

# Lasers Enable Smartphone Manufacturing

by Ralph Delmdahl and Torsten Rauch,  
Coherent

Today's smartphones pack enormous processing horsepower, together with sophisticated touch screen displays, in a compact, rugged package. Laser processing plays a critical role in fabricating nearly every significant component in these products. Indeed, lasers can be said to be a key enabling technology in attaining the high level of functional sophistication, miniaturization and durability achieved in these devices. We take a look at just a few of the more important laser based processes commonly used in producing smartphones and other advanced microelectronic devices.

The major components of two types of smartphones, namely, those based on traditional liquid crystal displays (LCDs) and those utilizing new organic light emitting diode (OLED) technology, are shown in the simplified schematic diagram of Figure 1. The construction of both types of smartphones can be broadly broken down into four elements, namely, the back cover, the printed circuit board, the display and the touch-screen. Needless to say, each of these elements itself consists of numerous individual components.

## Printed circuit board fabrication

The electronics of a smartphone incorporate several integrated circuits (ICs), each a few millimeters in size, which are mounted onto a printed circuit board (PCB). The PCB consists of an electrically insulating substrate with conductive traces that form the appropriate interconnects for the ICs. A typical PCB has many layers of traces, which are electrically interconnected as necessary.

The drive towards increased functionality and processing speed in smartphones translates into increasingly complex PCBs. Specifically, this means a higher density of circuitry in ever smaller packages. The use of a flexible substrate, rather than traditional rigid materials, also enables greater freedom in terms of final device size and shape.

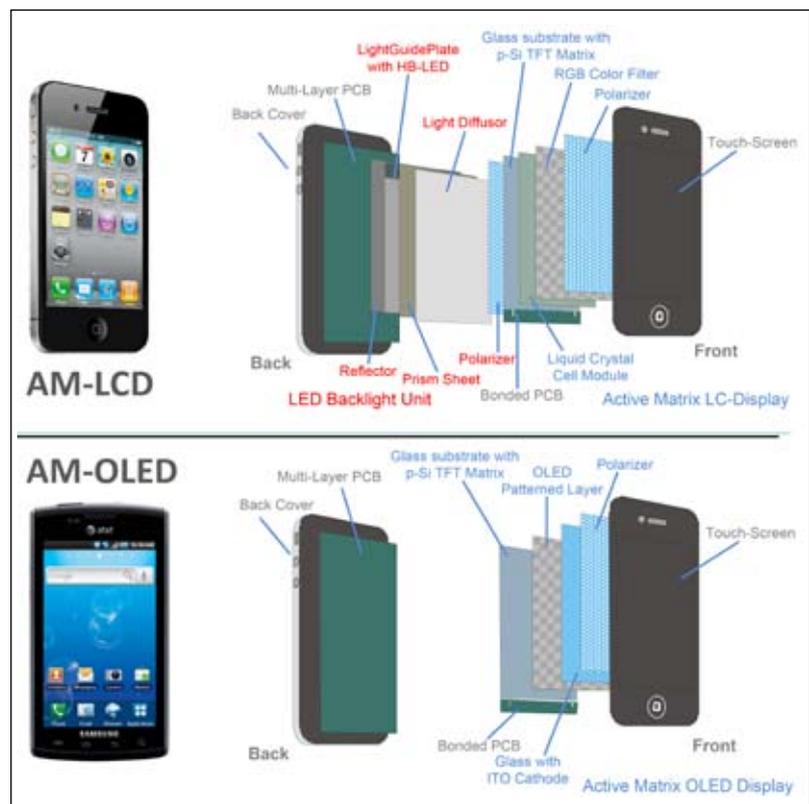
The traditional method for fabricating PCBs requires making a series of phototools, which are film-like masks containing clear and opaque areas in the actual pattern of the desired circuit elements – one mask for each layer in the board. These masks are then used sequentially to contact print onto a photoresist coated panel using a UV lamp as a light source. The exposed panel is then developed using chemicals

and plated with copper to produce the circuit traces.

