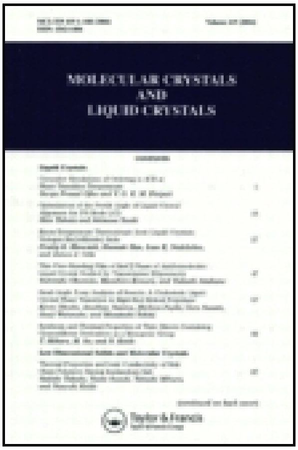

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The field emission characteristics of an oxidized porous polysilicon were investigated using different oxidation process with Pt/Ti multi layer electrode. The surface oxidation layer on an oxidized porous polysilicon was formed by thermal oxidation and electrochemical oxidation. The emission efficiency of thermal oxidation which was performed in a dry O_2 with O_2 flow rate of 3 l/min at 900°C for 60 min showed 3.36% at $V_{ps} = 16\,V$. The electrochemical oxidation was formed by solution containing 1 M sulphuric acid under 10 mA/cm^2 for 40 sec and was annealed 5 hr to improve oxide quality at 600°C. The emission efficiency of electrochemical oxidation showed 3.81% at $V_{ps} = 14\,V$.

Keywords: electrochemical oxidation; FED; field emission; porous polysilicon; thermal oxidation

INTRODUCTION

The rapid progress of PDP (plasma display panel), LCD (liquid crystal display) and OLED (organic light emitting device) technologies has been accelerating to replace CRT (cathode ray tube) for FPDs (flat panel displays). There is still a constant demand, however, for new FPD technology that can realize higher natural picture, as well as lower power consumption. FEDs (field emission displays) [1–3] have been also studied intensively with various geometric structures in

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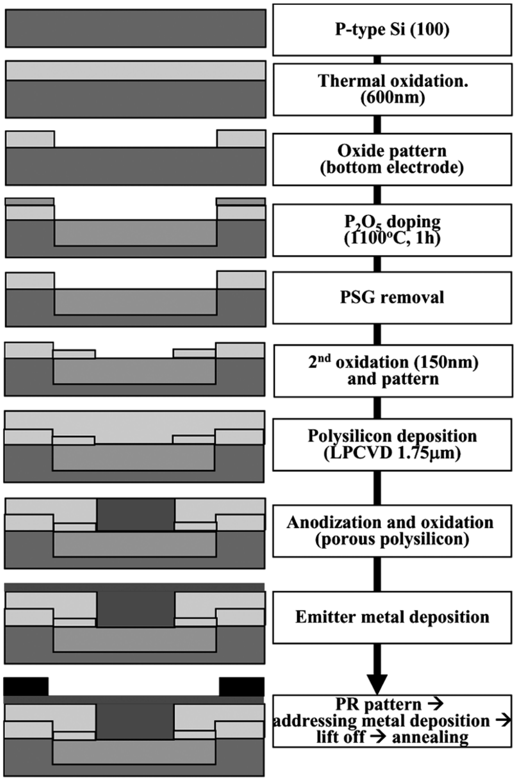
order to obtain a long time stability and better characteristics. Recently, oxidized porous polysilicon (OPPS), a new type of emitter, was proposed as being the most promising candidate for field emission display because of its simple fabrication process, stable performance in a lower vacuum atmosphere, and highly directional electron emissions at a low voltage of 10 V [3–5]. Although OPPS has been proposed, there are still many issues to overcome. Emission efficiency is below 1% due to large driving current and the sample is not reliable because the thickness of a thin metal electrode is below 10 nm. Therefore, the OPPS field emitter [6,7] needs to be investigated with regard to the details in order to improve its emission efficiency and reliability in terms of its application to display devices.

