Flat Panel Display Defect Repair Using High Peak-Power Picosecond Lasers

As flat panel displays and screen resolution increase in size, the need for testing and repair of the panels become critical. As the panels become larger, the number of pixels and defects will increase [1] and even a single defect can result in the panel being scrapped. Therefore a tool for defect repair adds significant value to flat panel display production. In general, the numbers of defects are not large, so only a localized minor repair is required [2]. Manufacturing challenges for gen10 displays arise, as resolution and feature sizes are getting smaller (micron scale), while mask sizes are getting larger. In fabrication, the patterned layers are built up sequentially, so defects can be removed after each individual layer has been patterned [3], [4]. Laser repair of the defects also become more challenging as the complexity of the layers increase and the range of materials used in display manufacturing expands [5].

A laser is a well-suited and useful tool to target individual defects and remove them by laser ablation. Currently DPSS, excimer and femtosecond laser technologies are deployed for LCD mask and photomask repair [6], [7]. A schematic of a basic Thin Film Transistor (TFT) structure is shown in Figure 1. TFTs are built up from layers of (i) transparent conducting oxides (TCO's) such as indium tin oxide (ITO) and zinc oxide, (ii) metals such as aluminum, molybdenum, copper, gold and (iii) dielectrics such as silicon nitride, silicon dioxide amongst others. There are two main types of defects: 'open circuit' and 'short circuit.' The 'open' defects are caused by broken contact lines in the deposited structures. Shorting of contact lines cause the 'short' defects.

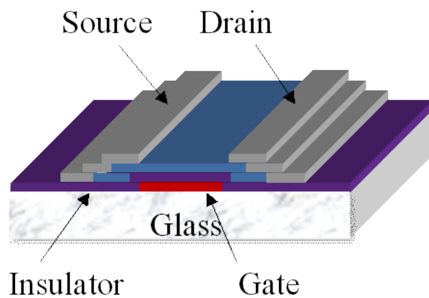

Figure 1. *Basic thin film transistor structure.*

Laser Repair Requirements

There are three main types of laser repair: cutting, welding and point defect removal. For cutting repairs, the laser pulse cuts a transistor structure such as its source gate or drain, as shown in Figure 2(a). Long pulse width lasers tend to be used for welding repair, as seen in Figure 2(b) [2], since melt generation is required to create a contact between different layers on the panel. Finally, point defects adhere to the surface and can be removed with targeted laser pulses as shown in Figure 2(c). The criteria for laser repair include:

(1) The underlying layer(s) should not be damaged.
(2) No debris on the regions surrounding the repair site or any degradation in quality.
(3) No re-deposited materials on any transparent regions around the repair site.
(4) The repair site should not be thermally affected.
(5) The repair method should be able to remove the smallest dimensions on the mask.

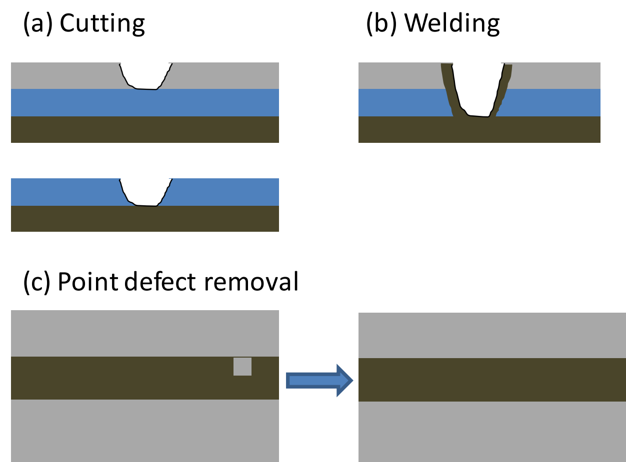

Figure 2, *Laser repair by (a) cutting, (b) welding and (c) point defect removal.*

With feature sizes/linewidths approaching 1µm for gen10 displays [4], coupled with the requirement for no damage to surrounding circuitry, highly precise laser

removal is required. The thermal penetration depth of even short nanosecond laser pulses is greater than the thickness of the layers (0.5-1μm), so it is difficult to repair one layer without damaging the underlying layer. The laser pulses need to be capable of selectively removing thin film layers <0.5 μm thick with minimal Heat Affected Zone (HAZ) and surface debris. Hence, the high quality features produced by short picosecond pulse durations [8], [9] are of interest for LCD repair. Using such laser pulses ensures that most of the energy is dissipated into the work area and not into the substrate or other layers in the panel.

