Patterning of the ITO Electrode of AC PDP using $Nd:YVO_4$ Laser

Kwang Ho Kim, Min Hyung Ahn, and Sang Jik Kwon*
Department of Electronics Engineering, Kyungwon University, San 65, Bokjung-dong, Soojung-gu, Seongnam City, Kyunggi-do 461-701, Korea
TEL:82-31-750-8517, e-mail: sjkwon@kyungwon.ac.kr.

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Abstract

Laser-ablated ITO patterns showed the formation of shoulders at the edge of the ITO lines and a ripple-like structure of the etched bottom. When the laser ablation was applied in the fabrication of PDP panel, the laser-ablated ITO patterns showed a higher sustaining voltage than that of chemically wet-etched ITO.

1. Introduction

Indium tin oxide (ITO) thin films are used in flat panel displays such as LCDs, PDPs, OLEDs. The patterning of ITO electrodes is generally carried out by photolithography via etching in acidic solutions. However, the use of hazardous acid is an environmental problem that incurs significant disposal costs and a higher device price than that in the case of conventional photolithographic manufacturing.[1] Among FPDs, one very successful technology for large-format displays is the plasma display panel (PDP). Most issues in reducing the PDP fabrication cost are focused on reducing the processing time, material costs, and machinery costs. A single photolithography process requires a minimum of six processing steps, each step costing several million dollars to handle a Gen. 7 mother glass panel. One alternative is a direct writing technique that enables maskless patterning of the ITO films using a fine focused laser beam.[2-4] In the present work, Q-switched diode-pumped $Nd:YVO_4$ (neodymium-doped yttrium vanadate, λ=1064 nm) was used to pattern the ITO bus electrode of the PDP. In the IR region such as 1064 nm, an ITO layer with the thickness of 150 nm absorbs about 80 % of the laser light and the glass substrate is almost transparent, so that heating occurs only in the ITO film itself.[5,6] In this study, we ablate the ITO layer, using a $Nd:YVO_4$ laser, in order to obtain the patterns of PDP bus lines.[7,8] The scan speed and power of the laser light are varied to achieve complete removal of the ITO layer and a ripple-free structure of the etched groove. Also, optimum conditions are applied to fabricate an operational PDP test panel of a 2-inch diagonal size. The laser-ablated samples are observed by optical microscopy, secondary electron microscopy (SEM), and stylus profilometer.

2. Experimental

The experiments on laser direct patterning were conducted on 130 nm thick ITO film sputter deposited on to a PDP-grade glass substrate (PD-200, ASAHI Glass, Japan) 2.8 mm thick. The specified sheet resistance of the ITO layer was about 30 Ω/□. The laser used is a diode-pumped, single-mode, Q-switched $Nd:YVO_4$ solid-state laser with a wavelength of 1064 nm. The set up for experiments is shown in Fig. 1.

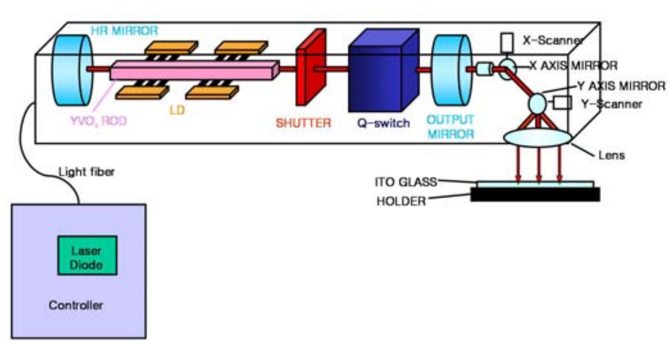

Fig. 1. Experimental setup for laser direct patterning of ITO films.

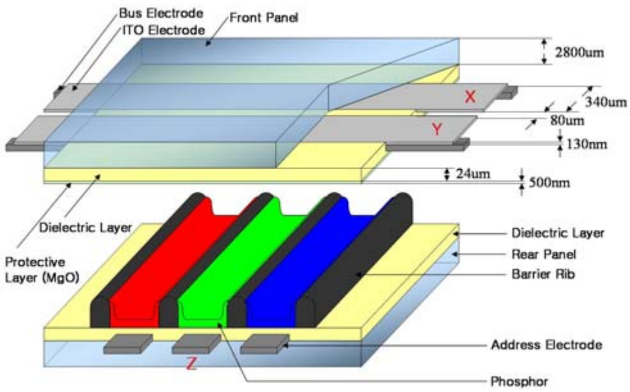

Fig. 2. Cell structure of the AC PDP panel fabricated for the experiments.

