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Field emission characteristics of an oxidized porous polysilicon field emitter using the electrochemical oxidation process

Soon-Il Kwon[a], Sung-Won You[a], Young-Soo Sohn[b], Yong-Soo Cho[a], Byung-Nam Park[a], Sie-Young Choi[a,*]

[a]*School of Electronic and Electrical Engineering, Kyungpook National University, 1370 Sankyuk-dong, Buk-gu, Daegu, 702-701, South Korea*
[b]*Daegu Gyeongbuk Institute of Science and Technology, Daegu, South Korea*

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Abstract

The field emission characteristics of an oxidized porous polysilicon (OPPS) were investigated with Pt/Ti multilayer electrode using the electrochemical oxidation (ECO) process. A Pt/Ti multilayer electrode, using ECO, showed highly efficient and stable electron emission characteristics; moreover, it can be applied to large area of a glass substrate with a low temperature process. Electron emission characteristics were improved with O_2 annealing at 600 °C after the ECO process. It was found that forming a high quality oxide layer from the ECO-formed SiO_2 was crucial in improving electron emission characteristics. The Pt/Ti OPPS field emitter, which was annealed at 600 °C for 5 h, showed an efficiency of 3.81% at $V_{ps} = 14$ V.

Keywords: Electrochemical oxidation (ECO); Field emission; Porous polysilicon; O_2 annealing

1. 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) [1,2] have been also studied intensively with various geometric structures in 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 [3,4]. 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 [3–5] 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. First, the thin emitter metals on OPPS play an important role in electron emission efficiency and the stability of field emission. O_2 annealing after electrochemical oxidation (ECO) showed better stability and characteristics.

In this study, we investigated the field emission characteristics of an OPPS field emitter using the ECO process, which will contribute to a larger panel size and a reduction in process costs. Also, we studied the effect of the O_2 annealing time on the efficiency and stability of the OPPS field emitter.

2. Experiment

Fig. 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 (1 0 0) Si wafer that had a thickness of 600 nm. The field oxide was patterned and the

*Corresponding author. Tel.: +82 53 950 5518; fax: +82 53 950 6827.
E-mail address: sychoi@ee.knu.ac.kr (S.-Y. Choi).

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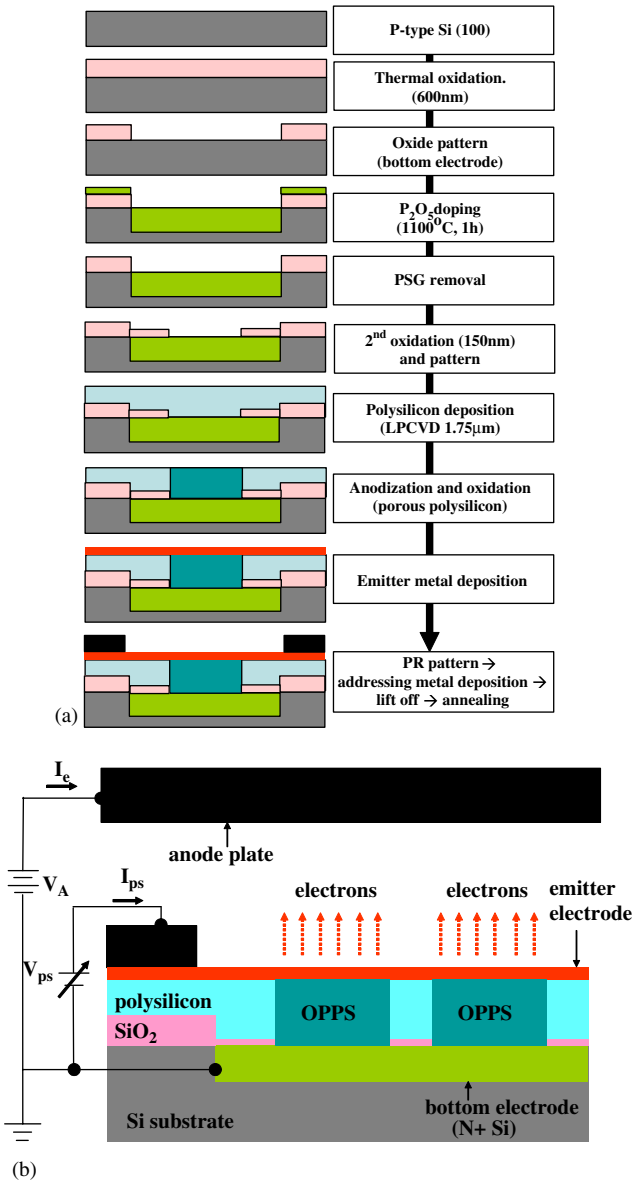

Fig. 1. (a) Fabrication of an OPPS field emitter and (b) cross-sectional view of the OPPS field emitter and the electrical connection for the analysis of its field emission characteristics.

