31.3: Rapid Laser Patterning of ITO on Glass for Next Generation Plasma Display Panel Manufacture

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Abstract

Rapid Laser Patterning (RLP) of ITO on glass offers a cost effective alternative to wet-etch lithography in the manufacture of PDPs. It is demonstrated that RLP can effectively pattern ITO to industrial standards. It is also shown that the process is rapid and has major cost benefits vs. lithography.

1. Introduction

In the manufacture of Flat Panel Displays (FPDs) one of the primary manufacturing costs is the use of wet-etch lithography. Given the price pressure on all FPDs in the global market, alternative more cost effective techniques are being sought. One such technique is the use of lasers to directly pattern thin-films, usually Transparent Conducting Oxides (TCOs) on glass. This has been investigated for over fifteen years using various laser technologies of varying pulse durations and wavelengths [1- 3]; however it is only in recent years that a credible industrial laser technique has been developed to compete with wet-etch lithography [4- 5].

This technique uses multiple high average power, nanosecond pulse duration, diode-pumped, near infrared lasers to remove TCOs from glass in a single processing step. To distinguish it from 'Laser Direct Write', a wide-ranging description, we choose to call it Rapid Laser Patterning (RLP). This paper seeks to demonstrate that a high average power, Q-switched, diode-pumped solid state laser at 1064nm wavelength can effectively remove ITO thin films from glass. This process is assessed using optical microscopy and corroborated using Atomic Force Microscopy (AFM). Furthermore the technique is compared in quality to that of wet-etch lithography for the removal of ITO regions of similar dimensions. White light interferometry is employed for analysis.

The structure of Plasma Display Panels (PDPs) is well suited for the RLP process, see Figure 1 below. This is due to the ITO coated glass front panel requiring pixel sizes of the order of 100s to 1000s µm with a positional accuracy of 5µm or so – well within the capabilities of RLP.

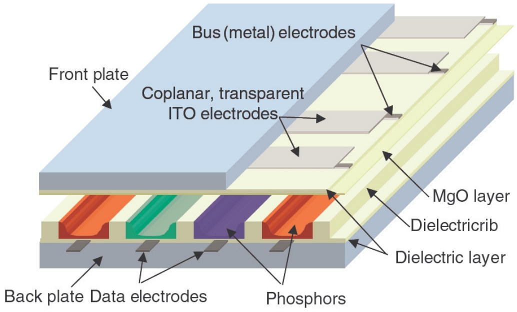


Fig. 1. PDP architecture schematic [6]

It is also demonstrated that using multiple lasers it is possible to pattern ITO on glass at commercially attractive rates. In this paper, the authors seek to show that RLP is not only technically viable but also commercially compelling – particularly for the manufacture of Plasma Display Panels.

2. Experimental

The purpose of the experimental design is to investigate RLP of thin film ITO on glass using industrial grade samples. Removal characteristics are compared and corroborated using different techniques; process rates at optimal settings can then be extrapolated to illustrate potential industrial processing rates.

The experimental set-up is as follows: all substrates are 100nm thick ITO coated on PDP grade glass 2.8mm thick (Corning). The laser used is a 400W Starlase AO4 Q-switched Diode Pumped Solid-State Laser (DPSSL) at the Nd:YAG fundamental wavelength of 1064nm. At 6kHz repetition rate output pulse energy is 53mJ with pulse duration of 35ns. The laser is attenuated externally using a proprietary Powerlase unit. Power measurements are made at the workpiece using a Molectron power meter. The beam is collimated using a Galilean telescope and homogenized by an integrated orthogonal microlens array manufactured by LIMO GmbH. The beam is imaged on to a test mask; this mask plane is demagnified and projected on to the substrate using a Rodenstock f-theta 163mm focal length lens. A HurryScan 25 galvanometric scanner manufactured by Scanlab GmbH is used to scan the beam across the sample. A pixel size of 1mm^2 is achieved at the workpiece. ITO ablation is assessed using a Nikon LM1500 optical microscope with a PC interface via a 12 Mega pixel camera into Lucia G software. This software allows microscopic measurements to be made against a Nikon calibrated standard. Further assessment of the ITO ablation is done using an Atomic Force Microscope (AFM). To further corroborate the RLP process identical shapes are patterned on the ITO using RLP and wet-etch lithography. The wet-etch samples are created by a sub-contractor Photonix Ltd in the UK. These samples are then compared using a white light interferometer from Veeco.