Figure 2 shows the cell structure of the PDP panel fabricated for the application of direct ITO patterning. The glass plate has a size of 60 × 90 mm^2 and a thickness of 2.8 mm. The size of the effective luminescent area is 35 × 35 mm^2. Each width of the two ITO electrodes per cell is 340 um with a gap of 80 um, and the cell-to-cell pitch is 1080 um.

First, laser patterning of ITO bus electrodes of the PDP devices was conducted. Processing parameters of the laser processing were the pulse repetition rate, scan speed, and power etc. After laser processing, the morphology of the test samples was observed by optical microscopy and SEM. In addition, the formation of shoulders and the roughness of the etched grooves were measured with a stylus profilometer. To establish the optimum conditions for laser processing, PDP test panels were fabricated using different scan speeds of the laser beam at a fixed power. A reference sample of the ITO electrode prepared with by wet chemical etching was also prepared to compare the characteristics.

For the front panel, after the laser patterning of the ITO layer, auxiliary Ag electrodes were printed by screen printing along the patterned ITO lines, and then the dielectric layer with a thickness of about 24 um was printed over the bus electrodes. Finally, the MgO layer with a thickness of 5,000 Å was deposited, using an e-beam evaporator, on to the dielectric layer. For the rear panel, address Ag electrodes were first printed on the glass substrate, followed by the dielectric layer, with a thickness of about 24 um. Then barrier ribs with a height of 120 um were printed on the dielectric layer by screen printing, and finally, the phosphor layer was printed between the barrier ribs.

To measure the PDP characteristics, the front glass plate and the rear glass plate were placed into a vacuum chamber, facing each other with a gap formed by the presence of the barrier ribs. The chamber was evacuated to 1 × 10^{-6} Torr using a turbomolecular pump. Ar gas was filled to 250 Torr and the panel was annealed at 300°C for 1 h. After annealing, the chamber was again evacuated to the base vacuum level of about 1 × 10^{-6} Torr at room temperature. After evacuation, the gate valve of the turbomolecular pump was closed and the gas mixture of Ne with 4% Xe was introduced into the chamber until the gas pressure indicated by the pressure gauge reached 400 Torr. The discharge current, including displacement current, was measured using a current probe (TCP-A312).

3. Results and discussion

Experiments were conducted using the fundamental wavelength (1064 nm) of the Nd:YVO$_4$ laser. First, the scan speed was varied from 100 mm/s to 2000 mm/s. At this point, the pulse repetition rate was 40 kHz with a beam spot size of 40 um and a scan pitch of 20 um, which yield giving a spatial overlay of about 50 % between the successive pulses.

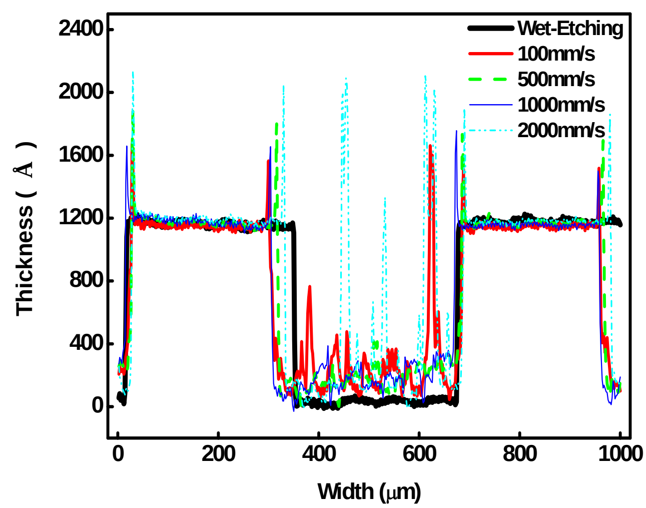

Fig. 3. Stylus profiles measured across the laser-ablated grooves formed with various laser scan speeds.

The stylus profiles for various scan speeds are shown in Fig. 3. The shoulders at the edge seem to be relatively smooth for all samples except in the case of 100 mm/s scan speed. Additional inspections will be necessary to verify the reason why rough shoulders were obtained with 100 mm/s scan speed. The shoulders formed at the edge of the laser-ablated ITO lines indicate that the removal of ITO film occurs by thermal evaporation. Furthermore, the incomplete removal of these shoulders results in the formation of a rippled structure at the bottom and within the line of the etched groove.

Moreover, landing error of the laser beam arises as the scan speed exceeds 1000 mm/s, as shown in the micrographs in Fig. 4.

