UV Lasers Enable Smart Phones and Other Microelectronics

Solid state and excimer lasers are reliable workhorses for the various needs of semiconductor industry

The smaller package sizes and increased functionality of today's smart phones create numerous manufacturing challenges, many of which are now being solved with high performance UV lasers.

Laser technology's role in semiconductor and microelectronics fabrication is growing dramatically as manufacturers seek to economically produce smaller and more energy efficient devices having ever greater functionality. Nowhere is this trend more clearly evident than in the current generation of smart phones, which combine impressive processing horsepower with high quality displays in a handheld package. In many cases, component manufacturers have turned to ultraviolet (UV) and deep UV (DUV) lasers to meet the extreme demands of smart phone production. One reason for this is because short, UV wavelengths enable very high spatial resolution processing, thus allowing greater circuit density and improved process utilization. Also, high energy UV photons typically produce minimal damage to surrounding material, an outcome that is difficult to achieve with many traditional fabrication techniques. This article reviews three laser-based applications in smart phone manufacturing, and some of the diverse UV laser technologies that have been developed to service them.

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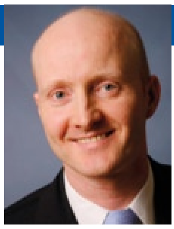

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Wafer Inspection

The purpose of wafer inspection is to find yield limiting or performance reducing defects during chip manufacturing. As critical circuit dimensions shrink, manufacturers are tasked with finding smaller and smaller killer defects. Current state-of-the-art for integrated circuit fabrication is 65 nm critical dimensions. This is expected to transition to 45 nm, and then 32 nm within the next five years.

Most laser-based wafer inspection utilizes scattering and absorption phenomena to locate defects or contamination. There are several different configurations for how laser inspection is implemented, depending upon the type of surface being examined (pattern or unpatterned wafer), and the type of defect being sought (pattern defects, contaminants, voids, etc.). Broadly, laser wafer inspection schemes can be classed as either "brightfield" or "darkfield," where the wafer appears bright with defects showing as dark areas, or vice versa. Typically to implement these schemes, the laser is either transformed into a line or scanned across the surface of the wafer under test, and scattered or returned light is detected by a photomultiplier or array detector (Fig. 1).

Two critical inspection parameters are sensitivity, that is, the ability to accurately identify defects of the size range desired, and throughput speed. Meeting the need for higher sensitivity and decreased feature

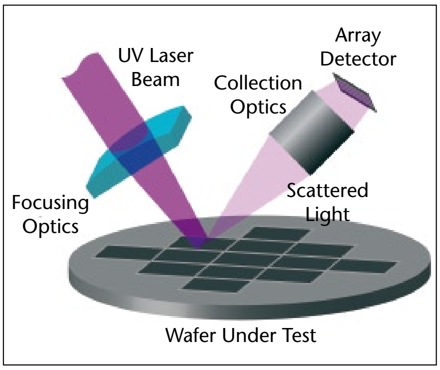

FIGURE 1: **Schematic of patterned wafer inspection.**

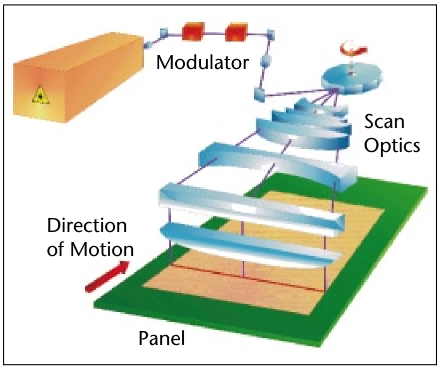

FIGURE 2: **Schematic of LDI operation.**

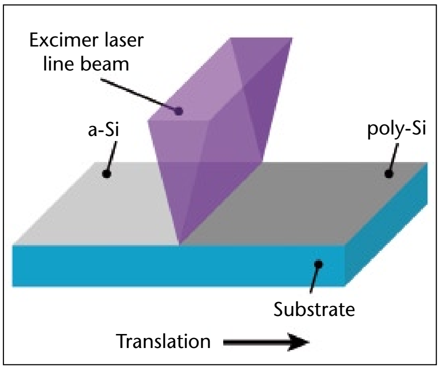

FIGURE 3: **Schematic of ELA.**

sizes has pushed tool builders to transition visible wavelengths (600 – 800 nm) to deep into the UV, in particular to 355 nm and 266 nm. The demand for throughput is met by increasing output power.