3. Results & Discussion

3.1 RLP Results

In generation of the results, for single pulse ITO ablation of a large pixel size, a Starlase AO4 is run at 6 kHz repetition rate. This is the highest rep. rate at which maximum pulse energy of 53mJ (at 35ns pulse duration) can be achieved. Therefore for this laser it represents optimal performance for largest pixel size and resulting throughput, and so all experiments are carried out at this setting. Nominal pixel dimensions are 1x1mm, and the empirical mask used creates an example electrode structure on the ITO that is illustrative of that in production PDPs. The pixels are 'stitched' together to create large area electrode structures. A range of trials is conducted from $1.2\text{-}3.4\text{J/cm}^2$ in 0.2J/cm^2 increments in order to determine ablation threshold for the ITO film by fluence.

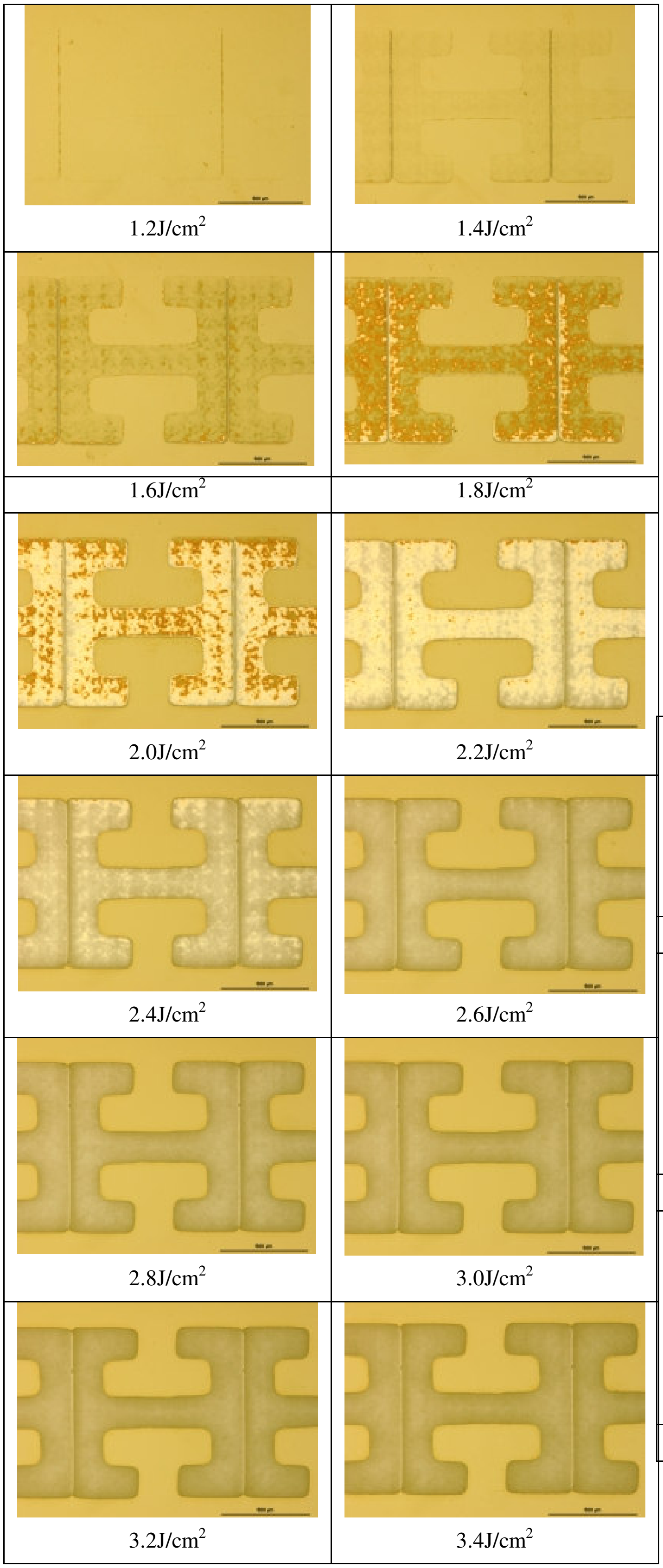

1.2J/cm^2
1.4J/cm^2
1.6J/cm^2
1.8J/cm^2
2.0J/cm^2
2.2J/cm^2
2.4J/cm^2
2.6J/cm^2
2.8J/cm^2
3.0J/cm^2
3.2J/cm^2
3.4J/cm^2

