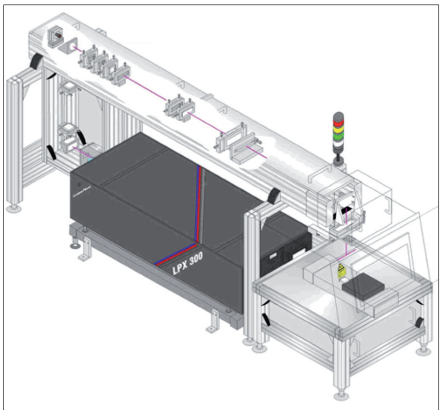
Large-area laser lift-off processing in microelectronics

UV laser lift-off delamination opens the path to both novel three-dimensional wafer-based electronic device structures and polymer-based active matrix display panels such as AMOLED for smart-phones, readers, tablets and potentially large size TVs.

The proper choice of wavelength, optical system and fluence enables layer-selective laser lift-off (LLO) to process functional thin films in a way not achievable using other heat sources, something that becomes increasingly important as feature size and film thickness in microelectronics applications continue to decrease. Such trends motivate the ongoing development of suitable excimer laser sources and optical beam delivery systems for the most appropriate wavelengths, 248 nm and 308 nm.

LLO processing of wafers or large size polymers on glass substrates requires sequentially exposing areas of the substrate to be released to single UV laser pulses until the entire surface area is covered. When it comes to large size wafers up to 300 mm diameter or large Gen 5.5 to Gen 8 substrate panels which have to be released from polymer thin films, it is most effective to use line beam scanning for LLO within one or two consecutive scans.

The figure below shows an optical system for line beam generation. At typical fluence levels of above 250 mJ/cm² line beam lengths of up to 750 mm are commercially available supporting high throughput processing of even the largest wafers or display panels. The typical thickness of the polymer film spin-coated on the glass carrier is only ~150 µm. Only the 308 nm wavelength provides a suitably shallow penetration depth and thus leaves the temperature sensitive circuitry entirely unaffected. The optimum processing strategy in LLO for LED manufacturing relies on rastering the substrate to be delaminated by square fields of up to 5 mm x 5 mm covering many LED dies with each laser pulse. Whereas polymer delamination from glass is achieved at relatively low fluence, in LED LLO processing an energy density at the sapphire/GaN interface of at some 700 mJ/cm² has to be provided to decompose the GaN into metallic gallium. Due to these requirements, the excimer laser, especially the KrF excimer laser operating at 248 nm, is the first choice for LLO.



Schematic layout of a line beam optical system for wafer LLO

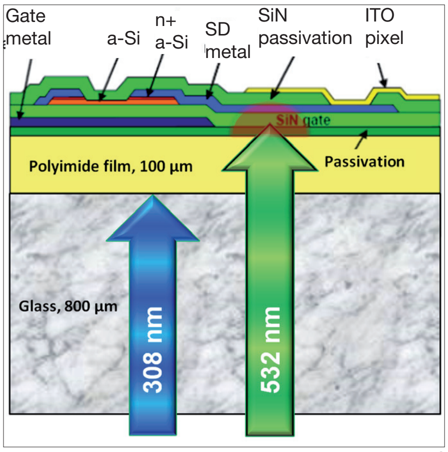
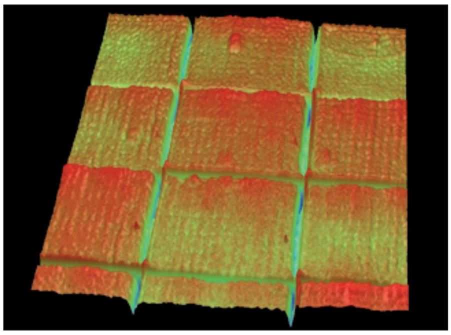


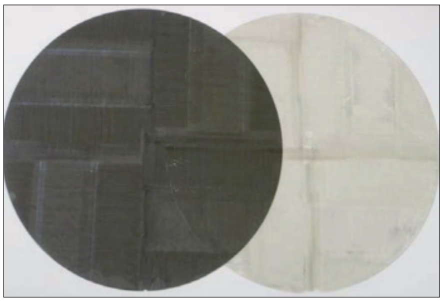
Illustration of the UV wavelength advantage in LLO

248nm line sapphire wafer separation

The figure below is a white light interferometry image of a gallium nitride (GaN) epi-wafer after LLO processing and removal of the sapphire wafer. Clearly visible is the regular pattern of trenches but prior to wet chemical removal of the metallic gallium. Trench depth is only about 25 nm and due to the slight overlap of neighbouring pulses. Industrial process rates are achieved using square fields at low pulse rate, as listed in the table below.



GaN surface after 248 nm LLO of sapphire



308 nm LLO removal of 70 µm thin silicon wafer from glass carrier

Thin silicon device wafers separation

LLO of thin silicon device wafers from their glass carriers is done by ablating the polymer layer through the glass wafer. After laser lift-off, the glass wafer can be easily removed from the silicon wafer, as shown in the figure above. Both the device and carrier wafer generally need to be cleaned to remove the remaining polymer film which is a few hundred nanometres thick at the glass side and some microns thick at the thin wafer side. Rectangular field processing using one large rectangular pulse per area with a 5% overlap to the adjacent pulse results in fast and cost-efficient processing even at low pulse frequency.

In a manner very similar to that applied to polymer bonded glass wafers, glass panels can be delaminated from polymer films by irradiating at 308 nm from the glass side. However, from an industrial manufacturing viewpoint line beam scanning is the preferred approach as this strongly reduces the number of scans required for covering the entire panel.

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Microelectronics Application	Substrate Size	PRF	Field size	# pulses	Throughput
High Brightness LED Wafer	6 inch	20 Hz	5 x 5 mm²	~ 1,000	> 60 wafers/hr
Thin Device Wafer	12 inch	20 Hz	50 x 2 mm²	~ 1,000	> 60 wafers/hr
Flexible Display Backplane	Gen 4.5	200 Hz	370 x 0.4 mm²	~ 5,000	> 60 panels/hr

Model processing parameters of excimer laser lift-off complying with industrial throughput rates