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Laser Direct Imaging of Transparent Indium Tin Oxide Electrodes Using High Speed Stitching Techniques

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To accomplish an electrode patterning in large area, we present a high speed stitching technique used in an ultraviolet laser processing system and investigate the interaction between laser beams and indium tin oxide (ITO) thin films deposited on glass substrates. After optimizing the process parameters of the laser direct imaging (LDI) for the large-area electrode patterning, the ablated lines looked like regularly fish-scale marks of about a 40 μm diameter and a 120 nm depth around the processing path. The parameters includes the laser power of 1 W, the scanning speed of galvanometers of 800 mm/s, and the laser pulse repetition frequency of 50 kHz. Moreover, the resistance value of the ablated ITO thin film is larger than 200 MΩ that is electrically insulated from the other regions of electrode structure. LDI technology with UV laser beam has great potential applications in patterning on wafer or sapphire substrates and patterning a conductive layer deposited on the touch panels for semiconductor and optoelectric industries, respectively.

Keywords: electrode patterning, high speed stitching technique, ultraviolet laser, indium tin oxide (ITO), laser direct imaging (LDI)

1. Introduction

Due to the high optical transparency and better electrical conductivity, indium tin oxide (ITO) thin films have attracted great interests for various electrode or conductor applications in thin film solar cells, touch screen cellphones, liquid crystal displays, and light emitting diodes.[1–4] In recent years, laser direct imaging (LDI) has been developed to produce the surface texturing, scribing, marking, grooving, depositing, milling, cutting, drilling, and patterning on various materials. Henry et al.[5] indicated an optimum industrial fluence of 2.8 J/cm^2 irradiated on ITO thin films with a thickness of 100 nm that could obtain high quality ITO patterns. The process time for a 42” plasma display panel (PDP) could be less than 20 s fabricated by the laser direct writing technology. Solieman et al.[6] developed UV laser direct writing techniques to pattern ITO films deposited on the borosilicate glass. The experimental results revealed that the patterned line widths increased with increasing laser powers and the number of scans. Moreover, the minimum patterned line width was about 90 μm and the roughness of patterned surfaces was less than 10 nm. Račiukaitis et al.[7,8] used high repetition-rate picosecond lasers at various wavelengths to pattern ITO films deposited on glass substrates. The removal of ITO films by a 266 nm laser radiation occurred when the laser fluence exceeded the threshold of 0.2 J/cm^2, whereas the ablation threshold for the 355 nm laser radiation was two times higher and over 0.46 J/cm^2. These results showed that the ablated trench had a minimum recast ridge and less surface contamination produced using the UV laser radiation with a fluence close to the ablation threshold. Tseng et al.[9] adopted a Nd:YAG laser with wavelength of 1064 nm to scribe the ITO thin films deposited on soda-lime glass, polycarbonate (PC), and cyclic-olefin-copolymer (COC) materials, respectively. The better edge qualities of the scribed lines could be obtained when the laser power was of 2.2 W, the pulse repetition frequency of 100 kHz, and the exposure time extends from 30 to 60 μs. Barbucha et al.[10] used a processing system with UV diode laser of 375 nm wavelength and integrated with LDI technologies to manufacture high density patterns of the circuits on the printed circuit board (PCB). After the LDI process, the machined patterns had a dimensions of 50/50 μm tracks and spaces density on the photoresist layer. The reported processing system was suitable for realizing a PCB patterns of lines and ball grid array (BGA).

In this study, a system with a UV laser of 355 nm wavelength integrated with high speed stitching techniques was used to pattern the ITO thin films deposited on glass substrates. The effects of the overlapping rate of laser spots on the ablated mark width, depth, and electrical properties of the patterned film were investigated. After LDI, the surface morphologies were examined by a three-dimensional (3D) confocal laser scanning microscope. The reaction between individual laser spot and ITO thin film could produce stitch line features in the ablated area of ITO/glass substrates, and was also examined by the 3D confocal laser scanning microscope. The electrical properties before and after LDI process were measured by a four-point probe instrument. In addition, the isolated performance of the ITO thin films was also discussed.

