

Thin Film Processing with UV Excimer Lasers

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Driving cost-efficient material and process development in display and microelectronics industries is largely facilitated with the flexible VarioLas family of UV excimer laser surface processing systems. Two processing approaches, line-beam scanning or large-area square-field step and repeat processing can be chosen supporting selective layer annealing as well as various lift-off tasks. Shrinking structures in microelectronics put UV excimer lasers in the forefront as to the formation of ultra shallow junctions (USJ) for ever smaller CMOS logic devices such as CPUs and memory chips, of power devices such as insulated gate bipolar transistors (IGBTs) and of advanced CCD or CMOS based image sensors. The respective functional structures are activated by diffusion-controlled, 308nm excimer laser annealing with low-thermal-budget. Excimer laser wavelength, repetition rate, fluence and pulse width can be flexibly adapted to optimally match the device-specific process windows and vary structure sizes and processing depth over a wide range.

Keywords: UV excimer laser, thin film processing, annealing, laser lift-off, dopant ion activation

1. Introduction

UV excimer lasers have emerged as the enabling tool in improving display performance and advancing product innovations such as faster pixel switching rates, reduced power consumption, weight and thickness or paper-like mechanical flexibility which are critical to keep pace with ever-changing customer demand [1,2].

Aiming at driving cost-efficient material and process development in display and microelectronics industries Coherent has invented the VarioLas family of excimer surface processing systems.

This article reviews the flexible VarioLas product structure and their enabling potential for driving developments in large-area UV surface processing and UV laser annealing.

UV photons can either be applied via demagnifying a mask pattern image or by scanning a homogenized excimer beam across the substrate area. 193nm, 248nm and 308nm wavelength applications are supported.

2. Experimental

The VarioLas excimer laser based UV optical system shown in Figure 1 consists of entirely modular building blocks both for parameter control and lab safety requirements.

These can be flexibly added to best reconcile individual technical and budget requirements.

Two basic excimer laser processing geometries, namely large-width line-beam scanning or large-area square-field step and repeat processing can be realized with the new VarioLas family depending on the individual type of application as is shown in Figure 2.

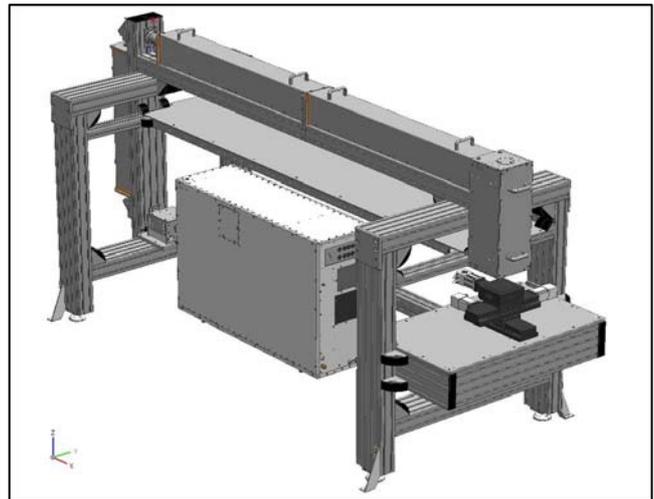


Fig. 1 Basic layout of the flexible VarioLas optical platform.

Therefore, both low-temperature line-beam or step and repeat annealing and patterning of flat panels and wafers up to 4 inch diameter are possible.

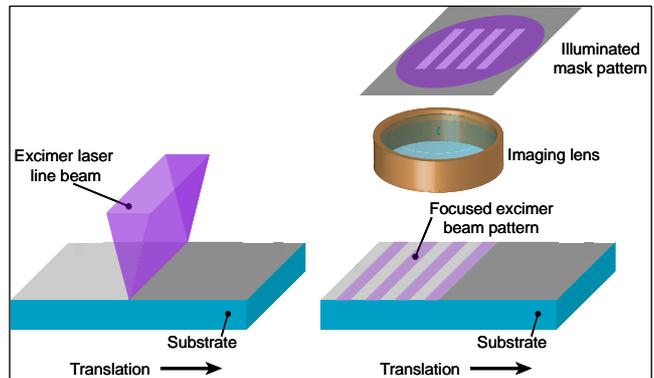


Fig. 2 Line beam scanning (right) and mask patterning (left).

