PICOSECOND SCRIBING AND DRILLING OF PHOTOVOLTAIC FILMS

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Industrial picosecond lasers are well-suited to the scribing, cutting and drilling of thin films. A combination of high average laser power, extremely high repetition rates and 24/7 reliability results in superior quality, improved yield, and lower cost of films made of metals, semiconductor, plastics and dielectrics. In this article we look at some applications examples from photovoltaics – an industry that needs the 24/7 processing and high yield of traditional microelectronics, yet can only sustain one-tenth the cost.

Emerging applications in thin film solar devices

While crystalline silicon devices currently own the largest market share, thin film solar is an important alternative that is steadily growing because it involves lower material costs and offers the promise of deployment on curved and/or flexible surfaces. There are several different types of thin film solar products, with individual manufacturers favouring different semiconductor materials as well as different panel sizes. All thin films currently in production rely on a sequence of scribing steps, called P1, P2 and P3, which are used to pattern the various layers following vapor deposition – see Figure 1 (and all the rigid products are based on glass front panels with a thickness in the 2-3 mm range).

By alternating the use of vapor deposition and scribing, the semiconductor and conductor layers are patterned to create active strips, 5-10 mm x >1000 mm, that are physically in parallel and electrically connected in series. In this way, the overall panel is able to generate hundreds of watts of power.

The first step is to deposit a uniform (a few hundred nm) layer of transparent conductive oxide (TCO) on the glass which will form the frontside electrodes through which sunlight passes to reach the active semiconductor layer. The TCO is then patterned by the P1 series of scribes which must cut through the entire TCO thickness. This is followed by deposition of p- and n-type semiconductor, with a total thickness of 2-3 microns. The P2 scribe then cuts through the semiconductor layer dividing it into active strips. A thin (< 1 micron) layer of metal (aluminum or molybdenum) is then deposited across the entire panel to form the rear electrodes. This is patterned by the P3 scribe which cuts through both the metal and semiconductor layers.

Why picosecond laser processing?

Photovoltaic panel fabrication needs closely-spaced narrow scribes, minimising the area of the panel that is wasted (inactive), as shown in Figure 1. But this also means that the application cannot tolerate peripheral thermal or mechanical damage such as microcracks or debris.

Nanosecond lasers have proved to be a good match for the P1 scribes which remove a few hundred nanometers of TCO. However, the P2 and P3 scribes involve thicker layers (semiconductor or metal) and the challenge is to fully cut through these layers without causing thermal damage to nearby or underlying material. The picosecond laser is a good match for this task because the pulse width is short compared to the thermal diffusion time; minimising thermal damage by cold picosecond ablation eliminates the chance of short circuits. Just as important, commercial mode-locked lasers provide extremely high repetition rates and high average power (up to 100 W). The combination of low pulse energy and high repetition rates also

