Characteristics of Laser Direct Patterned Indium Tin Oxide Layer by Overlapping Rates of Laser Beam

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Abstract

A diode-pumped Nd:YVO_4 laser was used to obtain indium tin oxide (ITO) patterns on glass substrate with various overlapping rates. The results showed that the overlapping rate of laser beam influences on the edge structure of ITO pattern and the surface roughness of ablated groove bottom. At a laser repetition rate of 40 kHz, the optimized condition of overlapping rate was 75 %

1. Introduction

Indium tin oxide (ITO) film is a transparent conductive oxide and has widely been used as transparent electrodes for solar cells, microelectronic devices and flat panel displays (FPDs) [1, 2]. The conventional patterning techniques of ITO have used the photolithography process, which used the photo mask and the wet etching process, to ablate the ITO material on the substrate [3, 4]. However, the wet etching process usually accompanies many problems, such as chemical pollutions, under-cut effect, swelling, high fabrication cost, and the damage of substrate [5]. Therefore, dry etching process has been replacing the photolithography. As a method of the dry etching methods, laser direct patterning technique is used to form the pattern in the ITO film [6].

It is no necessary to consider the tool wear problem in laser processing because it is a non-contact processing. Laser processing has also the advantages such as the simple process, the high-accuracy, the little thermal effect, the small environmental pollution and the flexible production. Therefore, the laser processing becomes a novel technology in the manufacturing processes. Laser processing has widely applied to ablate the material on the work piece, including the dicing, the cutting, the drilling, the marking, the scribing and the lift-off technique [7-11].

Therefore, this paper is concentrated on the laser direct patterning of ITO on glass substrate with a diode-pumped Nd:YVO_4 laser by varying process conditions and the optimized conditions will be obtained. For the optimization, the new concept of overlapping rate will be defined.

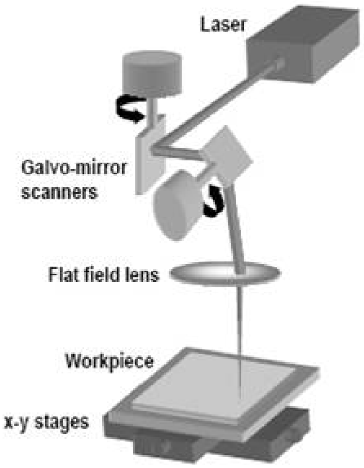


Fig. 1. Schematic diagram of the experimental setup of the laser system.

2. Experimental

The experiments on laser direct patterning were conducted on the 130 nm thick ITO film sputter deposited on PDP glass substrate (PD-200, ASAHI) with a thickness of 2.8 mm. The specified sheet resistance of the ITO layer was about 30 Ω/□. The ITO glass has been cleaned using an ultrasonic cleaner and dried using a drying oven. Then, a Q-switched diode pumped solid stated (DPSS) Nd:YVO_4 laser (ML-7111A, MIYACHI Co.) was used to pattern the ITO electrodes on glass substrate. The experimental setup is shown in Fig. 1. The laser has a wavelength of 1,064 nm and a pulse duration of τ = 10 ns (full width at half maximum, FWHM). The laser beam was scanned by a built-in galvanometric beam scanning system and de-magnified across the sample area of 100 mm × 100 mm using a f-theta 160 mm focal length lens. The working distance between the f-theta lens and specimen was 175 mm.

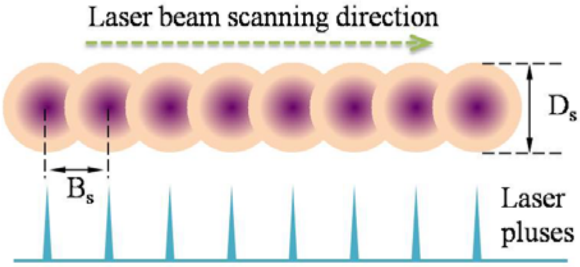


Fig. 2. Schematic diagram about the definition of the overlapping rate of laser beam

We patterned the ITO film on glass substrate with several different overlapping rates of the laser beam. The overlapping rate is usually an important parameter in the laser direct patterning process and depends on the scanning speed and the subsequent repetition rate of laser beam. Here, we varied the overlapping rate by controlling the scanning speed from 100 to 1000 mm/s at a given repetition rate of 40 kHz. Fig. 2 shows the schematic diagram about the definition of overlapping rate and it can be presented as following:

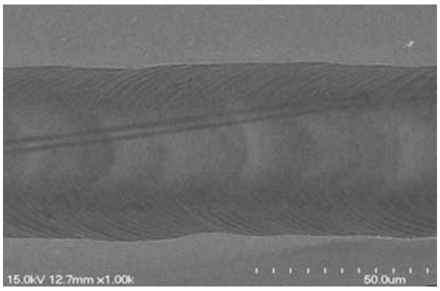
$$Overlapping\ rate = \frac{D_S - B_S}{D_S} \times 100\% \qquad (1)$$

Where, the B_s is the laser beam bite size (mm), and D_s is the laser beam spot size (mm).