Fig. 2. Increasing fluence vs. ITO ablation

Figure 2 shows optical microscope images of the resulting ITO ablation at increasing fluence. A clear trend emerges from the images: at low fluence the ITO is barely affected, from 1.6J/cm^2 onwards structure appears that corresponds with the ripples on the top of the homogenised structure and more ITO is removed with increasing fluence. As the energy density reaches 2.6J/cm^2 the ITO removal becomes very uniform and from 2.8J/cm^2 to maximum fluence there is no discernable change in the ablated ITO region. This suggests that above a certain threshold all the ITO is removed and that the process effectively saturates. Using this visual assessment we can take the ITO ablation threshold in this case as a conservative value of 3.0J/cm^2. It is also encouraging that the ITO removal is consistent from this point on because it means that the process is reasonably tolerant of energy variation and is therefore well suited for practical industrial use.

The results shown in figure 2 are simply a change in visual contrast between the processed and unprocessed regions. The analysis above is therefore only an interpretation of these images, so to ensure that the ITO thin film really is being removed it is necessary to corroborate these results using another analytical method – in this case Atomic Force Microscopy (AFM). AFM employs a fine silicon carbide needle mounted upon a piezo-electric actuator. The needle is rapidly scanned across a 100x100µm square area and a 15nA nominal current maintained by height control between tip and substrate. By use of a laser interferometer measuring the position of the tip, surfaces can be mapped with nanoscale resolution.

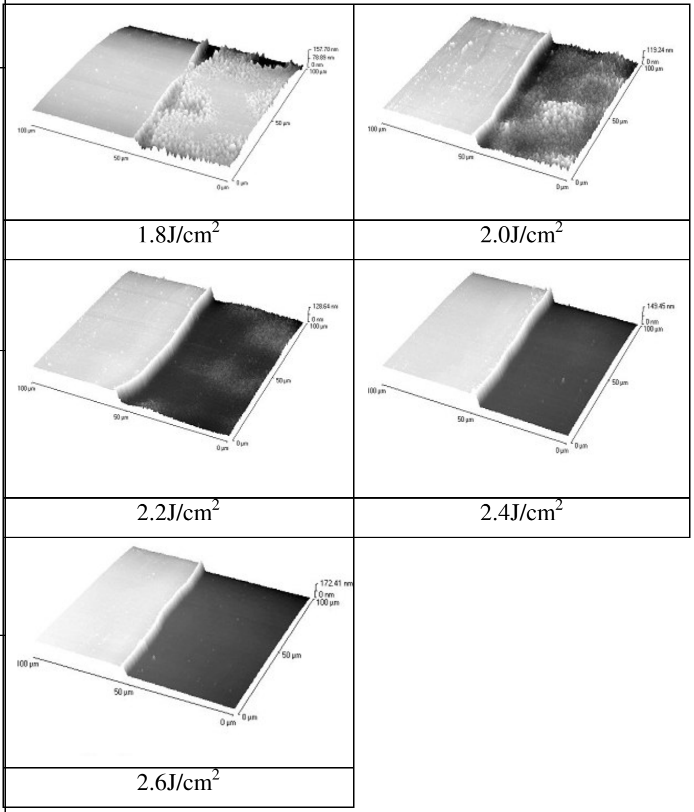

1.8J/cm^2
2.0J/cm^2
2.2J/cm^2
2.4J/cm^2
2.6J/cm^2

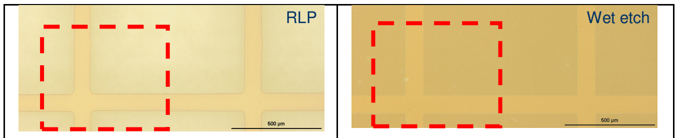
Fig. 3. 3D AFM scans across an unprocessed ITO boundary at increasing fluence

Figure 3 is highly informative and gives detailed insight into the ITO removal. At 1.8 J/cm^2 the bulk of the ITO remains, but the surface is damaged. As fluence increases the ITO residue diminishes until it appears completely removed by 2.4J/cm^2. Figure 3 also serves to illustrate the precision of this process; the edge between the virgin ITO and remaining glass substrate clearly defined with the ITO a consistent 100nm above the glass; and a 1µm edge interface in sharp relief. The ablated area is also as flat as the virgin ITO, a further indicator of a selective, precise process.

