A Trenchant Edge

Laser technology enables precise material processing.

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All images: JPT

Driven by the need for energy conservation and pollution reduction the markets for building-integrated photovoltaics, centralized photovoltaic power stations and new energy vehicles have grown significantly. This increases the demand for glass that requires more precise micromachining methods.

Transparent and brittle materials, such as glass and sapphire, have been widely used in architecture, consumer electronic products, automobiles, solar panels, and others due to their good optical transparency, chemical stability, physical strength and electromagnetic interference immunity. Conventional machining methods for brittle materials use a polycrystalline diamond cutter, a grinding wheel or chemicals, which easily introduce external stress that produces surface and sub-surface microcracks, fragmentations, or environmental pollution. Moreover, glass is becoming thinner and thinner. This adds more difficulties in machining using conventional methods. To overcome these problems, picosecond laser technology that can generate high peak power pulses has attracted a lot of attention.

Laser processing technology focuses the laser beam on the surface of objects, and utilizes the high energy density of the focused spot to gasify or melt the material to be processed. It has the following advantages:

- non-contact processing, and therefore no reintroduced pollution or damage,
- a small heat-affected area,
- high accuracy, suitable for automation integration,
- good processing flexibility, it can be applied to cut or drill irregular shapes/patterns.

In recent years, ultrafast laser processing technology has shown great potential in improving the glass manufacturing process and improving product properties.

Picosecond laser technology

High power picosecond lasers usually consist of a seed source, pre-amplifier and main amplifier modules, which is a master oscillator power amplifier (MOPA) structure. Short wavelength laser output can be generated by a non-linear frequency converting mechanism with crystals.

- The wavelength of picosecond seed lasers used in industry is usually at 1,064 nm or 1,030 nm. The seed laser source can be realized by ytterbium-doped fiber-based mode-locking, all-solid crystal mode-locking or direct semiconductor laser modulation. As passive mode-locking has proved its reliability and stability through long-term running, it has become the main technical route for picosecond seed lasers in the market. Commercial passively mode-locked fiber lasers mainly use a SEmiconductor-Saturable Absorber Mirror (SESAM) [1] or nonlinear loop mirror [2] to serve as a saturable absorber. Seed lasers with a SESAM-based linear cavity have the advantage of high consistency, high reliability and good self-starting probability, but only short single-point lifetime. A long lifetime can be obtained by automatic point change on the SESAM-based plate. There are no vulnerable devices in the nonlinear loop cavity so that its lifetime can be guaranteed, but the realization of 100 % self-starting needs a special circuit design.

■ There are a few ways to build the main amplifier of industrial high-power picosecond lasers, such as rod crystals, disks, Innoslab, and photonic crystal fibers. The laser output power amplified with fiber-based coherent combination [3], disk [4] and Innoslab [5] has exceeded one kilowatt. At present, the mainstream high power, infrared, picosecond lasers have an output power of 100 – 400 W, but usually working in burst mode (pulse string within an envelope), and the maximum single pulse energy is between hundreds of microjoules and one millijoule. It is a great challenge to further improve the power.

The picosecond laser with a disk amplifier structure can generate high average power and good beam quality output. However, since the gain length of a single pass through the thin disk is too short, a complicated multi-pass cavity is needed, and the stability of the laser output therefore relies highly on its mechanical robustness and is easily affected by circumstantial vibration.

Picosecond lasers with an Innoslab amplifier show high power and good beam quality output capabilities because of their large cooling surface. Good reliability of 100 – 200 W average power output has been demonstrated in the industrial field, but long-term operation at higher power output (e. g. 500 – 1000 W) is still a challenge.

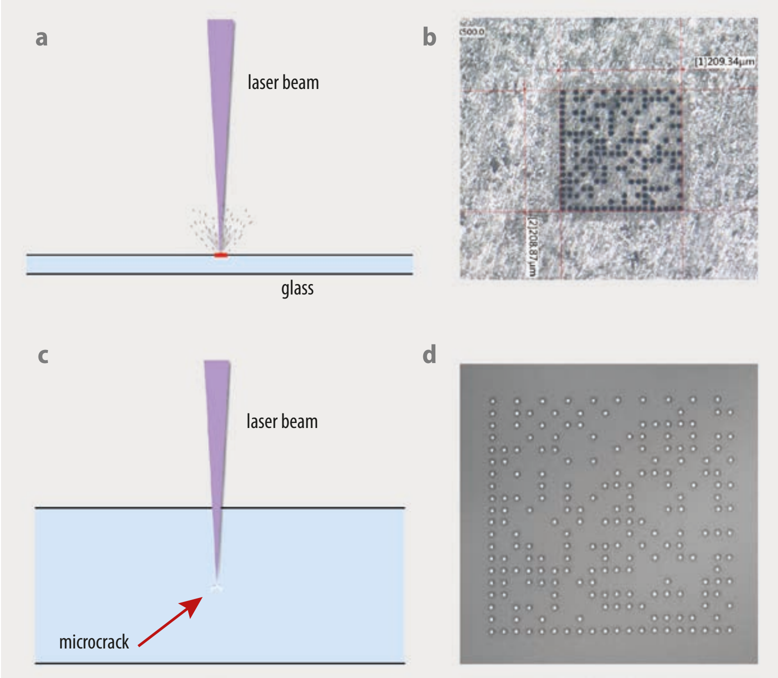

Fig. 1 A laser beam focused on the surface (a) or on the inner layer of glass (b) creates a QR code on the surface (a and d respectively).