Parameters for maximum on-sample field sizes (2mm x 2mm), energy densities (up to 3.5J/cm²) and minimum feature sizes for low resolution (<30µm) and high resolution (<5µm) square field systems as well as the line field system (50mm x 0.6mm) enable high-resolution over a large area at the dominating micro-processing UV wavelengths 193nm, 248nm and 308nm.

3. Large-Area Thin Film Processing

VarioLas UV processing solutions aim at driving advancements in various low-temperature, thin-film processing areas three of which will be outlined in the following.

Note, that either of these application examples can be conducted using line-beam scanning and step and repeat mask imaging, respectively.

Flexible displays have enormous commercial potential, but their introduction has been slowed by several significant technical challenges and process development has to be advanced.

In particular, the thin plastics substrates used for flexible displays are too delicate to be handled with traditional tooling, and will typically lose their limited rigidity at the high temperatures experienced in some production steps.

UV laser beam techniques such as *Surface-Free Technology by Laser Annealing* (SUFTLA) enable fabricating the display circuitry on a rigid substrate using traditional methods, and then use the UV photons to deposit highly localized energy at an interface, inducing lift-off of the active devices from a rigid carrier material [3].

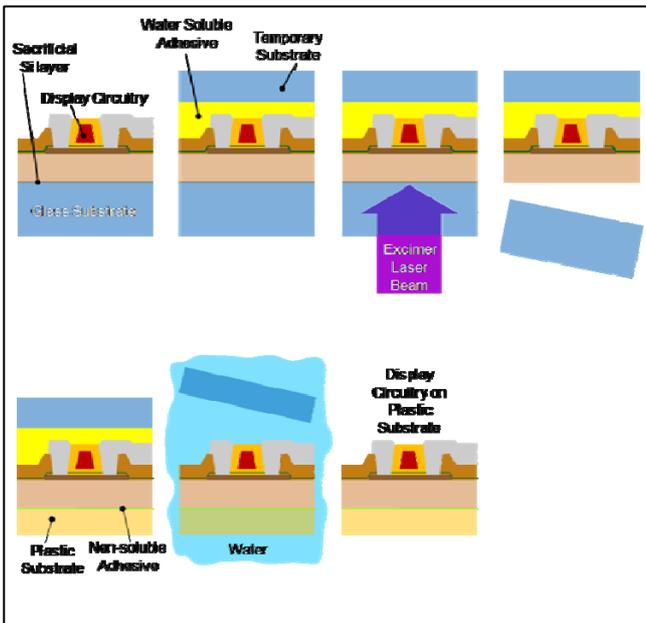


Fig. 3 Sketch of the process steps of the SUFTLA method.

In the SUFTLA process, shown in Figure 3, a sacrificial silicon layer is deposited on a standard substrate, and display circuitry is fabricated on top of this layer using completely traditional methods.

A series of steps are performed to bond the circuitry to a temporary substrate, release the original glass substrate and then bond to a permanent, flexible plastic substrate.

Laser Lift-Off (LLO) is a crucial processing step in producing high-brightness LEDs (light emitting diodes) based on GaN [4].

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.

With LLO, the GaN can be favorably grown in an epitaxially manner on sapphire with 248nm excimer laser light which is subsequently directed through the sapphire substrate, which itself is transparent at UV excimer laser wavelengths.

As depicted in Figure 4, the absorption of the 248nm excimer laser photons occurs at the interface between GaN and sapphire layers resulting in a thermally induced homogeneous and crack-free debonding of the adjacent layers.

With the VarioLas, a mask projection system can be used to deliver a large, square (2mm x 2mm) field on to the sapphire substrate.

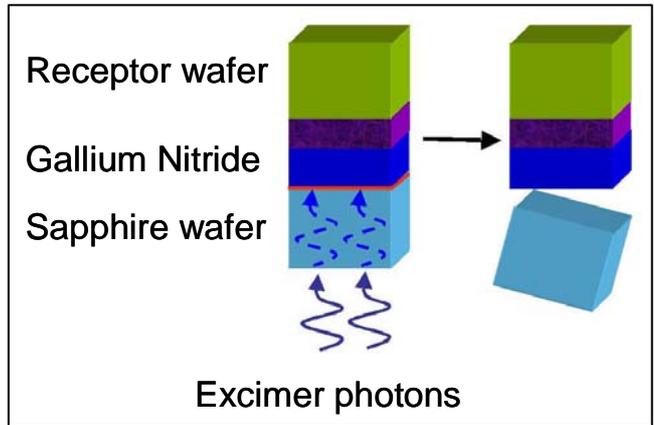


Fig. 4 Interfacial absorption of the excimer laser light and lift-off.