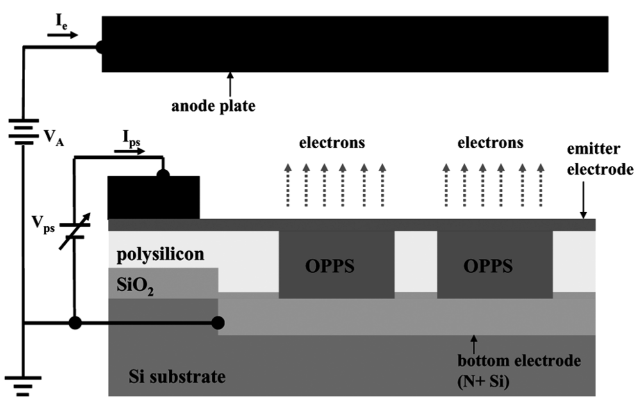
In this study, we have investigated the field emission characteristics using different oxidation process with Pt/Ti multi layer electrode. The surface oxidation layer on an oxidized porous polysilicon was formed by thermal oxidation and electrochemical oxidation. In case of electrochemical oxidation (ECO), it could be processed low temperature and contribute to a larger panel size and a reduction in process costs.

EXPERIMENTAL

Figure 1(a) shows the process procedure for the fabrication of the OPPS field emitters used in this work. The field oxide was thermally grown on a p-type (100) Si wafer that had a thickness of 600 nm. The field oxide was patterned and the P_2O_5 source was coated on to the patterned Si wafer so as to define the bottom electrode. After diffusion at 1100°C for 1 hr, the phosphosilicate glass (PSG) was removed, and a second oxide layer was grown and patterned to define the porous polysilicon (PPS) region. Low-pressure chemical-vapor deposition (LPCVD) was used to deposit a polysilicon with a thickness of 1.75 μm at 625°C. The polysilicon layer was anodized in a HF (49%): ethanol = 1:1 solution with a current density of 10 mA/cm^2 for 15 sec. The surface oxidation layer on an oxidized porous polysilicon was formed by different oxidation methods. First, the thermal oxidation of the PPS layer was performed in a dry O_2 atmosphere with O_2 flow rate of 3 l/min at 900°C for 60 min. Second, thin SiO_2 layers on the surface of the nanocrystallite Si were formed by the ECO process. Samples were put into an aqueous solution containing 1 M sulphuric acid (H_2SO_4) [8] and current source of 10 mA/cm^2 was applied for 40 sec to the PPS layer with respect to the solution. The process temperature of the anodization and the ECO process were about room temperature. The Pt/Ti electrode was deposited using a DC sputter and the



(a)



(b)

FIGURE 1 (a) Fabrication of an OPPS field emitter and (b) schematic diagram of the OPPS field emitter and electrical connection for the investigation of field emission properties.

thickness was controlled by an electric current and deposition time. The Pt/Ti addressing electrode with a thickness of 10 nm was deposited on PR patterned OPPS samples and lifted-off using PR stripper.

Figure 1(b) shows the schematic of the OPPS field emitter fabricated in our work. The electrical characteristics of the OPPS field emitters were investigated in a vacuum chamber at a pressure of 3×10^{-5} Torr and there was a space of 3 mm between the anode (1.2 kV) plate and the OPPS sample. The diode-voltage (V_{ps}) across the OPPS layer varied between 0 V and 15 V, and the emission efficiency ($100 \times I_e/I_{ps}$) was calculated from the ratio of the emission current (I_e) to the driving current (I_{ps}, current flow through the OPPS layer). The anode voltage was 3 kV, and the light-emitting pattern was observed on a green phosphor-coated ITO (indium tin oxide) glass plate. In addition, there was a space of 9 mm between the collector plate and the OPPS sample.