2. Experimental Procedure

2.1 UV laser processing system

Figure 1 shows the schematic diagram of the UV laser processing system. The system consisted of an Nd:YVO_4 laser, a beam delivery system, a 2-axis (X–Y) scanner, a focusing lens, and a PC-based controller. The Nd:YVO_4

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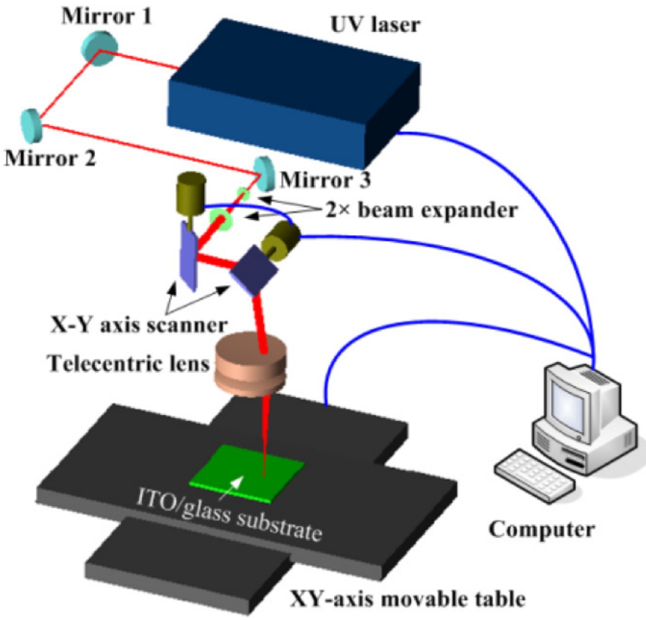

Fig. 1. (Color online) Schematic diagram of the experimental setup for laser direct imaging.

laser with a wavelength of 355 nm was produced by Coherent AVIA 355-14. The pulse repetition rate could be adjusted from 1 to 300 kHz, and the maximum laser output power was 14 W. The beam delivery system included three prefect mirrors and a 2× magnification beam expander. The telecentric focusing lens was used in this system with the focal length of 110 mm and the scanning area of $60 \times 60\,\mathrm{mm}^2$. Moreover, the minimum spot size was estimated of about 30 µm. An XY-axis movable table with ball-screw mechanism was used to stitch the ablated lines on ITO thin films.

2.2 *Sample preparation*

ITO films with a thickness of about 40 nm deposited on glass substrates were used in this experiment. Figure 2 shows a cross section image view of ITO film deposited on the glass substrate observed by a scanning electron microscope (SEM). The average sheet resistance of these films was 370 Ω/□ measured by a four-point probe instrument. The spectrometer (Lambda 900) was used to measure the transmittance and reflectance of the ITO films deposited on glass substrates. The data were shown in Fig. 3. The average transmittance of ITO/glass substrate under the visible waveband ranging from 400 to 700 nm was measured to be 88.6%. The light transmittance and reflectance values at Nd:YVO_4 laser wavelength (355 nm) were approximately 53.1 and 38.1%, respectively. Therefore, the absorptance value was 8.8% at the specified wavelength for the ITO/glass substrate.

2.3 *Laser direct imaging parameters*

A nanosecond pulsed UV laser system with wavelength of 355 nm was used to ablate the isolation lines on ITO thin films. The operation parameters for the thin films material removal in LDI included laser fluences, pulse repetition frequencies, and scanning speeds of galvanometers. The overlapping rates (O_R) of laser spot for the designed patterns with 0, 40, and 90% O_R could be defined and calculated by the following equation:[11)]

$$O_R = \frac{D - B_s}{D} \times 100\%, \qquad (1)$$

where D and B_s are the laser spot diameter and the bite size between laser spots, respectively. The B_s values can be represented as

$$B_s = \frac{V}{F}, \qquad (2)$$

where V and F are the scanning speed of galvanometers and the laser pulse repetition frequency, respectively.

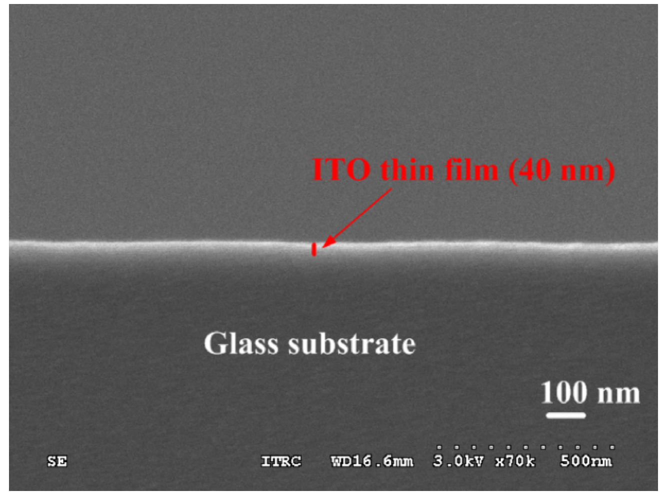

Fig. 2. (Color online) A SEM cross-section view of the ITO/glass substrate.