Combined the microscope and AFM data generates a strong opinion that ITO is completely removed by the laser direct write process. The AFM threshold for ablation is 2.4J/cm^2, but given the desire to be conservative for a robust industrial process, we suggest 3.0J/cm^2 as determined by optical microscopy as the optimal value for this example industrial substrate. In other work the authors have investigated these results using other nanoscale analysis techniques such as Scanning Electron Microscopy (SEM) which corroborate these findings [7].

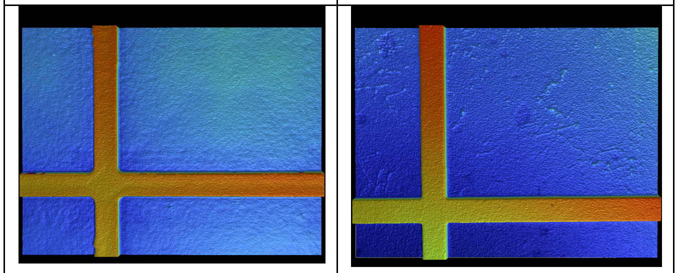
3.2 RLP vs. Wet Etch

To assess RLP by way of comparison with the traditional industrial process for patterning ITO – wet-etch lithography, a sequence of work is undertaken whereby identical patterns are created using both techniques and are then analysed and compared; in this case employing white light interferometry.



RLP - Microscopy

Wet-etch - Microscopy



RLP - Interferometry

Wet-etch - Interferometry

Fig. 4. Comparison between RLP and wet-etch lithography for ITO removal

Figure 4 above is a comparison between two identical features patterned in ITO, 850x850µm squares, using both techniques. We see fundamentally that the results are similar in both cases – clearly defined edges are achieved for the ITO feature to the same scale. Close analysis highlights some differences: first that the wet-etch process suffers from some residue, compared with RLP; second that the edge resolution from wet-etch is 3-4µm compared to ≈ 1 µm for RLP – a significant factor if smaller pixels are required for example for HDD PDP manufacture; and thirdly that the wet-etch can suffer from side etching 'mouse-bites'. When the roughness of the ITO processed areas are measured, the values are very similar: 1.64nm Ra for RLP vs. 1.40nm Ra for wet-etch.

This initial comparison suggests that RLP is at least comparative in terms of quality with wet-etch lithography for patterning ITO and may in fact offer some benefits. In future work the authors will investigate this in more depth.

4. Commercial Comparison

There are a number of significant advantages to RLP vs. wet etch. The latest generation PDP manufacturing, Gen. 8, requires the processing of 2160 x 2460mm glass panels to create x8 42" PDPs per mother panel. The minimum number of process steps required to pattern ITO lithographically is six, and this is shown in figure 5 by comparison with those needed for RLP [7, 8].

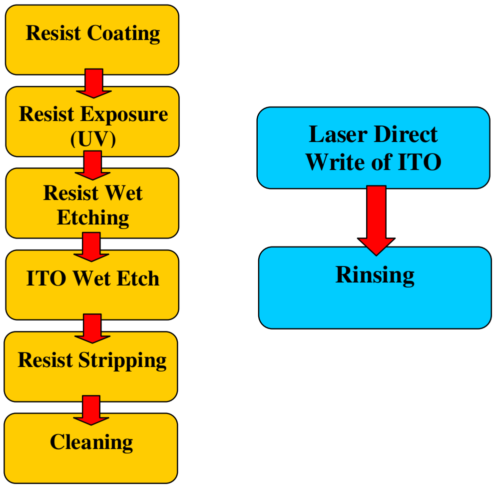


Fig. 5. Process comparison for ITO patterning by lithography vs. RLP

As can be seen the laser direct write process requires only 2 process steps versus a minimum of 6 for lithographic patterning of ITO. All processing stations will have to be large enough to accommodate a Gen. 8 panel with an area of $>5m^2$ therefore RLP offers a footprint advantage.