RESULTS AND DISCUSSION

1. Emission Characteristics of Thermal Oxidation on Porous Polysilicon

Figure 2 shows the thicknesses of oxide on polysilicon and p-type (100) silicon. The thickness of oxide on polysilicon was calibrated by measuring

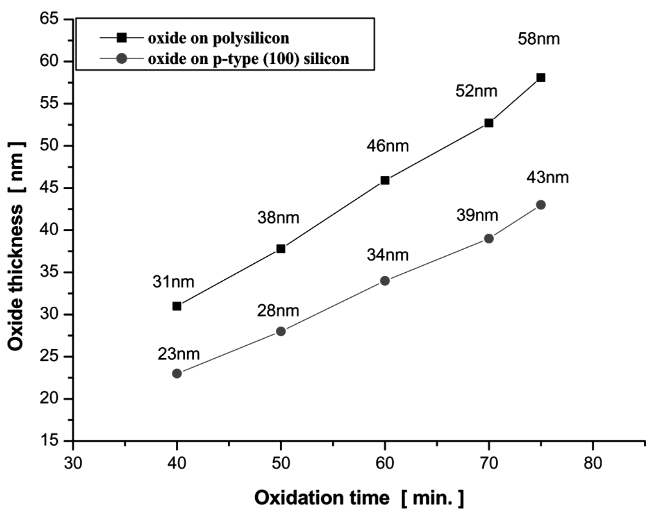


FIGURE 2 Thicknesses of oxide on polysilicon and p-type (100) silicon with oxidation time.

the thickness of oxide on p-type (100) silicon using ellipsometer. AES (Auger electron spectroscopy) depth profiling of each oxide was used for calibration of oxide thickness.

To fabricate more stable and efficient OPPS field emitter, we adopted Pt as an emitter electrode. Figure 3 shows I_{ps}, I_e, and efficiency for the OPPS field emitters which have Au/NiCr, as-deposited Pt, as-deposited Pt/Ti, annealed Pt/Ti, and addressed Pt/Ti emitter electrodes. The electron emission in vacuum starts at a V_{ps} of 7 V and gradually increases with increasing the V_{ps}. The starting point of electron emission accords with the abrupt increase of I_{ps}, which means the tunneling of electrons through the OPPS by applied electric field and the generation of hot electrons which can tunnel the oxide and thin emitter electrode. The OPPS field emitter which has Pt/Ti emitter electrode with thickness of 5 nm/2 nm shows the highest efficiency of 0.74% at $V_{ps} = 12\,V$ among as-deposited emitter electrodes. By comparing the as-deposited Pt and Pt/Ti emitter, we can reach a conclusion that thin Ti layer (2 nm) plays an effective role in adhesion and field distribution of Pt electrode.

To apply the OPPS field emitter to a display device, the frit or other sealing process is required to seal the emitter device with anode plate at the temperature of 300°C–500°C in vacuum atmosphere. Also the adhesion and other performances of metal electrode can be improved by subsequent thermal annealing. Accordingly, we investigated the effect of thermal annealing in N_2 atmosphere on the OPPS field emitter which has sputter-deposited Pt/Ti emitter electrode. Figure 3 shows the effects of thermal annealing on the I_{ps}, I_e, and efficiency of Pt/Ti OPPS field emitter. Annealing at 350°C/1 hr considerably decreased I_{ps} of addressed OPPS field emitter and its efficiency peaks to 3.36% at $V_{ps} = 16\,V$. These results show that tiny grains of as-deposited thin Pt and Ti coalesces with each other and form large islands of Pt or Ti on OPPS surface by annealing at 350°C/1 hr, which can give rise to the increase of resistance of Pt/Ti layer. In addition to the deformation of metal in itself, a little portion of Pt/Ti emitter metal can be diffused into SiO_2 and form shallow interfacial layer.