However, registration errors can occur between various layers because mask and panel materials expand and contract as a function of temperature and humidity. This makes it difficult to maintain exact registration for the high density interconnect (HDI) boards being used in smartphones.

Laser direct imaging (LDI) is an alternative method in which a focused laser beam is scanned across the panel, writing the pattern directly. This approach is unaffected by environmental conditions, and the size, orientation and shape of the written pattern can even be varied on the fly as needed to maintain optimum registration.

Figure 1 – Schematic diagram showing the major components of LCD and OLED-based smartphones



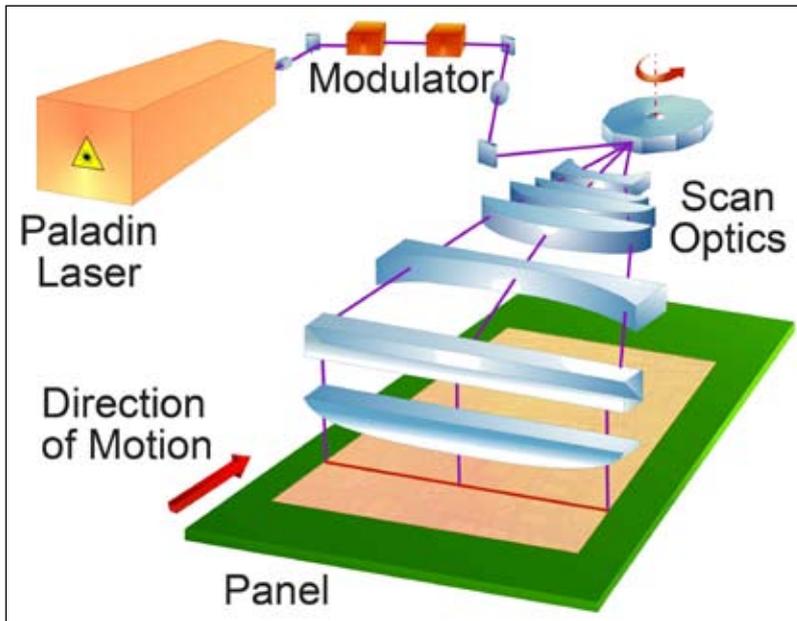


Figure 2 – In LDI, a UV laser beam is scanned over the photoresist coated panel to create the desired circuitry pattern

The specific laser requirements for LDI include ultraviolet output (to match the sensitivity of currently available photoresists), a high quality beam, multi-watt output and high reliability for 24/7 operation. Currently, the leading technology for this application is the modelocked, diode-pumped, solid-state laser with frequency-tripled output at 355 nm. Products with output of up to 24W, such as the Coherent Paladin, are now servicing this application. In particular, the all-solid-state construction of these lasers produces ruggedness, high reliability and long lifetime, and yields an output beam with excellent mode quality and extremely good pointing stability, power stability and noise characteristics.

### High density printed circuit board drilling

Another important step in the fabrication of HDI circuit boards is the drilling of small holes, called microvias, which enable electrical connections to be made between various different layers in circuit boards. Laser drilling has become the preferred method for microvia production, as it offers substantial practical and cost advantages over competing techniques. For example, mechanical drilling becomes

increasingly expensive as hole diameters drop below 250  $\mu\text{m}$ , and almost entirely impractical for hole sizes under 150  $\mu\text{m}$ .

Most microvia drilling for smart phone PC boards is performed using  $\text{CO}_2$  lasers in the 100W to 500W power range. An example of this is the Coherent Diamond K-225I, which produces up to 225W at a wavelength of 9.4  $\mu\text{m}$ . This wavelength is particularly useful since a large number of commonly used PCB substrate materials, including FR4, resin-coated foil (RCC), polyimides, PTFE, and aramids (Thermount), exhibit substantially higher absorption at this wavelength than at the more common  $\text{CO}_2$  output wavelength of 10.6  $\mu\text{m}$ .

