JPSA Applications Note
advanced laser technology

# Short pulse UV lasers in semiconductor applications

*Excimer and UV diode-pumped solid-state (DPSS) lasers can be used by the semiconductor industry, and others, in applications that cannot be performed by mechanical, chemical, or other laser fabrication methods. These lasers also produce better results than other methods in micromachining, dicing and scribing, and via drilling. In this column, some of the most important applications of excimer and UV DPSS lasers will be reviewed to illustrate how they can have a significant impact on the development and productivity of the semiconductor industry.*

Excimer lasers offer maximum power and the shortest wavelength (351, 308, 248, 193 and 157nm) of all narrowband UV sources, with a large beam that provides homogeneous illumination of large areas. DPSS lasers offer excellent beam quality and a high repetition rate while providing a small beam size for microfeatures. Vanadate (Nd:$YVO_4$)-based DPSS lasers are robust lasers that produce an infrared (IR) beam at ~1µm. Efficient frequency conversion allows these lasers to be used at 355nm and 266nm with several watts of available power.

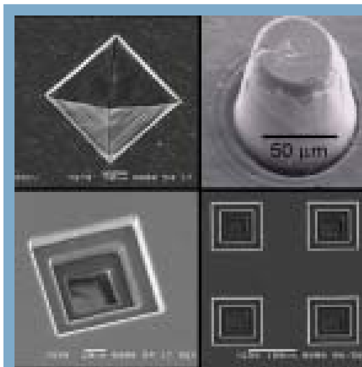
Excimer lasers are ideal sources for large-area patterning, lithographic processes, TFT display annealing, and LED laser lift-off. Micromachining is a broad application sector in which both excimer and DPSS lasers are used. Silicon, sapphire, polymers, CVD diamond, III-V semiconductors [gallium arsenide (GaAs), indium phosphide (InP), gallium phosphide (GaP)] and III-nitrides [gallium nitride (GaN) and aluminum nitride (AlN)] are materials routinely machined by both these lasers in applications such as structuring, via drilling, dicing, and cutting.

A projection technique is typically used in excimer laser processing. A pattern on a mask is imaged onto the workpiece with some demagnification factor. UV DPSS lasers are most often used at the focal point of the imaging lens in a direct writing technique. UV radiation typically leads to increased absorption in the material as compared to longer wavelengths, which allows higher-resolution machining. Using lasers with a pulse duration below 40nsec minimizes thermal affectation as compared to other longer-pulse industrial lasers. The choice of laser and wavelength is application-dependant and related to the light absorption behavior of the material and to the geometry required.

**3D micromachining**

Conventional chemical or plasma etching techniques for processing silicon are well-established techniques that produce high-quality results but are often slow and complicated, and provide limited options for the geometries that they can produce. In addition, for photonic applications in which sensitive optical devices are integrated onto silicon wafers, etching is often not possible or recommended. Short-pulsed UV lasers provide a fast and flexible alternative to create a wide range of features.

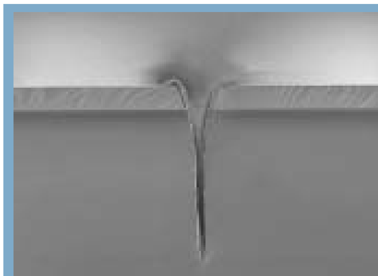
Excimer lasers excel in large area structuring and 3D micromachining. Adequate beam illumination and projection techniques allow for sharp-edged and uniform energy density distribution on target. This leads to fine control of the volume of material removed per pulse, enabling high-resolution machining and high-quality surface finish. Typical removal rates are between 0.05-1.5µm/pulse, for repetition rates up to 400Hz (for high pulse energy excimer lasers). When a single pattern must be repeated, the mask itself may contain an array of features, using the large-beam cross section for simultaneously machining multiple features. By coordinating the motion of both mask and workpiece, large and complex patterns can be created.




Complex 3D features

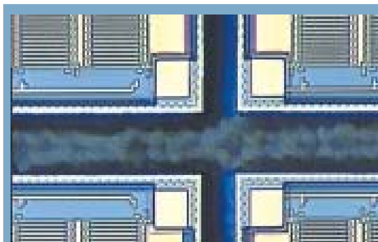
**Laser dicing and via drilling**

Robust, high-rep UV DPSS lasers are particularly suitable for dicing and via-drilling applications. At JPSA, they are routinely used to dice blue-LED and sapphire wafers at speeds of 75mm/sec, leading to a throughput >9wph (for a standard 2 in. dia. wafer with a 350×350µm die size), while creating a very narrow kerf (as narrow as 2.5µm), as seen here.



*Extremely narrow 2.5µm kerf in Sapphire wafer, higher die count*

With its high throughput and minimal impact on LED performance, the process is tolerant of wafer warp and bow and delivers much faster scribing speed than traditional mechanical methods. For III-V semiconductors, such as GaAs and InP, a cut depth of 40µm is typically achieved at speeds >150mm/sec. In addition, laser scribing leads to clean and straight narrower cuts. The laser scribing process operates within 20µm streets, providing significantly higher die count per wafer. Also, edge chipping for brittle III-IV materials is avoided, leading to higher yields due to fewer damaged die



*6µm streets on GaAs (cut & stretched) no surface cracks or chip outs*

Via drilling with DPSS lasers is performed using various techniques, depending on via diameter and required accuracy. Percussion drilling is used to machine small diameter vias (3-10µm), while vias larger than the beam diameter can be machined by using trepanning/helical drilling. In this technique, the spot beam is moved one or several times across a defined path until breakthrough is achieved. For machining of blind vias with smooth flat bottom surfaces, or vias with minimal taper, excimer lasers are typically used (instead of quasi-gaussian beam profile typical of DPSS lasers) because a constant density distribution on the target is required.