2. Emission Characteristics of ECO on Porous Polysilicon

To optimize the ECO process, we investigated the field emission characteristics at different oxidation times. Figure 4(a) shows the relationship between I_{ps} and I_e for the oxidation times of a Pt/Ti emitter electrode. In the case of the best characteristic sample, the electron emission in a vacuum starts at a V_{ps} of 5 V and gradually increases with the V_{ps}. The starting point of electron emission is in accordance

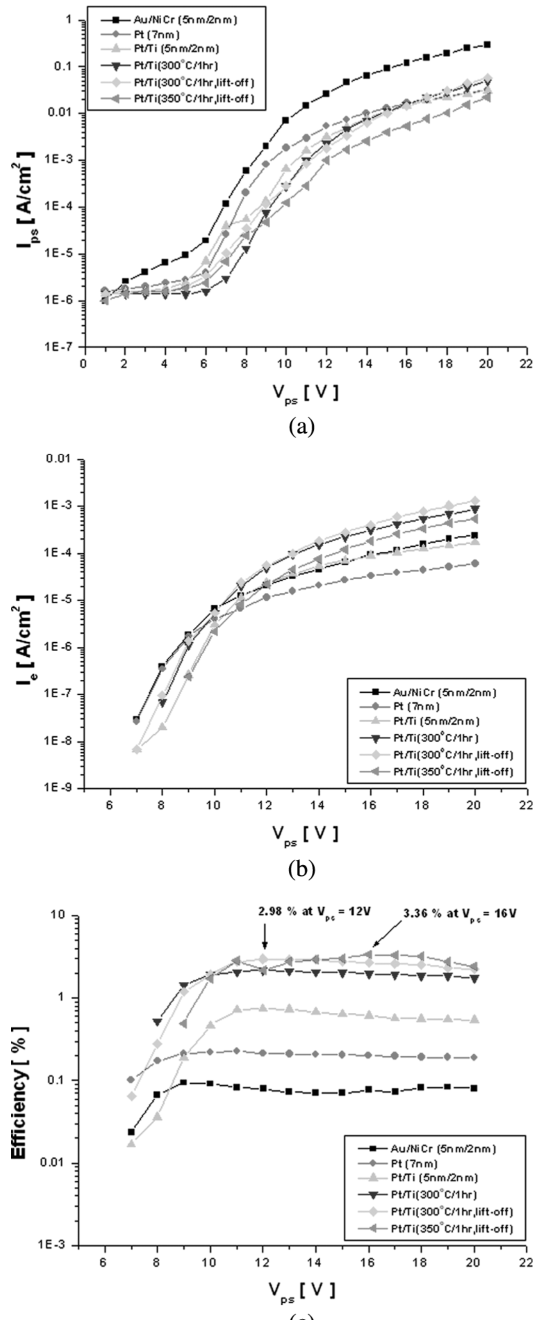
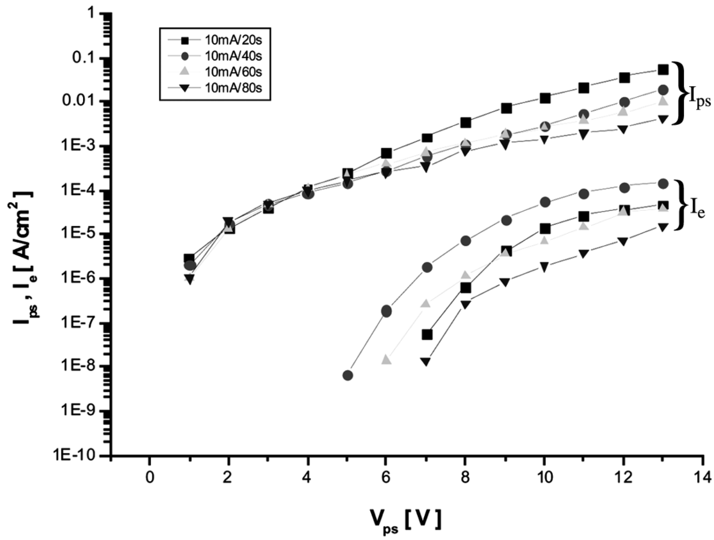
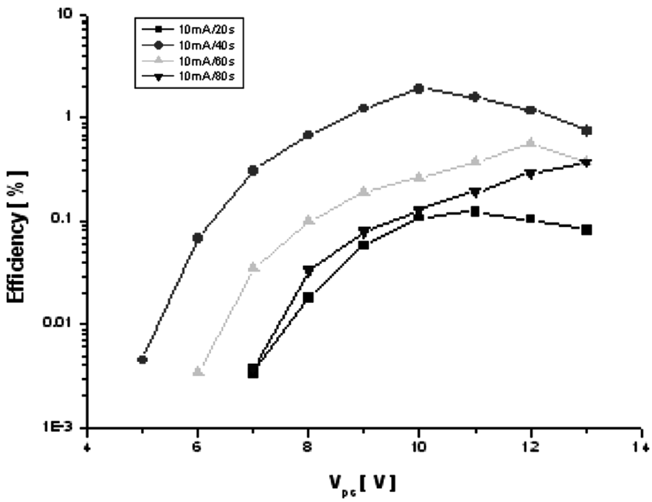