A typical laser source for wafer inspection is the Coherent Azure, which is a continuous wave (CW) laser that delivers 200 mW at 266 nm. The shorter wavelength enables the highest sensitivity and the combination of power, high beam quality and CW operation enables the surface of the wafer to be scanned relatively rapidly, thus supporting high throughput. To achieve this high UV power, the Azure doubles the output of a Coherent Verdi laser, which is a frequency doubled, diode pumped solid state (DPSS) laser operating at 532 nm. Specifically, the output of the Verdi is passed through a resonant enhancement cavity (a cavity that is closely matched to the wavelength and mode of the input so as to produce high intracavity power) to maximize the efficiency of frequency doubling to 266 nm.

Laser Direct Imaging

The demand for smart phones that fit more circuitry into a smaller space has also led to increased use of high-density interconnect (HDI) circuit boards, and Laser Direct Imaging (LDI) has become a key technology in the production of these. In LDI, a mode-locked UV laser is used to image a pattern directly onto a photoresist-coated panel, completely eliminating the use of a traditional photo tool, i.e. film. The most obvious benefits of LDI are the time and costs savings associated with the creation, use, handling and storage of these photo tools. In addition, LDI avoids any quality problems associated with film-related defects. LDI also delivers significantly better registration than traditional contact printing fabrication methods. This improvement can increase process yields, especially when dealing with the tight tolerances encountered in HDI boards.

In the most common LDI implementation, the front end CAM system is used to modulate a focused laser beam that is raster scanned across the panel (Fig. 2). The desired image pattern is built up line by line, analogous to the way in which an image is formed on a CRT display. After imaging is completed on one side of a panel, the panel is flipped and the second side is imaged.

Dimensional changes can occur in a circuit board during the fabrication process due to fluctuations in ambient temperature and humidity. The ability to correct for these changes, on the fly, is one of the key differences between LDI and traditional production methods. To determine the necessary transformations, an imaging system in the LDI instrument measures the precise positions of features or fiducial marks on the panel, and then uses these measurements to calculate exactly how the pattern should be altered in order to optimize registration for that unit or batch. Typically a side-to-side registration of 10 µm can be achieved over a 24″ x 32″ panel on a production basis. This ability to achieve tight registration tolerances can have a particularly significant yield impact on production of PCBs with small design rule tolerances.

FIGURE 4: **The high pulse energy and repetition rate for ELA are delivered by huge excimer laser systems.**

The Coherent Paladin laser was developed to meet the needs of LDI and other applications that need a reliable, high-power UV laser source with reduced operating costs. The Paladin is a mode-locked, diode-pumped, solid-state laser with frequency-tripled output at 355 nm. Output powers of up to 16W are available. The high output level of the all-solid-state laser system makes it possible to use less expensive dry films while still maintaining adequate process throughput rates.

Low Temperature Polysilicon Annealing

Display screens for high end smart phones such as the iPhone are based on poly-silicon rather than the amorphous silicon used for most flat panel displays. Poly-Si possesses substantially higher electron mobility than amorphous silicon. As a result, liquid crystal displays (LCDs) based on poly-Si technology can deliver higher resolution and brightness, greater 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 cost less to make than LCDs and have lower energy consumption.

Excimer laser based low temperature poly-silicon (LTPS) annealing is now the preferred approach for producing the critical poly-silicon 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).

