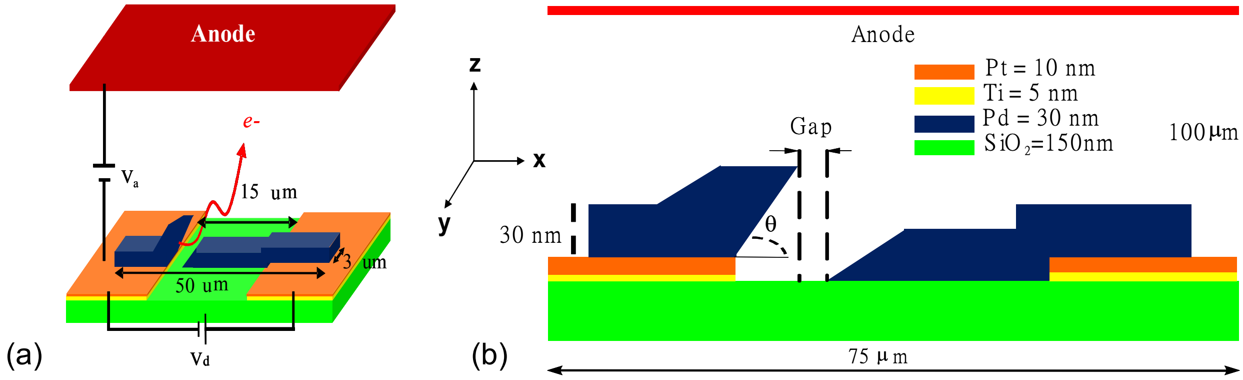

Fig. 1. A schematic plot of the SED structures and the cross sections of the SCEs on the xz plane. The SCE in (a) is fabricated by high pressure hydrogen absorption treatment. (b) The range of gap and tilted angle (θ) are illustrated. The thickness of this device is shown in right-upper corner.

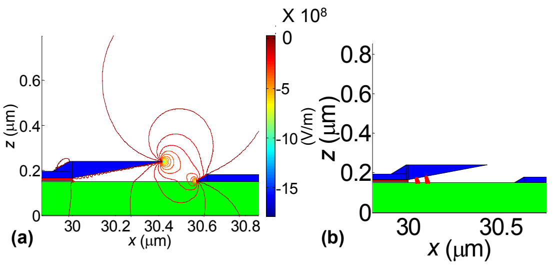

Fig. 2. (a) Plot of electric field. (b) Plot of electron trajectory. Both of them are with 10° tilted angle and 147 nm gap.

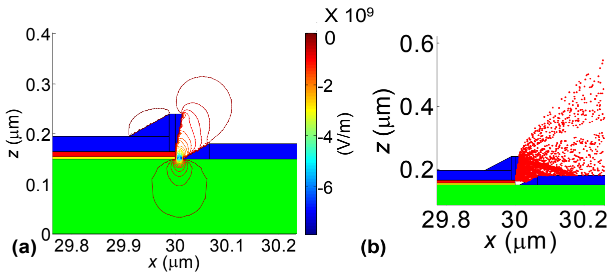

Fig. 3. (a) Plot of electric field. (b) Plot of electron trajectory. Both of them are with 80° tilted angle and 0 nm gap.

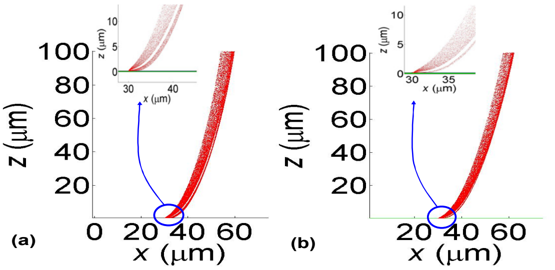

Fig. 4. (a) Plot of electron trajectory with 80° tilted angle and 0 nm gap (b) Plot of electron trajectory with 20° tilted angle and 27 nm gap.

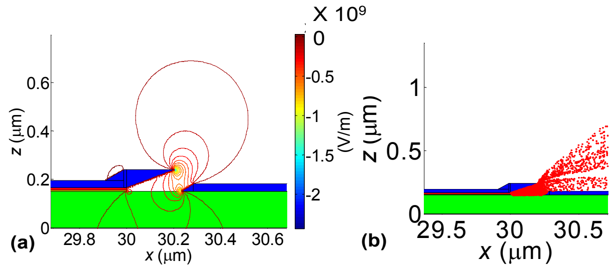

Fig. 5. (a) Plot of electric field. (b) Plot of electron trajectory. Both of them are with 20° tilted angle and 27 nm gap.

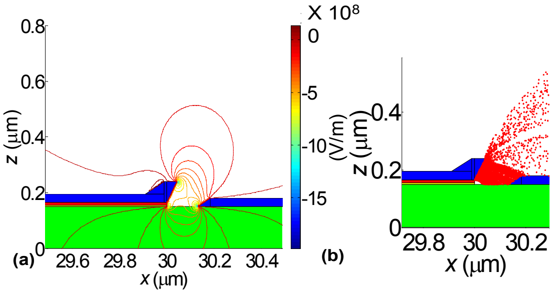

Fig. 6. (a) Plot of electric field (b) Plot of electron trajectory. Both of them are with 30° tilted angle and 87 nm gap.

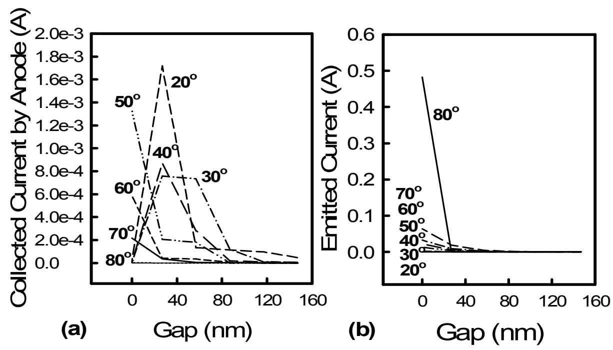

Fig. 7. (a) plot of the collected current by anode, where the gap is from 0 to 147 nm and tilted angle is from 10° to 80°. (b) Plot of the emitted current, where the gap is from 0 to 147 nm and tilted angle is from 10° to 80°.

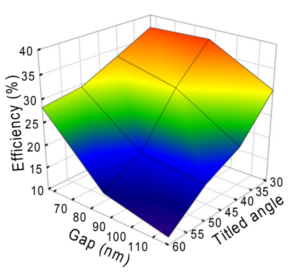

Fig. 8. Efficiency vs. gap which is from 57 to 117 nm and tilted angle which is from 30° to 60°.

Table I. The electric field, emitted current, collected current and efficiency are shown below, which are for 57 nm gap and 117 nm gap with tilted angle 30° and 60°, respectively.

	57 nm		117 nm	
	30°	60°	30°	60°
Electric field (V/m)	4.3E9	5.7E9	1.6E9	2.4E9
Emitted Current (A)	8.66E-04	9.33E-03	2.29E-06	8.56E-05
Collected Current (A)	3.47E-05	7.34E-04	4.13E-07	9.97E-06
Efficiency (%)	4.7	8.13	18	11.6