However, as circuit density increases, and hole sizes shrink below 75  $\mu\text{m}$ , there is a move towards ultraviolet (UV) lasers for this application. This is because high power UV light delivers a cleaner, higher-quality microvia with minimal heat affected zone (HAZ) surrounding the feature. Furthermore, UV light can drill both PCB substrates and copper traces, the latter being difficult to accomplish with  $\text{CO}_2$  lasers having infrared output.

A typical laser source for this application is the Q-switched, diode-

pumped, solid-state laser with frequency tripled output at 355 nm. Lasers of this type, such as the Coherent Avia series, are available with output powers of up to 45W. This high power, together with the laser's high repetition rate (up to 100 kHz) and extremely high beam quality enable rapid, precision microvia drilling.

### Display glass cutting

In order to minimize smart phone weight, manufacturers are using increasingly thinner glass in the fabrication of displays. However, this thin glass must still withstand being dropped or rough handling. Furthermore, for touch screens, pressing on the display glass is a normal part of device operation.

Mechanical glass cutting doesn't work well with substrates less than 1 mm in thickness. In particular, it produces microcracks, creates debris, and leaves significant mechanical stress in the finished edge. All these problems necessitate further post processing.

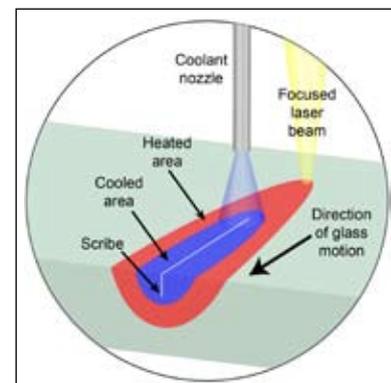
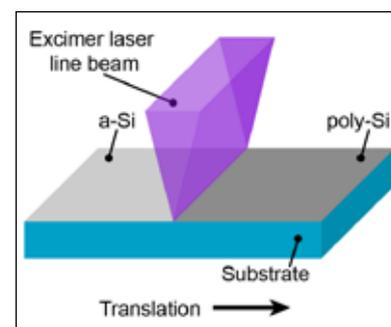


Figure 3 – Laser scribing involves heating the glass with a laser and then rapidly cooling it to create and propagate a crack  
Figure 4 – Schematic of ELA



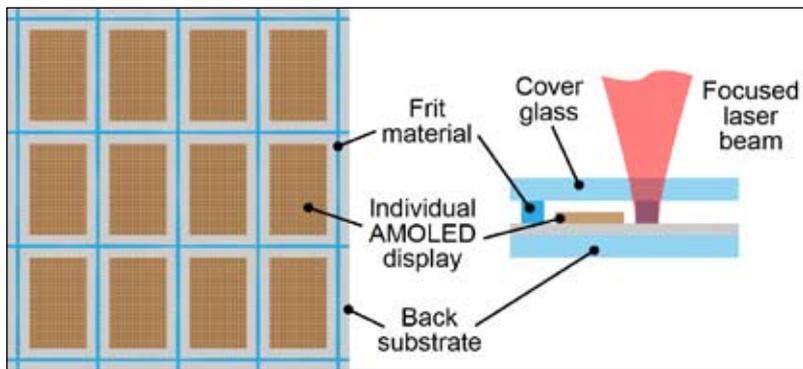


Figure 5 – A laser melts frit material to seal individual AMOLED displays prior to singulation

Laser glass cutting is a non-contact process that completely eliminates the problem of microcracking and chipping, and also produces essentially no residual stress in the glass, resulting in higher edge strength.