The advantage of this approach is that many LED dies (the typical die size is 400µm x 400µm) can be covered at once as indicated in the sketch in Figure 5.

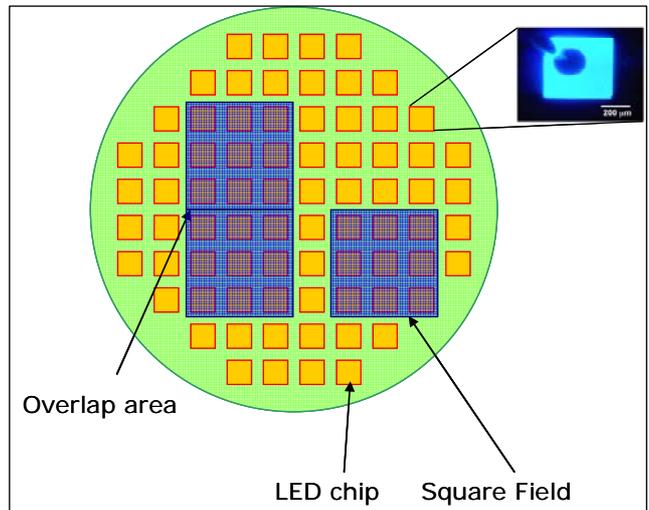


Fig. 5 Controlled delamination of epitaxially grown GaN.

In addition, the use of a large, highly homogeneous excimer laser beam avoids the creation of thermal gradients across the individual dies which might ultimately produce non-uniform delamination.

Diffusion or cracking is easily prevented by placing the excimer laser beam edges and overlaps of the illuminated areas in the trench regions between the respective dies.

Dopant Ion Activation by low-thermal budget excimer laser annealing at low diffusion depth is pivotal to the development of high-performance miniaturized electronic switching circuits. With CMOS structures approaching the 60nm node excimer lasers become pivotal for driving advancements in CMOS, PMOS and other related technologies [5,6].

As a matter of fact, full surface activation of boron ions implanted in silicon (100) wafers at a dose of $1.6 \cdot 10^{14} \text{ cm}^{-2}$ and with an energy of 15keV yield surface resistances of about 111mV/mA.

Annealing was done at 3J/cm^2 with a single pulse per area at a mask field homogeneity better than $\pm 3\%$ (within the 2σ confidence interval).

A surface map of a doped five inch silicon (100) wafer obtained after activation by excimer laser annealing is visible in Figure 6.

The false color image indicates the high level of homogeneity in surface resistance which is achievable with UV excimer laser annealing.

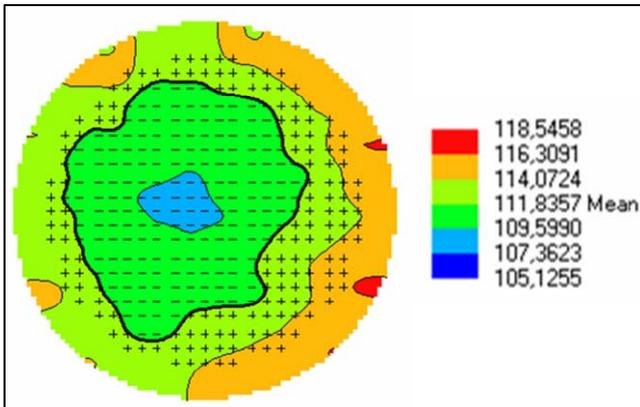


Fig. 6 Surface resistance plot of a doped wafer after excimer annealing at a wavelength of 308 nm.

For this specific case the field size was adopted to be 2.7mm x 2.7mm on the wafer surface during step and repeat excimer laser annealing.

Figure 7 shows a Scanning Electron Microscopy (SEM) image that shows the overlap pattern of the individual laser shots obtained in a large-area step and repeat melt-regime annealing process at a wavelength of 308nm.