Further advantages to RLP are that it does not require the use of corrosive etching chemicals. It therefore offers substantial environmental benefits. It is also a soft tooling process, so is much more flexible than lithography, requiring only optical mask changes to adjust pixel shape. Finally lithography over such a large area suffers major challenges in achieving uniformity of the cured photo-resist and also subsequent wet etching. This is largely due to the handling issues caused by such large glass mother panels. Consequently yields are not always aa high as might be hoped. RLP is a much more tolerant process being purely optical, and manufacturers suggest that yields of >99% may be possible in mature mass production [4-5].

It is on this basis that RLP becomes commercially compelling. The capital cost of RLP equipment is greater than that for wet-etch lithography – but higher yields and a lack of chemical costs offer significant cost of ownership advantages over wet-etch for the life of the production line.

4.1 Cost of Ownership

A widely touted TAKT time target for manufacturing PDP glass front panels is 100s per mother glass panel per production line – or x1 42" PDP panel every 12.5s.

Table 1. Assumptions for production processing

Energy density required (J/cm^2)	3
Laser rep. rate (kHz)	6
Pulse duration (ns)	35
Optical transmission laser to substrate (%)	52
No. of pixels patterned per pulse	2
Mother glass size (mm)	2160 x 2460
No. of 42" panels on mother glass	8
Panel Resolution	WXGA
No. of Pixels	1365 x 768
Load & align time (s)	30
Align marking time (s)	30
Side blank patterning (s)	32
Robot handling (s)	15
Laser Duty Cycle (%)	49.6%

Taking these assumptions it is calculated that an x8 laser system – where each laser generates either 600 or 800W average power can process a mother glass panel in 283s.

Taking x3 laser systems per production line as patterning x1 mother glass panel <100s (94s) allows us to calculate the Cost of Ownership (CoO) vs. wet etch lithography assuming identical productivity over 3 year depreciation.

Table 2. Key Metrics for CoO calculation

	Wet Etch	RLP
No. of 42" panels required/month	180K	180K
No. of Gen 7 mother glass panels/month	22,500	22,500
Total Capital Costs	$12M	$20M
Mask Costs	$1M	0
ITO Coated mother glass panel	$500	$500
Process Yield	80%	99%
Scheduled maintenance costs (3 years)	unknown (assume 0)	$2.4M
Chemical costs per month	$450,000	0
Yield costs per month	$2.3M	$0.1M

Therefore by calculating CoO over three year depreciation we see the following relationship.

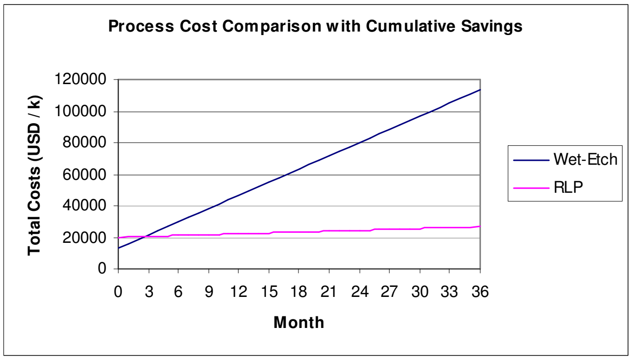


Fig. 6. Cost comparison with CoO savings RLP vs. wet-etch

As can be seen RLP is cost neutral after 3 months and over a three year depreciation potential cost savings are $86 Million for a single production line. (All data is obtained from literature, end users and industrial partners and is presented in good faith.)

5. Conclusions

It is demonstrated that RLP can pattern ITO on glass at a quality similar if not superior to that achieved by conventional wet-etch lithography. The material removal threshold is investigated using optical microscopy and AFM, whilst further comparative investigation is done using white light interferometry.

Having demonstrated that RLP is a technically credible alternative, it is shown that RLP may have significant commercial advantages over wet-etch as well – in such areas as chemical costs, footprint, process steps and yield. An example calculation is made of wet-etch vs. RLP for cost comparison over a 3-year depreciation. It is shown that whilst RLP capital costs are higher than wet-etch, RLP becomes cost neutral after 3 months and can demonstrate an $86M cost saving over 3 years with equivalent productivity for a single production line.

7. References

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