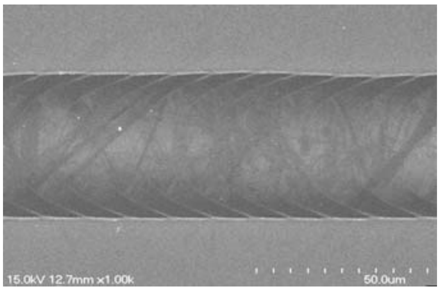
In order to verify the investigation to ablate ITO film on glass substrate with different overlapping rates, the scanning electron microscopy (S-4700, HITACHI), atomic force microscopy (XE-150, Park Systems), and stylus profilometer (alpha-step 500, KLA-TENCOR) were employed to make an analysis of the ablated ITO film.

3. Results and discussion

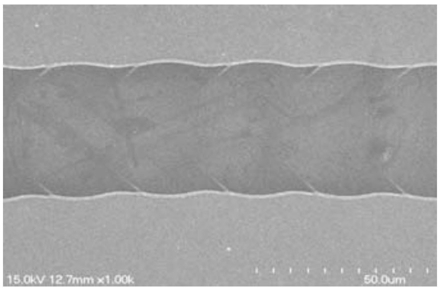
We were able to investigate that the cutting edges of the ablated ITO patterns would be affected by the overlapping rate of the laser beam as shown in Fig. 3. Fig. 3 (b) shows that the proper overlapping rate (75%) has better cutting edge, and a smaller or larger overlapping rate than 75% has a relatively poorer cutting edge, as shown in Fig. 3 (a) and (c). When the overlapping rate is higher than 75%, the laser beam spots overlap at the same position overmuch and the overlaps lead to the irregular edge structure. While, when the overlapping rate is much smaller, the distance between adjacent spots is so long that the laser beam cannot completely ablate the ITO layer. From the Fig. 3, we can also make sure that the overlapping rate of laser beam makes an effect on the linearity of the ablated ITO patterns. The linearity of the ITO patterns will play an important role on the discharging characteristics of plasma display panel (PDP). Therefore, we should find out the proper overlapping rate to obtain the optimal linearity. From



(a)



(b)

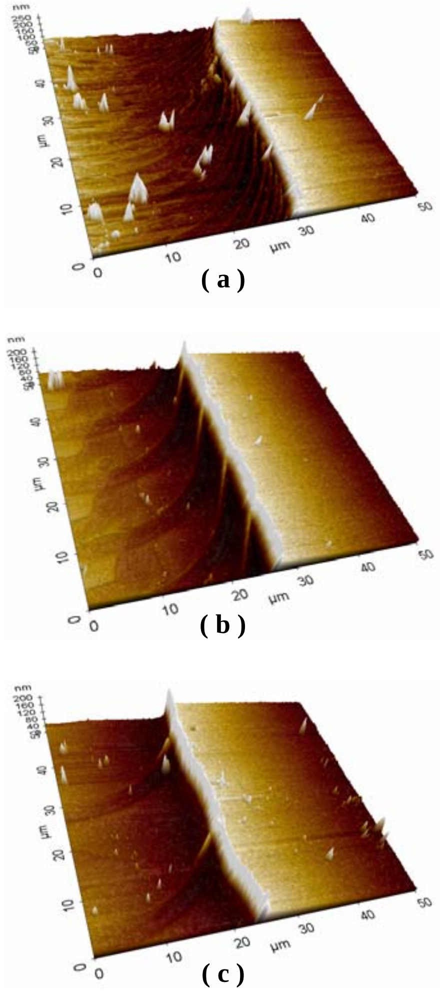


(c)

Fig. 3. SEM images of the patterned ITO ablated by laser with an overlapping rate of (a) 95%, (b) 75%, and (c) 50%.

above experimental results, the optimal overlapping rate was about 75%.

The results shown in Fig. 3 simply show changes in visual contrast between the ablated and native ITO regions. The above analysis is only an interpretation of these images. In order to ensure that the ITO thin film really is being removed, it is necessary to corroborate these ablated results using an Atomic Force Microscopy (AFM)



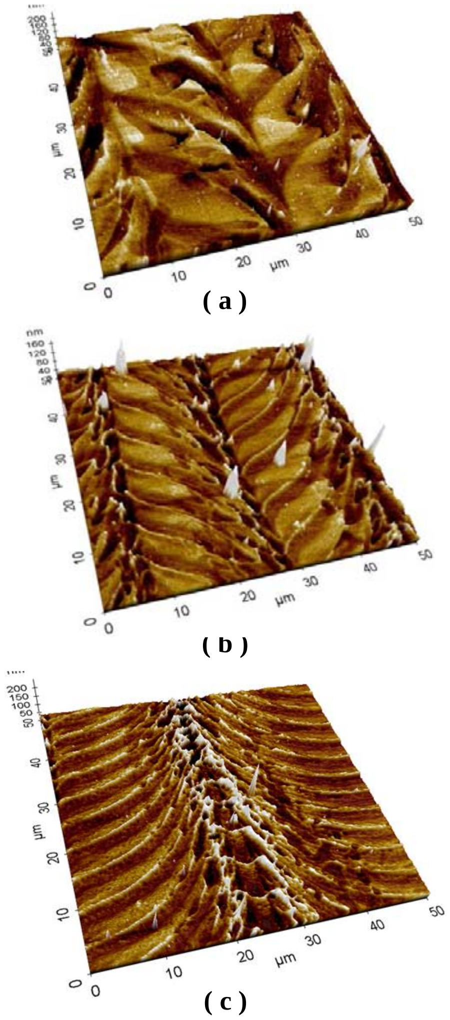
(a)