Selective Removal of Thin Films

Picosecond laser pulses offer the opportunity to selectively remove thin films by "laser spallation." This process can occur when the laser pulse duration is less than the thermal/acoustic response times of the material, allowing the thin film to be essentially spallated with a single laser pulse [10]. An example calculation is made for a silicon dioxide thin film of thickness, t ~100 nm. The speed of sound in the material, c, is ~4000 m/s, so the characteristic acoustic relaxation time, A, is given by:

$$A = t / c \qquad (1)$$

Using the above values, give a value for A of 25 ps, which is greater than the laser pulse duration of 10 ps. The thermal relaxation time, τ, is calculated by re-arranging the thermal diffusivity, τ, relation:

$$t = \sqrt{4\kappa t} \qquad (2)$$

$$\tau = \frac{t}{4\kappa}^{2} \qquad (3)$$

The thermal diffusivity of silicon dioxide is κ~0.009 cm^2/s, which in equation (3) gives a thermal relaxation time, τ of 2.8 ns. The 10 picosecond laser duration is less than both A and τ, so the thin film can be removed by laser spallation. In general, the acoustic/thermal relaxation timescales of most materials are in the order of several 10's of picoseconds; hence, 10 ps pulse duration is more suitable for selective thin film removal than longer pulse width lasers. This laser spallation process minimizes damage to the surrounding and underlying materials.

A schematic of the laser spallation process is shown in Figure 3, where (a) the incident laser light is optically absorbed at the interface between the thin film and the underlying layer since the optical penetration depth is typically greater than the film thickness (<0.5 μm), then (b) the interface region is heated by the laser pulse, followed by (c) generation of a shock wave that (d) removes the thin film by spallation, minimizing damage to the surrounding and underlying materials [8], [9], [10].

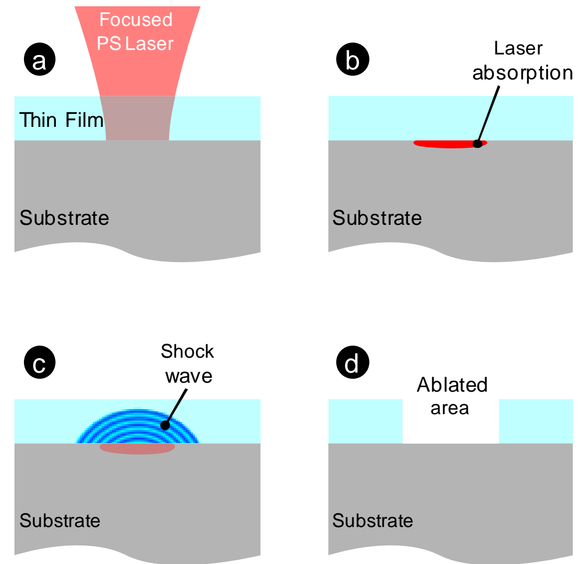

Figure 3, *Laser spallation process where (a) a focused laser beam is absorbed at an interface, (b) heating occurs in a thin layer, (c) a shock wave expands out, and (d) the thin film layer is removed.*

Controllable Pulsing

Coherent's Talisker laser features an internal Acoustic Optic Modulator (AOM), which acts as a pulse picker to control the laser output pulses. By dividing down the laser, the laser repetition rate of the output pulses can be adjusted without affecting the pulse energy, since every second, third, fourth, etc. pulse is selected by the AOM as illustrated by the schematic in Figure 4.

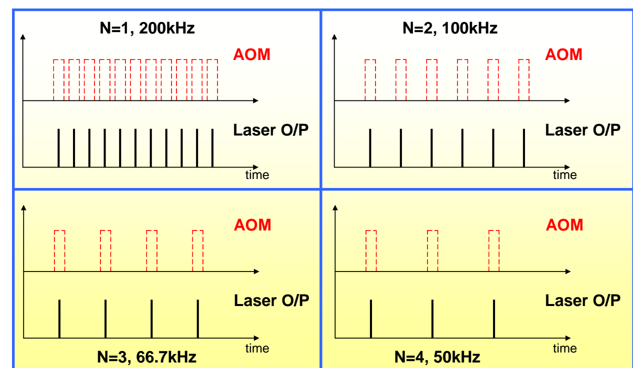

Figure 4, Illustration of divided mode, where lower laser repetition rate can be selected by dividing down the laser cavity repetition rate.