As for the photonic crystal fiber amplifier, as the output power increases, the heat accumulates, which will result in degradation of the beam quality, and the long-term operation reliability of the high power output remains to be verified.

■ For short wavelengths output frequency converting technology is used to convert the near-infrared output beam to a green or ultraviolet beam. The ultraviolet picosecond laser with high-efficiency and a long lifetime depends greatly on the advanced growth and surface treatment technology of non-linear optical crystals. Due to the design requirements of walk-off angle and module, the commercial laser mostly uses lithium triborate crystal (LBO).

A few institutes/companies are involved in research on LBO crystal such as CrystaLaser in the US, the physics and chemical institute of the Chinese Academy of Science, the Fujian Institute of Research on the structure and Castech in China. Research on increasing the laser damage threshold of optical thin films on crystals is being done by Sandia National Labs and Gamdan Optics in the US, the Laser Zentrum Hannover in Germany, the Shanghai Institute of Optics and Fine Mechanics, the Changchun Institute of Optics and Fine Mechanics and others. The Shanghai Institute of Optics and Fine Mechanics used atomic layer deposition technology to produce an HfO_2/SiO_2 antireflection layer for 355 nm wavelength. The measured reflectivity of the film layer at 355 nm is lower than 0.2 %, and the laser damage threshold reaches 24.4 J/cm^2 (at a pulse width of 7.8 ns) [6].

Processing brittle materials

The application of picosecond lasers for processing brittle materials includes QR code marking for information tracing, cutting, drilling, and surface layer removal.

QR code marking

There are mainly two kinds of laser marking: surface engraving and subsurface laser marking. Surface engraving focuses the laser beam on the glass surface (**Fig. 1a**). When the laser energy density exceeds the material damage threshold, the surface material instantly gasifies, and the target pattern is formed by controlling the movement path of the laser beam. Surface marking using a picosecond laser can not only avoid thermal deformation of the material, but can also greatly reduce the interior stress because of the small heat accumulation during processing. The pattern engraved using a laser beam does not fade when exposed to environmental influences (touch, temperature, etc.) and the engraved pattern is not easy to imitate or change, so it is capable of being used for anticounterfeiting. For example, when we mark the QR code in a way that even without any obvious touch feeling, we can still observe the code points very clearly under a microscope (**Fig. 1b**). Picosecond lasers have also been widely used for information tracing on semiconductor chips.

Glass subsurface marking is shown in **Fig. 1c, d**: When the laser beam is focused on the inner layer of glass, the laser pulse with high energy density produces microcracks in the order of micrometers to millimeters, which appear a different color compared to unprocessed areas due to the scattering of light. The ideal pattern is marked/engraved similarly by controlling the laser path in the interior of the glass.

Laser cutting

Laser processing technology has been used in cutting and separation of transparent brittle materials. Laser cutting methods for brittle materials can be divided into laser scribing and breaking method, laser thermal stress cutting method, laser filamentation method or Bessel beam cutting.

The laser scribing and breaking method is similar to the traditional mechanical method, which separates the object with the help of external force following laser scribing on the material, so the cutting quality is not fine enough, and the sharp edge still needs to be polished. The laser thermal stress cutting method relies mainly on the heating effect of laser beam, then a proper temperature gradient formed on or within the material surface with a cooling system. This will result in hot tensile stress, and when it exceeds the proper tensile strength threshold, microcracks will appear on or under the material surface and expand along the direction of laser movement, so the glass is cut.

Laser filamentation usually uses ultrafast lasers. When the energy density of the laser is greater than a certain threshold, a dynamic equilibrium can be established between the nonlinear self-focusing effect and the defocusing effect of the plasma. Then the light beam does not diverge and propagates several times longer than the Rayleigh length distance, with almost the same beam diameter in the medium. If this effect is used for glass separation, the application scenario is limited and difficult to control.