FIGURE 3 Effects of thermal annealing and addressing electrode on the (a) I_{ps}, (b) I_e, and (c) efficiency of Pt/Ti OPPS field emitter.



(a)



(b)

FIGURE 4 Change of (a) driving current I_{ps} and emission current I_e, and (b) efficiency at various oxidation times.

with the abrupt increase of I_{ps}, which means that the hot electron generated by an applied electric field tunnels through the OPPS field emitters. The OPPS field emitter, which has the ECO with a current density of $10\,mA/cm^2$ for 40 sec, shows the largest I_e among the three different OPPS field emitters. Figure 4(b) shows the emission efficiency ($100 \times I_e/I_{ps}$) for the three different emitter electrodes. The

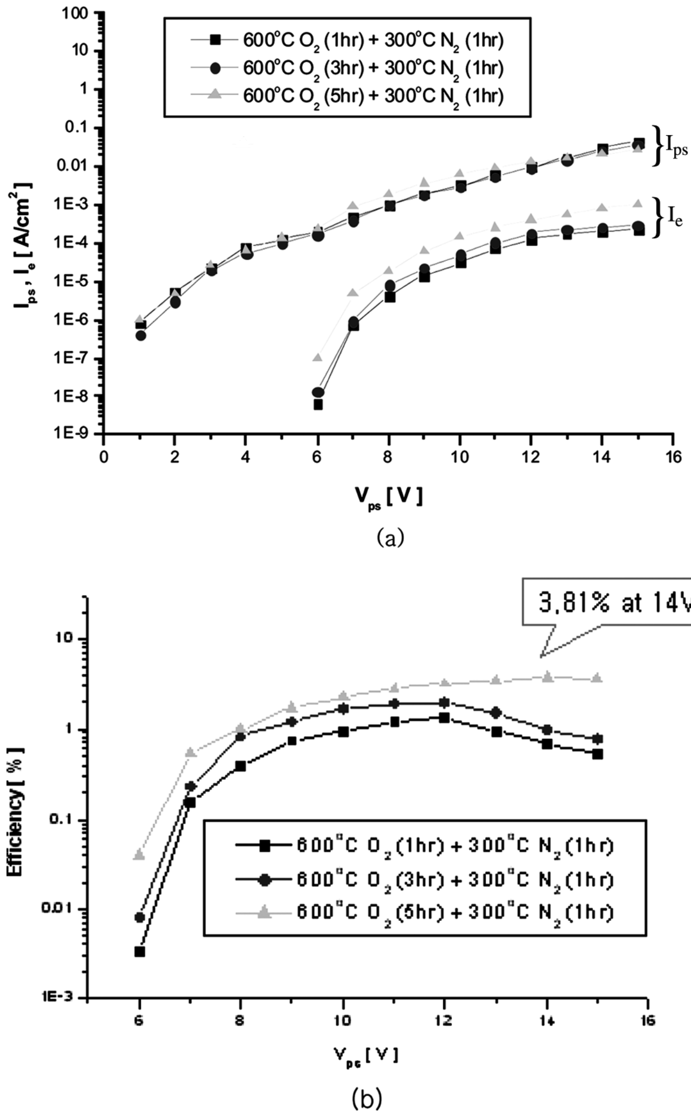


FIGURE 5 Effect of thermal annealing time on (a) the driving current I_{ps} and emission current I_e, and (b) the emission efficiency of the Pt/Ti OPPS field emitter.