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 h, 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 μm. The polysilicon layer was anodized in a HF (49%): ethanol = 1 : 1 solution with a current density of 10 mA/cm^2 for 15 s. Thin SiO_2 layers on the surface of the Si nanocrystallite were formed by the ECO process. Samples were put into an aqueous solution containing 1 M sulphuric acid (H_2SO_4) [6] and current source of 10 mA/cm^2 was applied for 40 s 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 thickness was controlled by an electric current and deposition time. Fig. 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 and 15 V, and the emission efficiency ($100 * I_e/I_{ps}$) 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.

3. Results and discussion

To optimize the ECO process, we investigated the field emission characteristics at different oxidation times. Fig. 2(a) shows the relationship between I_{ps} and I_e for the

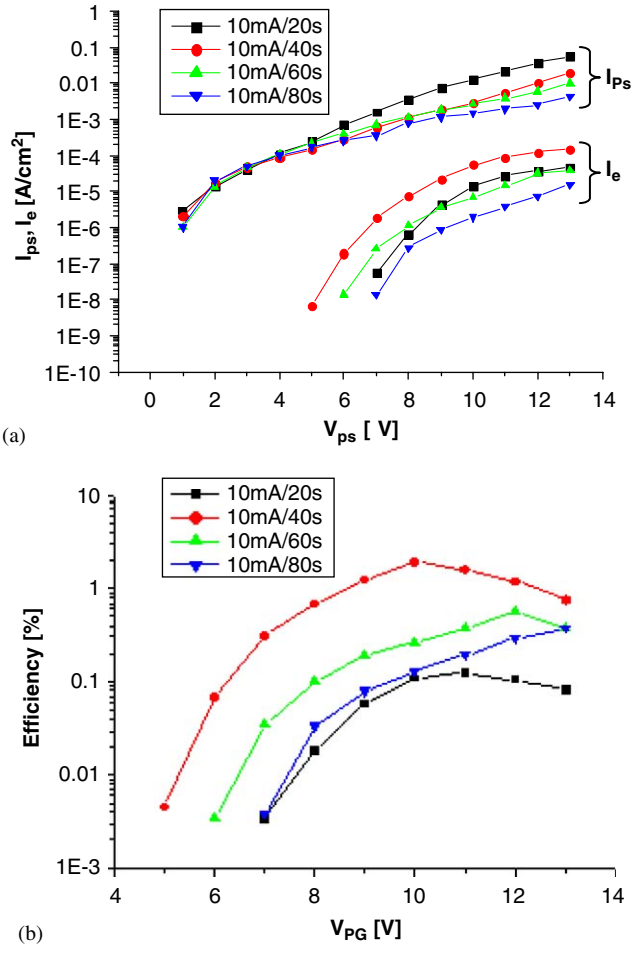

Fig. 2. Change of (a) driving current I_{ps} and emission current I_e, and (b) efficiency at various oxidation times.

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 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 s, shows the largest I_e among the three different OPPS field emitters. Fig. 2(b) shows the emission efficiency ($100 * I_e/I_{ps}$) for the three different emitter electrodes. The ECO sample, with a current density of 10 mA/cm^2 for 40 s, 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. Fig. 3 shows the effects of thermal annealing on the I_{ps}, I_e, and efficiency of the OPPS field emitter. Annealing at 600 °C for 5 h considerably increases the I_e 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.

Fig. 4 shows the time dependent variation of I_{ps} and I_e at a continuous $I_{ps} = 1$ mA/cm^2. Regarding the OPPS emitters of O_2 annealing for 1 h and 3 h, an abrupt increase of I_{ps} and decrease of I_e are observed, while the OPPS emitter of O_2 annealing at 5 h shows the best stable field emission behavior. These results show that a thick oxide layer efficiently blocks the diffusion of emitter metal. Increase of the O_2 annealing time can improve the stability of the emitter by preventing diffusion of Pt/Ti metal into OPPS field emitters.

To demonstrate the applicability of the display devices, we measured the brightness on the green phosphor-coated ITO glass plate in a vacuum. Fig. 5 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