Perfect crystallinity is obtained after controlled laser surface melting and recrystallization with excellent lot-to-lot process stability of the measured surface resistances.

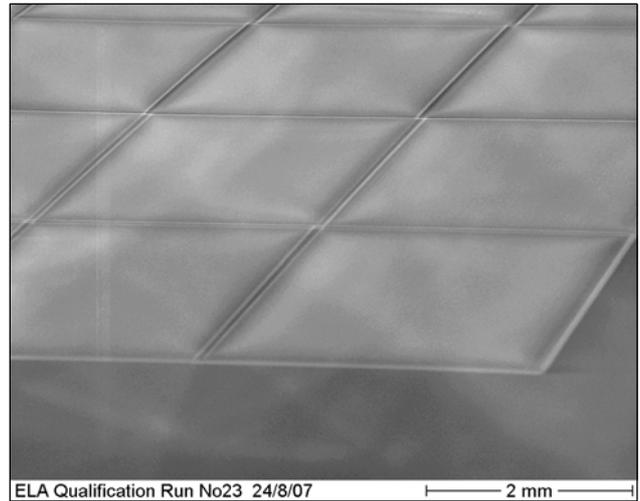


Fig. 7 SEM image of one-shot excimer laser annealed wafer dies obtained in a step and repeat process at 308nm.

Thin film growth by means of *Pulsed Laser Deposition* (PLD) has become one of the most popular techniques for excimer laser based depositing of a large variety of complex materials.

Reproducing the ablation target's stoichiometry is thereby regarded one of the greatest benefits of PLD for thin film deposition.

In fact, the last decade has seen virtually every class of materials to be grown in one of the many hundred thin film deposition labs throughout the world.

From metals and semiconductors to multi-stoichiometric ceramics, from carbon to organic polymers, and with certain premises even biological samples have successfully been deposited in thin layers.

As of today, major market demand for functional thin layers comes from display industry requiring transparent conductive oxide films (e.g. ZnO, ITO), the LED industry's need for e.g. GaN films as blue emitter as well as from the automotive and medical industry benefitting from diverse protective coatings such as diamond-like carbon thin films.

Over the last years a large industrial push of excimer laser based PLD has been exerted from the emerging high temperature superconductivity commercialization requesting oxide buffer layers and rare earth cuprate based superconducting films for manufacturing high performance coated conductors [7].

The basic structure of an excimer laser made coated conductor which is able to carry more than hundred times the current as compared with copper over the same area is shown in figure 8.

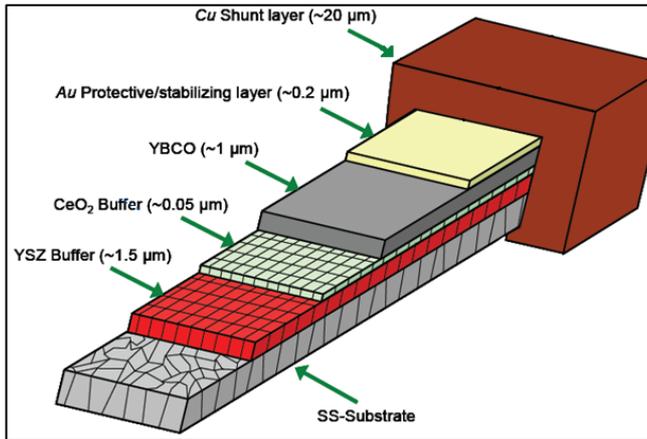


Fig. 8 Layered architecture of a coated conductor.

Excimer laser cylinder wall processing reduces the friction between piston rings and cylinder liners shown in Figure 9 which can account for as much as 60 % of a Diesel engine's total frictional loss.

Since Diesel engine technology uses high compression ratios, the tribological conditions of the pistons moving inside the cast iron cylinder liners are particularly arduous with respect to lubrication and wear.



Fig. 9 Cross section of excimer laser treated cylinder liners.

After conventional cylinder wall processing the inner walls of the cylinder liners exhibit a communicating micro-channel surface topography as shown in Figure 10 which are left over from mechanical polishing, the so-called honing process.

As a consequence, the oil escapes along these micro-channels during the piston's movements thereby severely reducing the desired lubrication effect between piston ring and cylinder wall.