ECO sample, with a current density of $10\,mA/cm^2$ for 40 sec, has the highest efficiency of 1.93% at $V_{ps} = 10\,V$.

We studied the effect of thermal annealing in an O_2 atmosphere on the OPPS field emitter, which has a sputter-deposited Pt/Ti emitter electrode. O_2 annealing made a high quality oxide layer which is formed with the ECO. O_2 annealing played an important role in improving field emission characteristics. Figure 5 shows the effects of thermal annealing on the I_{ps}, I_e, and efficiency of the OPPS field

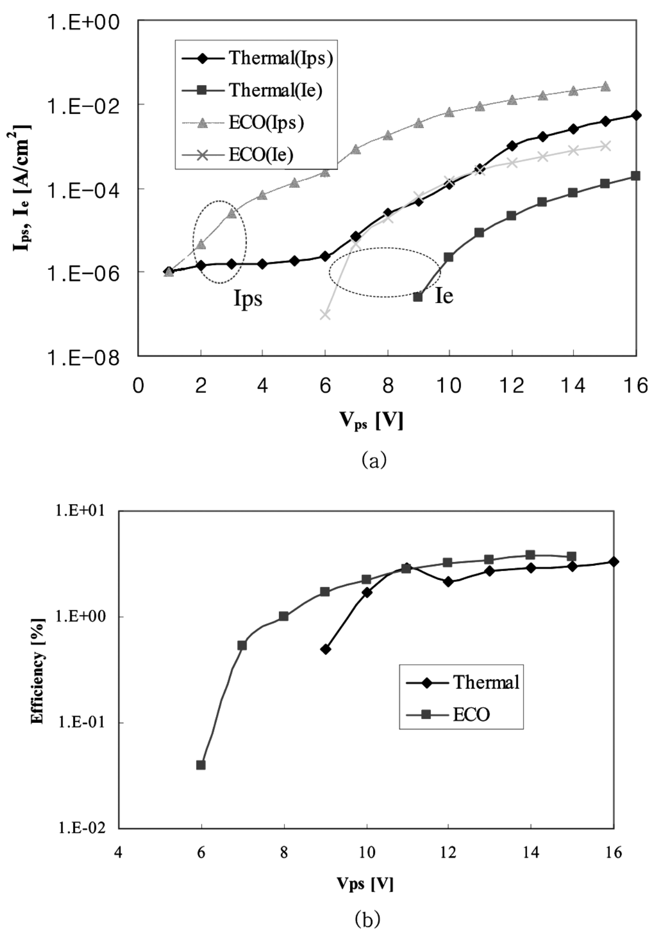


FIGURE 6 Change of (a) driving current I_{ps} and emission current I_e as a function of driving voltage V_{ps} and (b) field emission efficiency of thermal oxidation and ECO as a function of driving voltage V_{ps}.

emitter. Annealing at 600°C for 5 hr considerably increases the I_e and an efficiency. The maximum efficiency of 3.81% is observed at $V_{ps} = 14$ V. In spite of a high voltage, it is thermally stable according to the driving current.