Consequently, the low pulse overlap required for low damage removal can be maintained at low translation speeds by selecting a lower repetition rate for the laser output. Also, the number of laser shots required to remove a given defect is easily controlled by presetting the number of pulses using the AOM in burst mode. These modes of laser operation offer the freedom to address individual defects with high precision.

Selective Removal of Multilayered Thin Films

The selective patterning of multiple layers of thin films is challenging, especially since the presence of melt or laser ablated particle debris can negatively impact performance. However, the laser spallation process with picosecond laser pulses allows high quality features to be laser scribed. For example, Figure 5 and Figure 6 show examples of single pulse removal of ITO from SiN and ITO from SiO_2 with no visible damage to the underlying layers or debris/molten material on the surface.

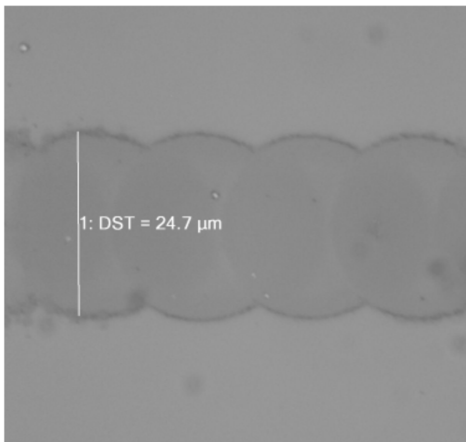

Figure 5, *Selective removal of ITO from SiN using 532 nm, 200 kHz, 5 µJ pulses at a scribe speed of 3m/s.*

These images show the holes as drilled with no post-process cleaning. Low pulse overlap is utilized to ensure selective removal of the thin films. Combined with the high repetition rate of the laser (200 kHz), it allows scribe speeds of up to several m/s.

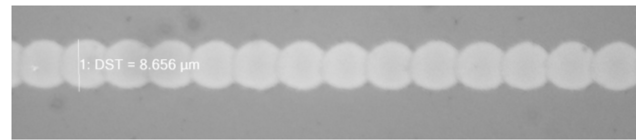

Figure 6, *Selective removal of ITO from SiO_2 using 355 nm Talisker, 200 kHz, 0.8 µJ pulses at a scribe speed of 1.5 m/s.*

Photomask Repair

Chrome deposited on glass is a common choice for photolithographic masks, and lasers can be used to remove dark defects from chrome masks. Many laser types have been used for this process, however nanosecond pulses tend to remove the chrome with a thermal process resulting in spatter and damage to the glass, both of which limit the effectiveness of the repair [11]. The thermal diffusivity, κ,, of chromium is ~ $2.9e^{-5} m^2/s$ and the speed of sound in chromium is ~4730 m/s. Using these values in equations (1) and (3) for a chromium film thickness of 70 nm, gives acoustic/thermal response times of ~15 ps and 42 ps, both of which are greater than the Talisker laser pulse duration of 10 ps. Therefore, picosecond pulses are a good choice for selective removal of chromium thin films. Figure 7 shows selective removal of 70 nm chrome from glass using 1064 nm picosecond pulses with no visible damage to the underlying glass.

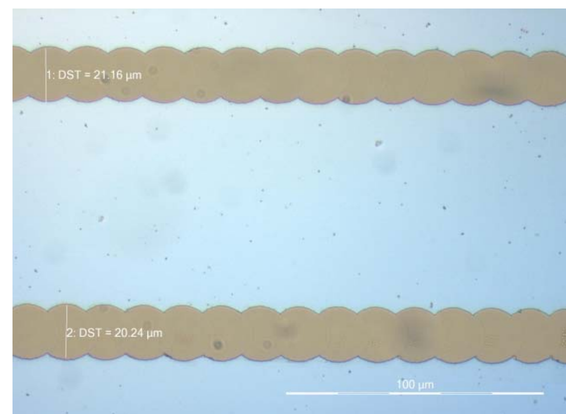

Figure 7, *Removal of 70 nm chrome from glass using 4 µJ, 1064 nm pulses at a scan speed of 3 m/s*

Summary

In conclusion, the short pulsewidth and easily controllable output pulsing of the Talisker laser offer advantages for the selective removal of thin films in multiple layer structures in flat panel displays. The picosecond pulse width is capable of producing material removal with very clean edges and minimal

damage to the surrounding materials allowing smaller and smaller defects to be targeted and removed. Hence, a picosecond laser system can prove to be an extremely useful tool in the repair of flat panel displays.

References

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