**Laser lithography**

Excimer lasers are widely used as the light source for microlithography scanners. In this application, the laser is used to project a mask pattern onto a photoresist-coated wafer. Since the achievable resolution depends on the laser wavelength, the semiconductor industry is pushing for shorter-wavelength stepper/scanners. Currently, ArF (193nm) steppers have replaced advanced KrF (248nm) systems and are being used to make ICs with <100nm linewidths. In terms of laser performance, ultra-narrow emission is required to support high-contrast imaging with a high numerical aperture (NA) of >0.8.

Additionally, reliable high-repetition rate lasers enabling high illumination power and wafer throughput are a fundamental requisite. Recent advances in immersion lithography at 193nm show that this process may be used to reach the 45nm node, and eventually the 32nm node.

**Laser annealing**

Excimer laser annealing for the formation of polycrystalline silicon is a proven technique with respect to its impact on quality, reliability, and economy. TFT flat-panel displays have been used for high-resolution, high-performance, and large-size active matrix liquid-crystal displays (AMLCD). With laser annealing, a thin film of amorphous Si deposited onto a glass substrate is transformed into polycrystalline form by heating the thin layer to just above the melting temperature. The strong absorption of excimer laser radiation limits heating to a thin layer and allows precise control over the heating cycle necessary to achieve polycrystals of sufficient quality and size distribution. To make the process efficient, large areas are irradiated with homogeneous energy density.

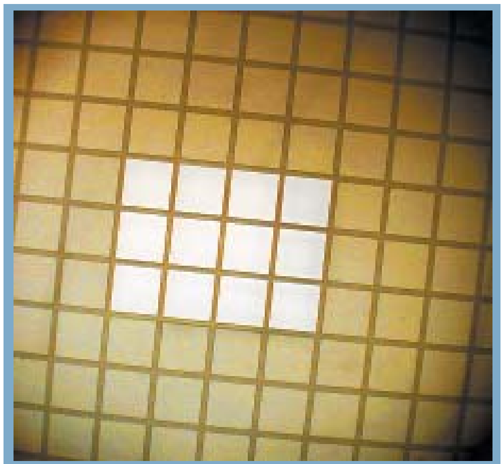
The duration of Si melting following excimer laser irradiation is sufficient to allow diffusion of dopant impurities throughout the molten regions of the film. Thus, laser crystallization can be augmented by including a laser doping procedure, thereby reducing the process steps in fabricating thin-film poly-Si devices. Alternatively, by immersing the wafer in a desired dopant gas, localized doping may be achieved by heating up the exposed areas with laser radiation.

The nanoscale pulse lengths and the materials selectivity offered by the UV wavelengths are potential advantages over more conventional rapid thermal processing techniques for dopant activation, alloying, and selective etching of the III-V nitrides. For example, a KrF excimer laser may be used to selectively process AlN/GaN bi-layers or activate dopants in AlN/GaN heterostructures. AlN, with a bandgap energy of 6.2eV, is reasonably transparent to the 248nm radiation (5eV) that is predominantly absorbed by the underlying GaN film (3.4eV bandgap). This selectivity allows for nonequilibrium annealing of the AlN/GaN interface to form metastable (Al,Ga)N alloy layers.

**Laser lift-off**

Excimer laser lift-off (LLO) of GaN-based light-emitting diodes (LEDs) is currently a production-capable technology. Major costs of LED fabrication are the sapphire and the scribe-and-break operation. LED LLO dramatically reduces the time and cost of the LED fabrication process. LLO may eliminate wafer scribing by enabling the manufacturer to grow GaN LED film devices on the sapphire wafer, for example, and then transfer the thin-film device to a heat sink electrical interconnect. The process creates free-standing GaN films and integrates GaN LEDs onto virtually any substrate. Additionally, this technique increases LED light output and has low operating costs due to low stress on the UV laser.

The basic concept behind UV LLO is the different absorption of UV light by GaN and sapphire. GaN, with a bandgap of ~3.4eV, strongly absorbs 248nm radiation (5eV), while sapphire is a poor UV absorber due to its high bandgap energy (9.9eV). The laser light goes through the back of a sapphire wafer, causing photo-induced decomposition at the GaN/sapphire interface, and creating a localized explosive pressure that debonds the interface. Innovative beam homogenization and synchronized high-speed stage motion-laser triggering ("fire-on-the-fly") techniques-allow high-yield LED LLO at ambient temperature, with running times shorter than 1 min/2-in. dia. wafer. The same technique is also used for AlN lift-off and for transferring other thin films.



**Laser lift-off of 12 dies simultaneously**

**Future directions**

To satisfy the growing demand to use lasers for microfabrication, surface treatment, and materials processing, excimer lasers are continuing to improve in performance, ease-of-use, and cost-of-ownership. Short-pulsed UV DPSS lasers continue to increase their average power, providing rugged industrial packages with longer lifetimes and hands-free operation. Simultaneously, a huge effort is underway to create reliable, ultrashort (pico and femtosecond) pulsed laser systems for industrial use. In addition to the development of more advanced laser systems, new machining techniques, improved beam delivery optical systems, and enhanced knowledge of laser beam-material interactions will also promote new applications.

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