In one technique, called laser scribing, the output of a CO<sub>2</sub> laser is focused onto the surface of the glass, which is being translated to create a continuous cut. Since all glasses strongly absorb the 10.6  $\mu\text{m}$ , all the laser energy is deposited at or near the surface of the glass, causing rapid heating. A jet of liquid or air is then used to quickly cool the glass, and the resulting thermal shock produces a continuous scribe in the glass that is typically  $\sim 100 \mu\text{m}$  deep. The glass then passes under a mechanical roller or controlled chopper bar that imparts enough force to propagate the scribe through the entire substrate thickness and break it. This break is free of debris and perpendicular to the surface, and this laser process has even been found to deliver higher yields. A suitable laser source for this process is the Coherent Diamond K250, which provides 250W at a wavelength of 10.6  $\mu\text{m}$ .

### Faster, brighter displays

Display screens for high end smart phones are based on polycrystalline silicon because it offers higher electron mobility than the as-deposited, amorphous silicon layer. Polycrystalline silicon (called polysilicon, or poly-si) ena-

bles higher resolution and brightness, increased angle of view, and higher pixel refresh rates. The use of poly-si also offers the possibility of display driver circuitry integration on the panel for the next step in the ongoing miniaturization process. In addition, poly-si enables newer display technologies, such as active matrix organic light emitting diodes (AMOLED), which do not require backlighting and have lower energy consumption.

Excimer laser based low temperature polysilicon (LTPS) annealing is now the preferred approach for producing the critical polysilicon layer during display fabrication. This is because it can be performed at temperatures as low as 200°C, eliminating the need for expensive

quartz or thermal glass substrates. At present, the most widely used LTPS technique is called excimer laser annealing (ELA).

In ELA, the rectangular beam from a 308 nm excimer laser is optically homogenized and re-shaped to form a long narrow line that has a high degree of energy uniformity throughout its profile. This line profile is directed at the silicon coated substrate which is then scanned relative to the beam.

Silicon efficiently absorbs 308 nm radiation making it possible to achieve near complete melt with each individual pulse. This leads to efficient crystal formation due to crystal growth in the vertical direction, starting at the interface between the molten and residual unmolten silicon.

ELA requires an excimer laser that combines high pulse energy (up to 2 joules) and repetition rates of several hundred hertz at very high energy stability. High pulse energy enables a wider area to be processed with each pulse, while maintaining fluence levels in the process window. High repetition rate is necessary to achieve the required throughput. Traditional excimer lasers delivered either high pulse

Figure 6 – Cross sectional profile of a hole produced with a single pulse having 10  $\mu\text{J}$  pulse energy and a 10 ps pulse width shows the quality that can be achieved with ultrafast processing

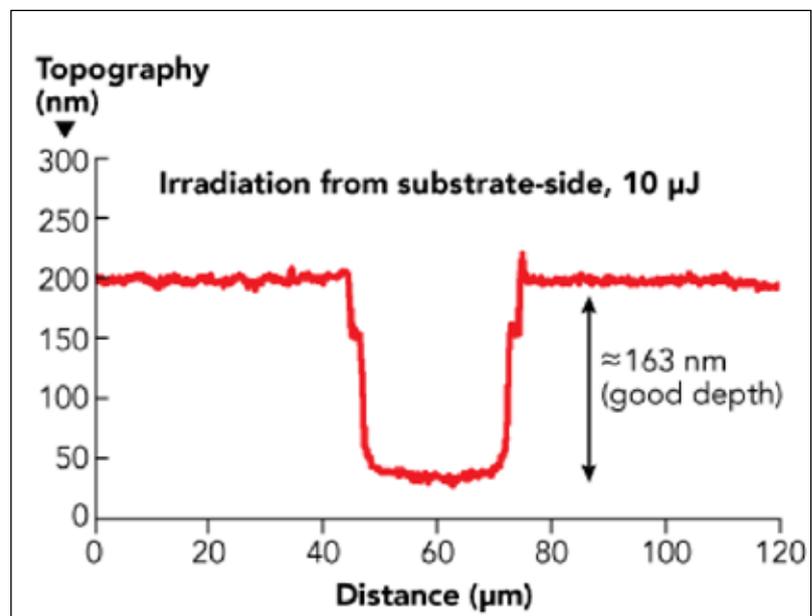




Figure 7 – Coherent's flagship platform for excimer laser annealing (ELA)

energy or high repetition rate, but not both.