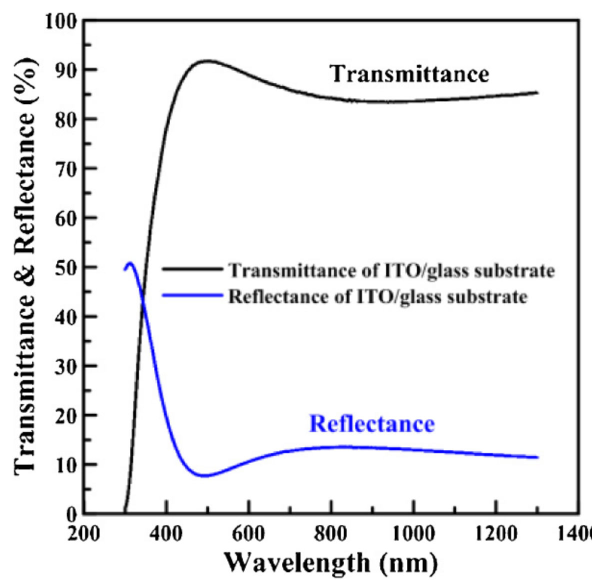

Fig. 3. (Color online) The transmittance and reflectance measurement of ITO thin films deposited on glass substrates.

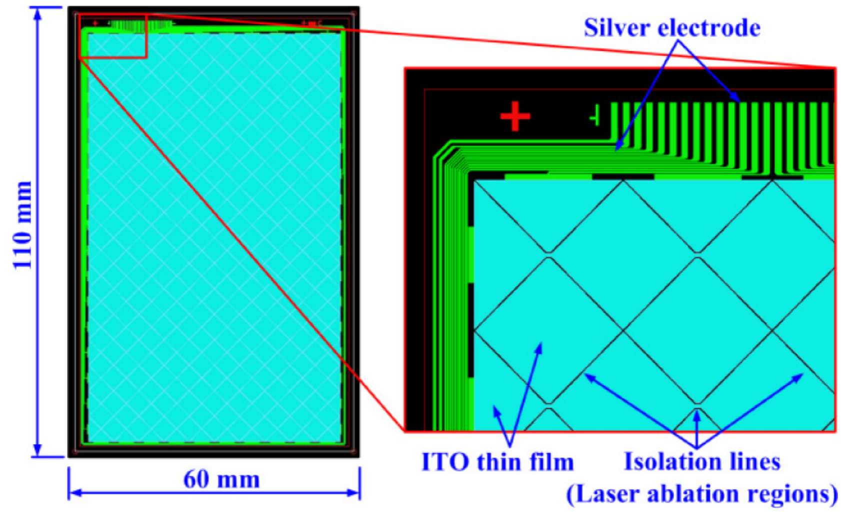

Fig. 4. (Color online) Dimensions and electrode layouts of the projected capacitive touch screen.

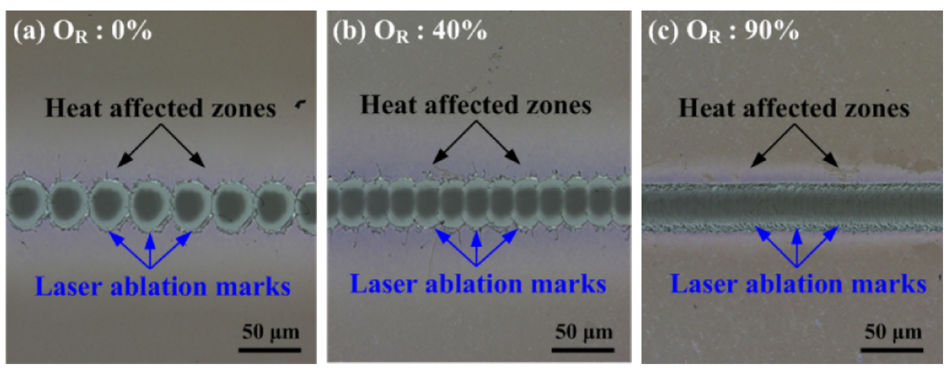

Fig. 5. (Color online) Pictures of isolated lines with different overlapping rates on ITO/glass substrates: (a) 0% O_R, (b) 40% O_R, and (c) 90% O_R.