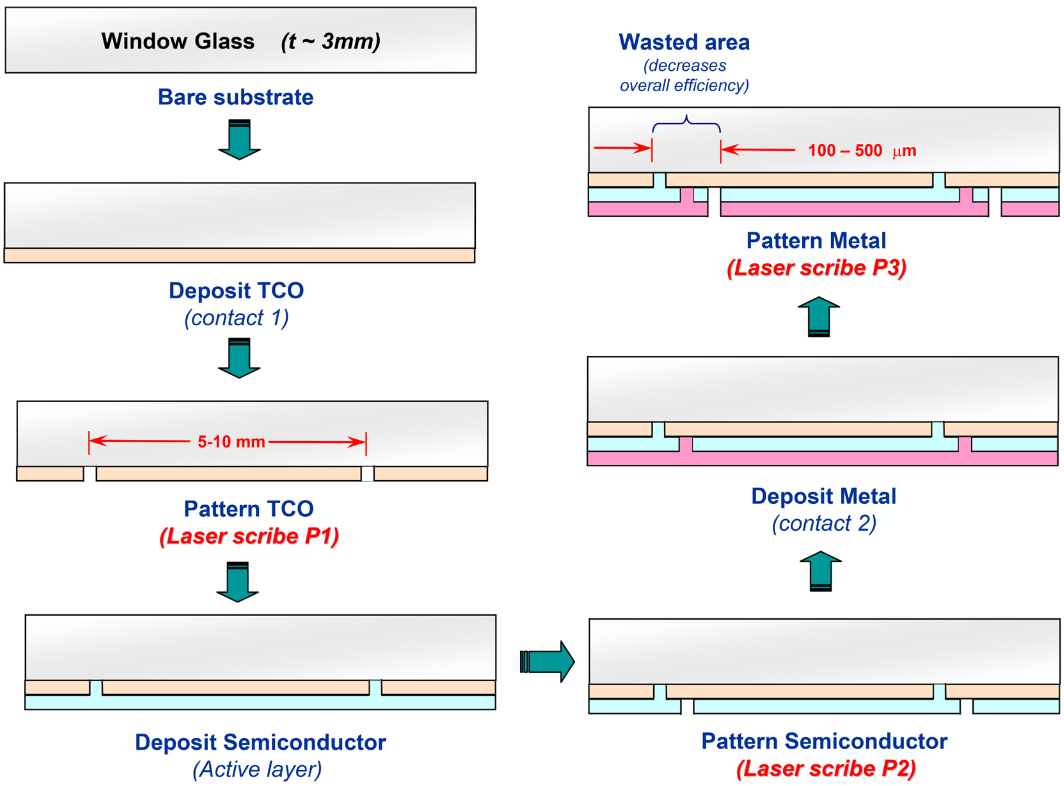

Figure 1: The fabrication of thin film solar panels involves three separate scribing steps which can all be performed by laser.

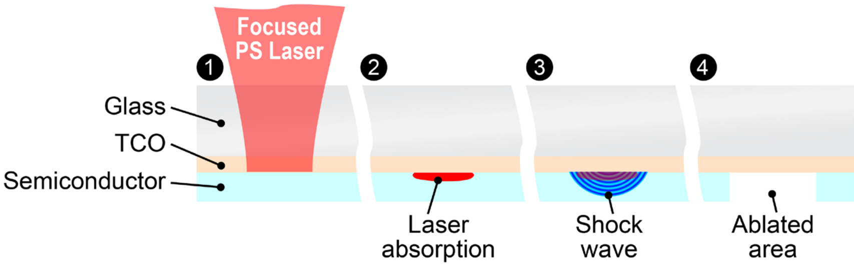

Figure 2: In spallation 1) a laser beam passes through transparent layers, 2) it is focused on the interface with a layer that absorbs the laser wavelength so that rapid heating occurs in a very thin layer, 3) a shock wave expands out, and 4) the target layer is blown off.

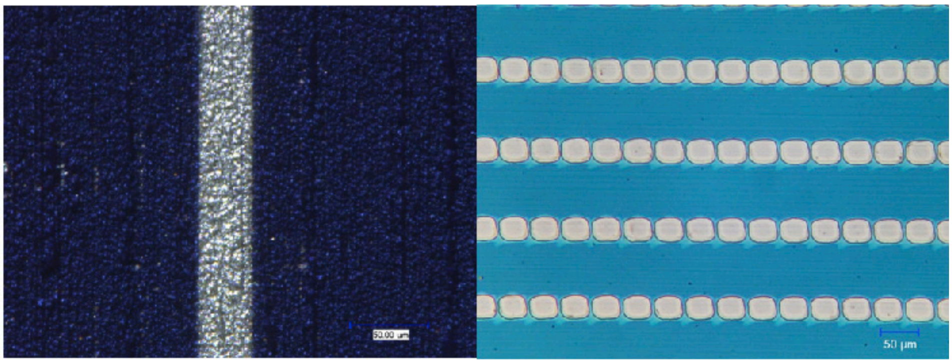

Figure 3: (left) A gaussian profile and overlapping pulses can create a high quality scribe in thin (< 100 nm) SiN on silicon, (right) Single shot ablation of a 70 nm thick SiN layer on silicon using a HYPER RAPID NX IR laser and a top hat beam optic; each dot is approx. 40 x 40 microns and the feedrate is >30 m/s.

delivers high throughput whilst eliminating the chance of functional damage to the panels.