In response, Coherent developed the Vyper series of excimer lasers to deliver a suitable pulse energy/repetition rate for ELA. And Coherent's latest flagship product for ELA (Figure 7) mates the 1.2 kW 308 nm Vyper excimer laser together with 750 mm length LineBeam optics to deliver a scalable platform that allows LTPS display manufacturers to seamlessly transition from the current panel generation (Gen 4) to larger Gen 6 panels, enhancing throughput significantly. Plus, the advanced design and capabilities of the system support designs through Gen 8, thus permitting manufacturers to also meet future stringent cost targets.

### AMOLED production

The AMOLEDs used in smartphones consist of a sandwich of two plates; the first contains the AMOLED backplane, and the second is clear coverglass that protects the display. These displays are actually produced in large panels which are then separated to yield individual displays. Frit welding is used to encapsulate each individual display. Specifically, powdered glass which has been doped so as to lower its melting point is deposited on the backplane in the required pattern. Next, the cov-

erglass is placed over the assembly, and a laser source is directed through this glass and used to melt the frit material.

The laser is useful for this application because it applies heat in a very localized manner, as opposed to simply heating up the entire assembly in an oven. Most commonly, a fiber delivered, high power diode laser, such as the Coherent HighLight FAP System, is utilized for this application. This is because these systems deliver sufficient power (60W in this case) at a near infrared wavelength at which the coverglass is entirely transparent. Fiber delivery enables the laser beam to be rapidly scanned over the surface of even a large panel, and the beam properties and reliability characteristics are particularly well matched to the needs of frit welding. In some cases, as many as 24 lasers are employed in parallel to rapidly process large panels.

### Touchscreen patterning

Smartphone touchscreens usually consist of a thin film of transparent conductive oxide (TCO). These films are scribed to create the required pattern of electrically isolated electrodes and interconnects. This is typically accomplished using either wet chemical photoetching, or direct ablation of

the TCO using a q-switched DPSS laser operating either in the infrared or green.

However, emerging applications, particularly for AMOLED displays, are now putting higher demands on scribe quality beyond just electrical isolation, which in turn requires a more detailed examination of scribe geometry and hence quality. With q-switched lasers, which have pulsewidths in the nanosecond regime, there is sufficient time for laser induced heat to flow out of the localized laser interaction zone and cause peripheral thermal effects. Since the laser focal spot is on the micron scale, the time for this heat flow is on the order of 10 ps or more. This means that with a laser pulsewidth of 10 ps or less, material removal can carry away most of the laser pulse energy, before there is time for thermal energy out-flow.

Industrial ultrafast lasers, such as the Coherent Talisker, supply the necessary combination of a few picoseconds pulsewidth to achieve the required thermal characteristics, together with a sufficient pulse repetition rate (up to 500 kHz) to enable the high throughput levels required for volume production. For example, even with 5  $\mu\text{J}$  pulse energies, high pulse-to-pulse overlap and multiple passes, Talisker can achieve net scribe speeds as high as 250 mm/s. And using the models with higher pulse energies (e.g. 10  $\mu\text{J}$  pulse energy 1.44 J/cm<sup>2</sup> fluence) isolating lines can be scribed at up to 2000 mm/s.

In conclusion, lasers have become an indispensable tool in many aspects of smartphone production. In particular, their ability to perform non-contact, high precision, high speed processing is essential for many process steps. Additionally, lasers often eliminate the use of wet chemicals, making them a more environmentally friendly tool. And finally, the high reliability and low cost of ownership of today's laser sources make them an economically viable alternative to most other technologies.