Figure 4 depicts the dimensions and electrode layouts of the projected capacitive touch screen. The substrate width and length are 60 and 110 mm, respectively. Moreover, the thickness of the soda-lime glass substrate is 1.1 mm. The designed dimension of each rhombus pattern was 2.5 mm wide and 2.5 μm long with a gap of 50 μm between the neighboring isolated regions.

3. Results and Discussion

The overlapping rate of laser spots was an important factor of the LDI parameters. The parameters, such as scan speed of galvanometers, laser pulse repetition frequency, laser spot size, and bite size of neighboring laser spots, intensely affected on the overlapping rate of laser spots. Figure 5 shows the pictures of isolated lines on ITO/glass substrates measured by the 3D laser confocal microscope with 1000× magnification under the conditions of the laser power of 1 W and pulse repetition frequency of 30 kHz in UV LDI operations. Figures 5(a) to 5(c) reveal the surface morphologies of isolated lines with 0, 40, and 90% O_R, respectively. The interaction between the laser spot and the film surface produced water drop marks of about a 40 μm diameter around the processing line path. These water drop marks were clearly observed on the ITO films with 0% O_R and 40% O_R. The isolated line formed straight and smooth edged line on the film surface by increasing the O_R value to 90%. Moreover, the heat affected zones (HAZs) near the line edges of the ablated lines are apparent. All ablation depths of ITO films mentioned above were averagely 120 nm that could effectively reach the complete electrical isolation.

The high speed stitching techniques to accomplish a large area electrode patterning for projected capacitive touch screen is proposed. The optimal processing parameters are determined as the laser power of 1 W, the scanning speed of galvanometers of 800 mm/s, and the laser pulse repetition frequency of 50 kHz. Figure 6 shows the surface morphologies of stitching electrode structures taken by the 3D laser confocal microscope. The surface morphology of the stitching electrode structure was measured using image assembly techniques, and Fig. 6(a) was constructed from 391 pieces of assembly blocks. The dimension of each assembly block was 500 × 703 μm^2. Figure 6(b) shows the enlarged ablated region of ITO films. The straight lines and smooth corners around the ablated path are observed. These

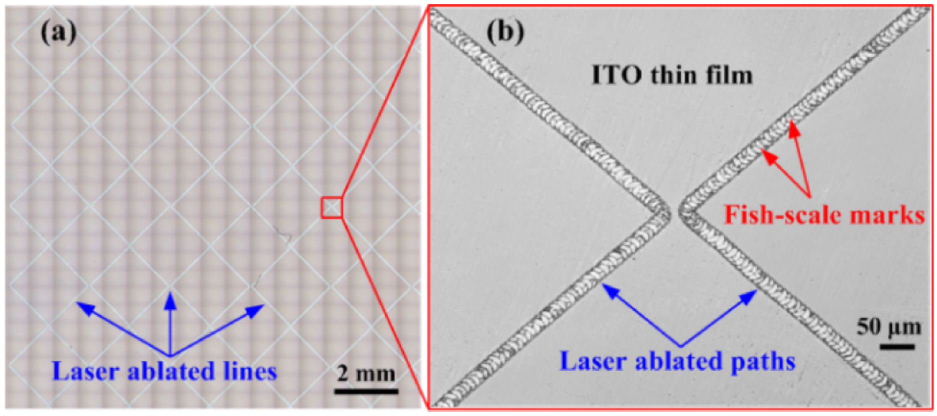

Fig. 6. (Color online) Photographs of (a) the stitching electrode assembled by 391 pieces of assembled blocks and (b) enlarged a partial electrode.

ablated lines looked like regularly fish-scale marks along a laser processing path and slightly melted ITO was found to pile up along the ablated edges. The resistance value of the scraped ITO thin film subjected to LDI was more than 200 MΩ measured by the four-point probe instrument. The laser ablated depth and width on ITO/glass substrates were approximately 120 nm and 40 µm, respectively. Moreover, the isolated performance of ITO/glass substrates scraped by the LDI was good enough for the transparent electrode layer of projected capacitive touch screens.

4. Conclusion

This study reported the successful development of laser direct imaging on a large-area indium tin oxide films for the projected capacitive touch screen application. The experimental results demonstrated that the scraped line was straight and line edges were smooth on the film surface by increasing the overlapping rate of laser spots. After the optimal LDI processing, the isolated structure of the large-area electrode on ITO thin films was achieved by using high speed stitching techniques. Moreover, the resistance value, the ablated depth and width on ITO/glass substrates were more than 200 MΩ, about 120 nm and 40 µm, respectively. This processing technology is of great potential application to pattern sapphire substrates and to enhance luminous efficiency of light emitting diodes (LEDs).

Acknowledgements

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