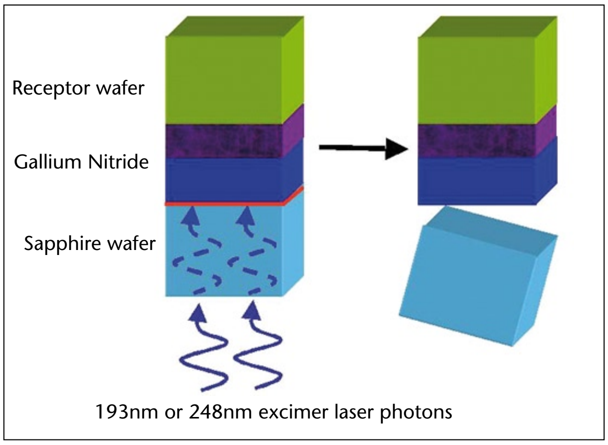

FIGURE 5: **Separating the sapphire substrate from the GaN emitter layer using LLO.**

In ELA, the rectangular beam from a 308 nm excimer laser is optically homogenized and reshaped to form a long narrow line (typically around 465 mm x 0.4 mm) 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 (Fig. 3).

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 and excimer laser that combines high pulse energy (1 Joule) 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 energy or high repetition rate, but not both. Coherent has met the needs of ELA with the LAMBDA SX, which can deliver 1 Joule pulses at a repetition rate of 500 Hz (Fig. 4).

THE COMPANY

Coherent Inc.

Coherent designs and manufactures a broad selection of lasers and supplies electro-optic instruments for laser test and measurement. The company's products include laser diodes and laser diode systems, CO2 lasers, excimer lasers, ion lasers, CW and Q-switched DPSS lasers and systems, ultrafast lasers and amplifiers. The company provides worldwide service and applications support.

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Excimer Laser Lift-Off Processing

Laser Lift-Off (LLO) is an enabling back-end processing step in producing vertically-structured LEDs (light emitting diodes) for efficient backlighting of display panels. GaN-LEDs are most commonly fabricated on sapphire substrates because this material provides a good lattice match for the growth of GaN crystals. However, the use of sapphire as a substrate limits LED output power because of its poor electrical and thermal conductivity, which prevents efficient heat dissipation.

Applying LLO, high quality GaN can be grown epitaxially on sapphire with the 248 nm excimer laser light subsequentially being directed through the sapphire substrate, which is transparent at UV wavelengths. Absorption of the 248 nm excimer photons occurs within a thin layer of some 100 µm at the interface between the GaN and the sapphire wafer resulting in thermally induced de-bonding and generation of free-standing GaN (Fig. 6).

FIGURE 7: **248 nm beam delivery system for homogeneous, large-field wafer illumination.**

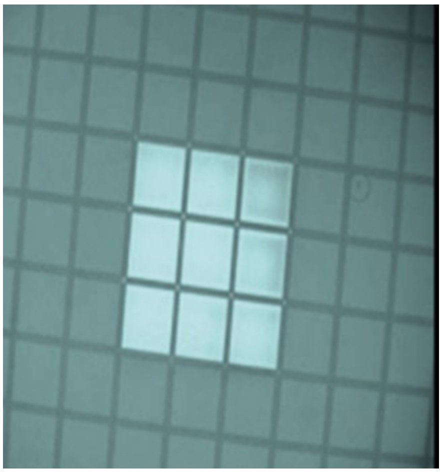

FIGURE 6: **Lift-Off processing of a sapphire wafer with a large, 2 mm by 2 mm square field.**

An excimer laser mask projection system can deliver a large 2 mm-by-2 mm field size on to the sapphire substrate wafer. The advantage of this approach is that many LED dies can be covered at once per individual laser pulse. For a two inch wafer containing as much as 27,000 dies, an overlap of nine dies per laser shot results in a fast cycle time of 100 wafers per hour using a pulse frequency of 100 Hz (Fig. 7).

Conclusion

A broad range of UV lasers have become indispensable tools in microelectronics production applications because they support the trend towards smaller circuit geometries with higher device performance, and often enable a greener and more economical process than other technologies, especially those based on wet chemistry. As miniaturization and increase in functionality of personal electronic devices continues, we expect that new and exciting applications requiring lasers generally, and UV lasers in particular, will develop as manufacturers seek enabling precision technology to produce the next generations of personal microelectronic devices.