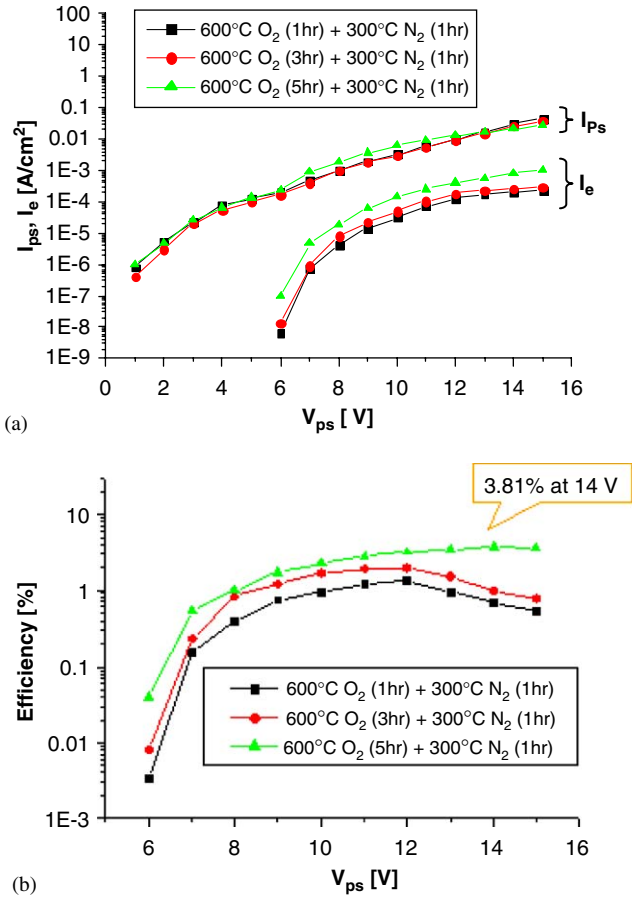

Fig. 3. Effect of thermal annealing time on (a) the driving current I_{ps} and emission current I_e, and (b) the emission efficiency of the Pt/Ti OPPS field emitter.

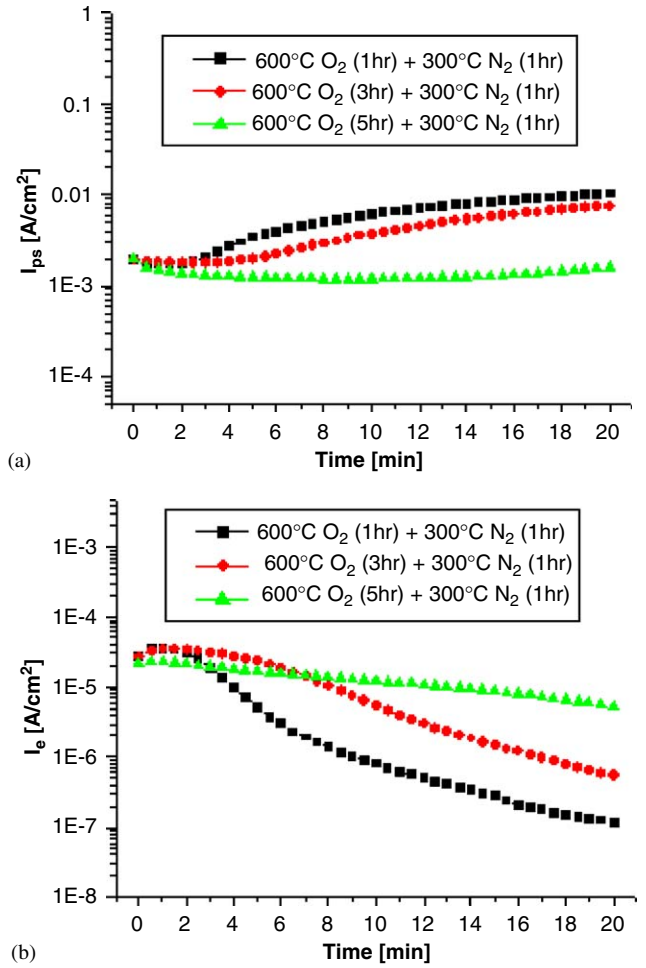

Fig. 4. Time dependent variation of the field emission characteristics of the OPPS field emitter.

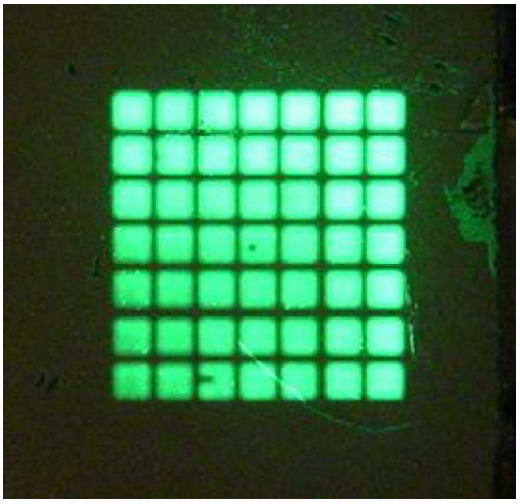

Fig. 5. Excitation characteristics of the P22 green phosphor using the Pt/Ti OPPS field emitter.

a V_{ps} of 15 V and an I_e of 230 mA/cm^2. These results show that the Pt/Ti OPPS field emitter can be applicable to display devices.

4. Conclusion

We fabricated OPPS field emitters and investigated the thermal annealing effects of an OPPS field emitter with ECO process. The ECO with 10 mA/cm^2 for 40 s emitter shows an efficiency of 1.94% at $V_{ps} = 10$ V. The Pt/Ti OPPS field emitter annealed at 600 °C for 5 h showed an efficiency of 3.81% at $V_{ps} = 14$ V. Accordingly, oxygen annealing plays an important role in disturbing the transformation of an electrode. Brightness increases linearly with the V_{ps} and reaches 4640 cd/m^2 at a V_{ps} of 15 V. Finally, the OPPS field emitter, treated with oxygen, can be applied to high quality field emission display devices.

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