3. Comparison Between Thermal Oxidation and Electrochemical Oxidation on Porous Polysilicon

To investigate the field emission efficiency, the oxidation layer on an oxidized porous polysilicon was formed by different oxidation methods, thermal oxidation and ECO. The thermal oxidation of the PPS layer was performed in a dry O_2 atmosphere with O_2 flow rate of 3 l/min at 900°C for 60 min. In case of ECO process, samples were put into an aqueous solution containing 1 M sulphuric acid (H_2SO_4) and current source of 10 mA/cm^2 was applied for 40 sec to the PPS layer. To improve the quality of ECO oxidation layer was annealed at 600°C in an O_2 atmosphere for 5 hr. Figure 6(a) shows the relation between driving current (I_{ps}) and emission current (I_e) as a function of driving voltage (V_{ps}) for the different oxidation method. Figure 6(b) shows the emission efficiency ($100 \times I_e/I_{ps}$) of the different oxidation. In the thermal oxidation sample, its efficiency has peaks

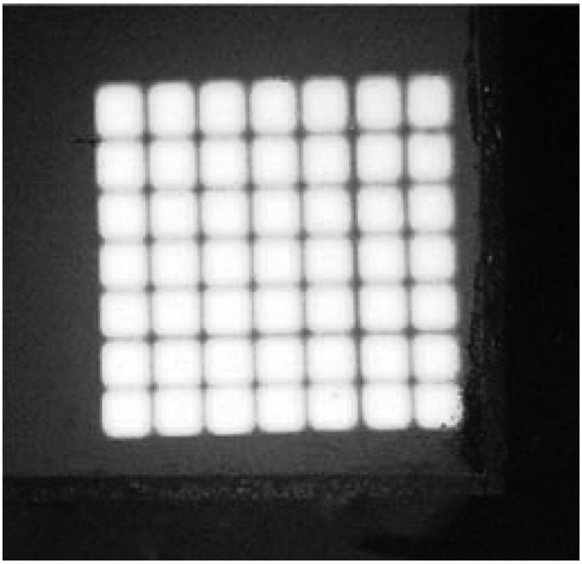


FIGURE 7 Excitation characteristics of the P22 green phosphor using the Pt/Ti OPPS field emitter.

to 3.36% at $V_{ps} = 16\,V$. In the ECO sample annealed at 600°C in an O_2 atmosphere for 5 hr, the maximum efficiency of 3.81% is observed at $V_{ps} = 14\,V$.

To demonstrate the applicability of the display devices, we measured the brightness on the green phosphor-coated ITO glass plate in a vacuum. Figure 7 shows the light emission pattern of the Pt/Ti OPPS field emitter at $V_{ps} = 11\,V$. At that time, the brightness is 2450 cd/m^2. At a distance of 9 mm between the OPPS sample and phosphor plate, we can observe a uniform and clear array of squares, which show the vertical electron emission of the OPPS field emitter. An increase in the V_{ps} makes the variation of brightness of the emitter. The brightness increases linearly with the V_{ps} and it reaches 4640 cd/m^2 at a V_{ps} of 15 V and an I_e of 230 μA/cm^2.

CONCLUSIONS

We have fabricated OPPS field emitters and investigated the emission efficiency of different oxidation in an OPPS field emitter. The thermal oxidation of the PPS layer was performed in a dry O_2 atmosphere with O_2 flow rate of 3 l/min at 900°C for 60 min. Thermal annealing in N_2 ambient considerable improved the field emission characteristics of OPPS field emitter, and addressed Pt/Ti (5 nm/2 nm) emitter annealed at 350°C/1 hr showed a prevailing efficiency of 3.36% at $V_{ps} = 16\,V$. In case of ECO process, samples were put into an aqueous solution containing 1 M sulphuric acid (H_2SO_4) and current source of 10 mA/cm^2 was applied for 40 sec to the PPS layer. The emission characteristic shows an efficiency of 1.94% at $V_{ps} = 10\,V$. The emission characteristic of ECO oxidation layer annealed at 600°C in an O_2 atmosphere for 5 hr showed an efficiency of 3.81% at $V_{ps} = 14\,V$. Therefore, the ECO oxidation could be applied for low temperature fabrication of OPPS field emitters.

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