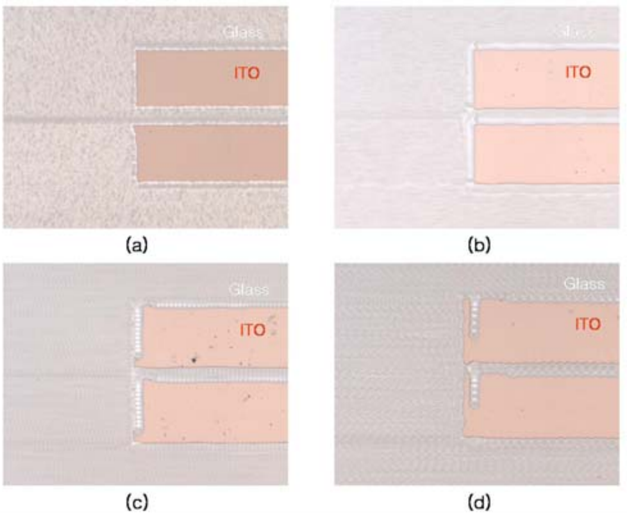

Fig. 4. Optical micrographs of the laser-ablated ITO films formed with various laser scan speed. (a) 100 mm/s, (b) 500 mm/s, (c) 1000 mm/s, and (d) 2000 mm/s

PDP test panels with a 2-inch diagonal size of the active luminescent area were fabricated by Nd:YVO_4 laser direct patterning of the ITO bus lines. Driving pulse voltages were supplied to sustain (X) and scan and sustain (Y) electrodes of the front glass plate. Address (Z) electrodes of the rear glass plate were maintained at ground level. The frequency of the rectangular pulses was 50 kHz and the width of the pulse was 3.0 us. For the PDP sample fabricated with laser patterning of the ITO film, part of the effective luminescent area does not emit visible light, as shown in Fig. 5, which is a result of shorting between X-Y lines due to incomplete removal of the ITO film from the etched grooves. Discharging characteristics in Fig. 6 show that the firing voltages (Vf) are about the same for all samples, however, the minimum sustaining voltages (Vs) are quite different between wet-etched ITO sample and the laser-ablated ITO samples. This seems to be correlated with the formation of shoulders and/or ripple-like structures in the cases of the laser-ablated ITO lines, although this is unconfirmed. Further experimental studies will be required for the verification.

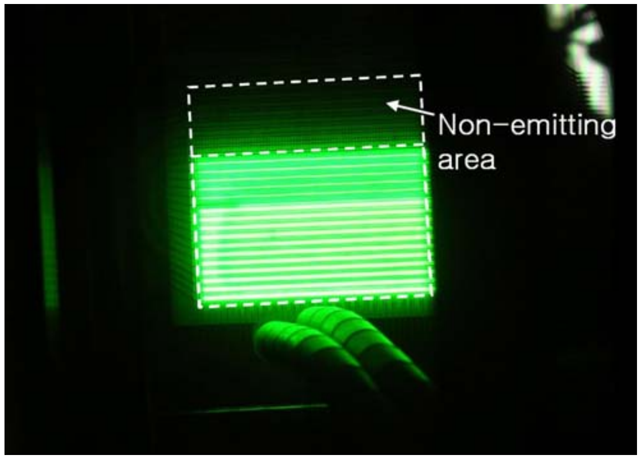

Fig. 5 Light emission with the applied pulse of 210 V for the PDP with laser-patterned ITO lines. (The brightness was 836 cd/m^2.)

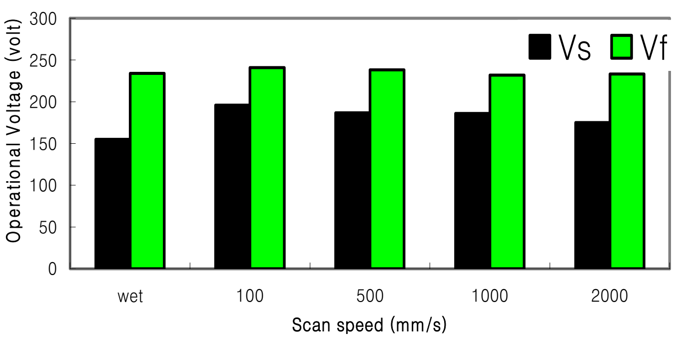

Fig. 6. Discharge characteristics of the PDPs as a function of laser scan speed.

4. Conclusion

ITO direct patterning was conducted using a Nd:YVO_4 laser. The shoulder at the rim of the laser-ablated lines and the roughness of the etched grooves are greatly dependent on the pulse repetition rate and the scan speed. With the Q-switched Nd:YVO_4 laser and a galvanometric scanning system, 500 mm/s was appropriate for the application to PDP manufacturing. Compared with the PDP cell having chemically wet-etched ITO lines, the firing voltage was nearly the same, but the minimum sustaining voltage was much higher in the laser-ablated samples. These can be correlated with the shoulders formed at the rim of the etched ITO lines and/or the incomplete removal of ITO films from the grooves. Further experiments on the removal of the shoulders and the remaining residue of the ITO films on the bottom of grooves are in progress, aiming at the practical application of laser process in PDP formation.

5. References

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