Picosecond lasers are now also available in multiple wavelengths, which allows the use of a highly efficient film patterning technique called spallation for both P2 and P3. In this process, the laser wavelength is chosen so that it passes through the glass and through the TCO but is strongly absorbed at the interface with the semiconductor (for P2) or metal (for P3). This vaporises a few atomic layers of the material removing the overlaying layers completely in a single laser pulse (Figure 2).

Picosecond processing is proven in c-Si solar

Picosecond laser scribing and cutting has previously been used successfully in the production of c-Si solar cells, for example in creation of openings through the SiN passivation layer to allow direct electrical connection to the active semiconductor layer. In some cases, the application needs a long continuous groove. This can be created by using a beam with a gaussian profile and then overlapping the pulses – see Figure 3 (left). However, some SiN on Si scribing applications need to avoid any pulse overlap to completely avoid any damage to the underlying silicon. Figure 3 (right) shows an example of this using a beam with a uniform profile shaped using a top hat optic. The closely spaced square holes in the (<100 nm thickness) SiN shown here confirm that the ps laser also causes no lateral thermal damage to the SiN. In these single pulse applications, the high repetition rate of the ps laser – up to 5 MHz – means that the limiting factor is the scan speed. Galvo scanners can deliver speeds up to 30 m/s, which translates into 1 million holes/s. Faster polygon scanners can increase the speed to several million holes/s.

Cutting glass modules

Packaging of solar devices is also benefiting from picosecond lasers. Specifically, a unique filamentation method for cutting glass called SmartCleave™ enables even strengthened glass to be rapidly cut in a cold process that can create tight curves and holes – see Figure 4 – and that produces excellent edge quality (Ra < 0.5 µm) often with no need for post-processing. In brief, as the picosecond laser beam passes through the glass thickness it automatically oscillates between focused and unfocused, drilling a narrow micro-perforation through the glass. Movement of the glass and/or laser creates a curtain of these filaments which define a smooth fracture, which in some glass types does not even need any kind of shock for separation. Unlike mechanical cutting, the edges are free of microcracks and residual stress, eliminating a common failure mechanism for thin glass panels.

Summary

Like most other electronic-related industries, the photovoltaic market has a growing need for precise micromachining that improves performance, yield and cost. The picosecond laser is proving to be an ideal tool for several tasks in this important industry.

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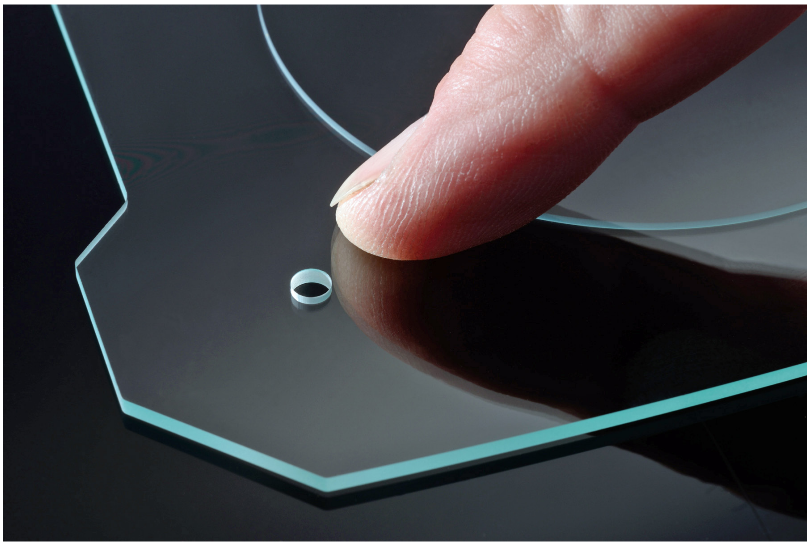

Figure 4: Picosecond lasers enable the SmartCleave™ filamentation process that can cut tight curves in glass, including pass-through holes.

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