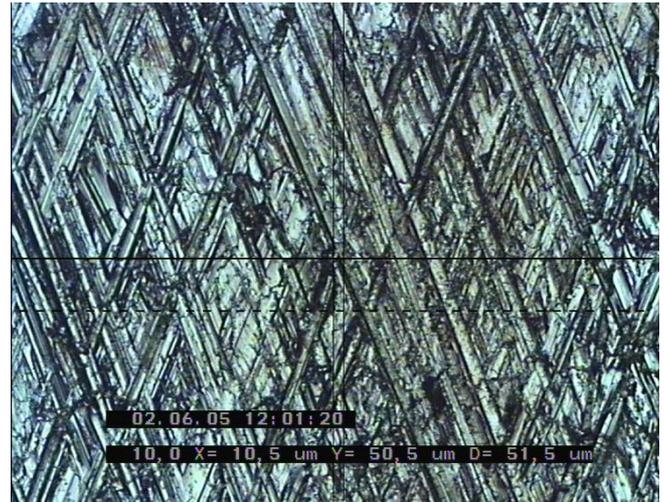


Fig. 10 Microscopic view of the surface structure of a conventionally honed cylinder liner.

Post-treatment of the cylinder liners with the UV photons of a 308 nm excimer laser and nitrogen-assist gas completely changes this surface situation from structurally unfavorable to structurally entirely beneficial as depicted in Figure 11 below.

The short wavelength, high energy photons of the excimer laser strongly interact with the cast iron material of the cylinder liner and produce a different surface via three effects:

- (1) Selective melting to a depth of ca. 2 μm leads to an overall smoothing of the cylinder liner's surface.
- (2) Due to the opening of graphite inclusions close to the surface, located grooves are formed acting as oil reservoirs.
- (3) The nitrogen-assist gas atmosphere induces an additional surface hardening due to the formation of nitrides and subsequent enrichment in the molten surface.

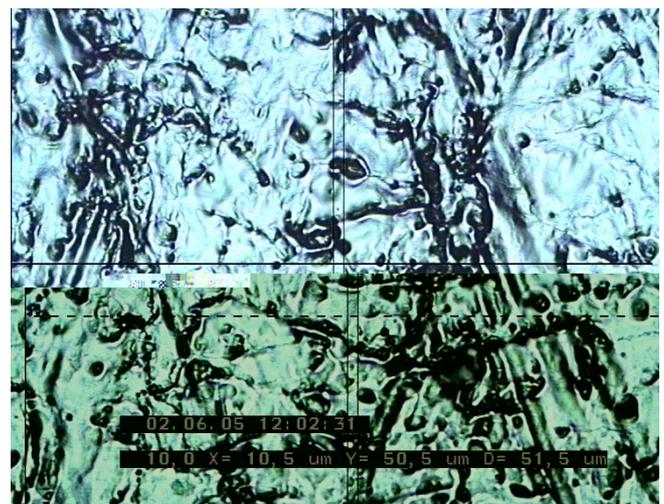


Fig. 11 Microscopic view of the liner surface structure after excimer laser post-treatment.

Comparative Diesel engine test bench programs have been conducted. These test results show the percentage reduction in wear of an excimer-laser-treated cylinder compared to a conventionally honed cylinder.

Depending on the duty cycle, the UV excimer laser process step leads to a relative wear reduction of up to over 85 % for both the cylinder liners and the piston rings. Moreover, the oil consumption is reduced by ca. 75 % compared to conventional mechanical honing [8].

The excimer laser process step thus improves fuel efficiency and decreases long-term wear, which in turn reduces oil consumption and particulate emissions helping to save our resources and to protect our climate.

For the engine manufacturer the economical benefit of the excimer laser process is twofold: he can easier meet legislation demands and as well clearly differentiate his product in a competitive market.

4. Summary

In conclusion, high power UV excimer laser light is a unique and useful tool for a wide variety of processing tasks which require high spatial resolution and minimal thermal damage to surrounding material.

Both the sample testing capability and the processing flexibility provided by the VarioLas UV optical systems enables university researchers and industrial process developers to gather meaningful thin film processing results which are largely transferable to subsequent excimer laser mass-production upscaling.

The reason for the transferability of processing results is based on the fact the VarioLas UV systems use very similar UV beam shaping and homogenization concepts as are found in large-scale manufacturing systems.

This eliminates the need for major process variations during production transfer and upscaling.

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