(b)

(c)

Fig. 4. AFM images of the groove edge of the patterned ITO thin film ablated by laser with an overlapping rate of (a) 95%, (b) 75%, and (c) 50%.

Fig. 4 is highly informative and gives the detailed insight for the ITO removal. We can describe that the ablated ITO layer were completely removed under the entire overlapping rate ranging from 50% to 95%. The AFM images of Fig. 4 also serve to illustrate the precision of the laser direct patterning. The region of sharp reliefs was found on the edge of the remaining ITO patterns. We defined the sharp relief a “shoulder”. It is difficult to directly read out the precise height of the shoulder from the figure. The shoulder occurs along the scanned laser beam line due to the insufficient evaporation of the melted ITO by the irradiated laser beam at the rim of the beam spot. It was reported that the shoulder line in the ITO electrode for PDPs will affect the discharge current, luminescence, lifetime, and so on [12]. Therefore, it is important to avoid the above demerits by the shoulder and to remove the shoulder lines.



(a)

(b)

(c)

Fig. 5. AFM images of the groove bottom of the ablated ITO thin film with an overlapping rate of (a) 95%, (b) 75%, and (c) 50%.

The surface morphology of the ablated groove bottom was also measured as shown in Fig. 5. It is distinct that the traces of the laser beam spot remained on the surface of the ablated glass substrate. The surface roughness (R_a) was 7.11 nm, 5.39 nm, and 4.71 nm for the overlapping rate of 95%, 75%, and 50%, respectively. Therefore, the glass substrate has been damaged on the ablated groove bottom and the overlapping rate of laser beam has a direct effect on the surface roughness of the ablated bottom.

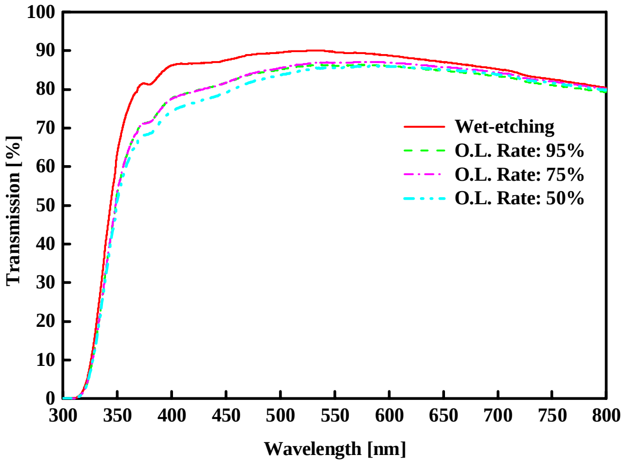


Fig. 6. Transmission of the ablated ITO thin film on glass substrate with different overlapping rates.

It is known that the transmission is one of the important parameters of ITO glass substrate and would be influenced by its surface morphology. From the Fig. 5, we know that the ablated groove area of glass substrate has different surface roughness and morphology. Therefore, we measured the transmission of the ablated groove area to analyze the damage effect on glass substrate. Fig. 6 shows the transmission results and they were compared with ITO electrode obtained by wet-etch process. From the figure, the wet-etched glass substrate has a higher transmission than the glass substrate ablated by laser. It is thought that the glass substrates are damaged by laser so that they have a relatively lower transmission than wet-etched glass substrate. Otherwise, for the glass substrate ablated by laser with the higher overlapping rate such as 50%, a lower transmission was obtained. This may be caused by its surface morphology.

4. Summary

The laser ablation technique was applied in the formation of ITO pattern to take the place of the conventional photolithography. In the experiment, we used a diode-pumped $Nd:YVO_4$ (λ=1064 nm) laser to obtain ITO patterns on glass substrate and discussed the influencing parameters of laser patterning for ITO layer.

The ITO films on glass substrate were ablated by infrared (IR) laser with different overlapping rates and the experimental results showed that the overlapping rate would affect the edge of the ITO pattern, the surface roughness and the transmission of the ablated groove bottom. When the overlapping rate was 75%, the optimal linearity of edge was obtained. And the surface roughness decreased with the overlapping rate decreasing. We also found that the glass substrates would be damaged by the laser beam and the transmission of the ablated glass substrates was a little bit lower than that in case of wet-etching process. For the more optimization of laser patterned ITO, it is necessary to concentrate on more works to solute the problems such as shoulder, damage on glass, and transmission, etc.

5. References

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