Bessel beams, known as 'non-diffracting beams', have a transverse light field distribution that does not vary along the propagation of the beam, and the main lobe diameter can be as small as a few micrometers, while the focal depth reaches several millimeters (**Fig. 2a**). With Bessel beams, it is easy to separate the glass at the laser-modified section by adding only a slight external force or thermal stress gradient (**Fig. 2b**). For example, for laser cutting of high aluminum cover glass we use a solid infrared picosecond laser with a Bessel cutting head. The Bessel laser head moves along the cutting line and pulses are controlled in position-synchronized output mode. After cutting, a

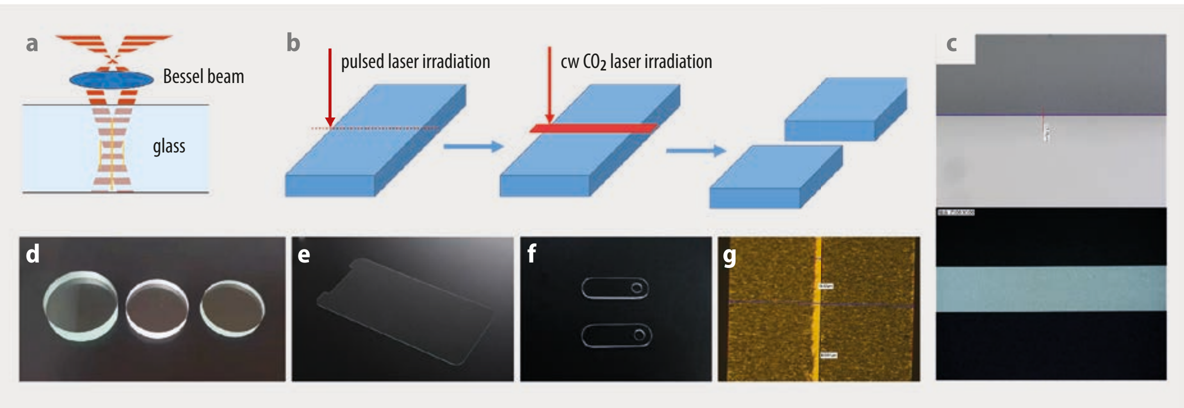

Fig. 2 The focal depth of a Bessel beam (a) can reach several millimeters. It is used for the cutting and splitting process of brittle material by an ultrafast laser (b). Shown are cross-sectional microscopic images (c), circular cuttings of thick glass (d), special-shaped cutting of cover glass (e) and camera (f) and laser cutting of double laminated glass (g).

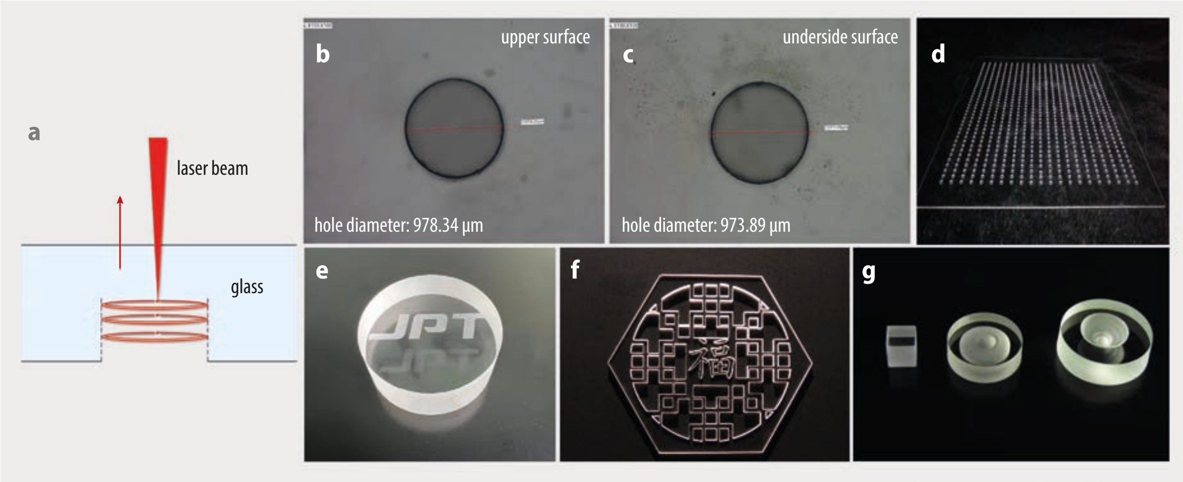

Fig. 3 The thin red arrow indicates the direction of movement of the laser beam during drilling. Shown are microscopic images of a 1 mm hole drilled in substrate glass (b, c) and images of laser drilled samples, including through holes and blind holes (d – g).

CO_2 laser beam (thermal stress) or mechanical stress is applied to the cutting line to separate the brittle object. In this method, the cutting positioning can be of high accuracy, and the whole process can be time-saving. The cover glass has a smooth cutting edge (**Fig. 2c**), and the chipping area can be controlled within 10 µm without debris. At present, this cutting technology is widely used in glass substrate, glass cover, display panel, camera and precision cutting of other electronic glass products (**Fig. 2d – f**), and this can be extended into photovoltaic glass and other industries.

Laser drilling

In laser drilling the laser beam focuses on the underside of the surface of the material through the glass, and the material is gasified (**Fig. 3a**). Then the laser beam rises in spirals, scanning layer by layer from the bottom up to the upper surface of the glass. As the opaque material can only be drilled from top to bottom, the gasified material flowing on the surface easily absorbs the laser energy to generate a plasma, thus reducing the processing efficiency and producing a tapered through-hole with a large entrance and a small exit. The bottom-up drilling method for transparent glass avoids the surface plasma masking effect, and achieves high processing efficiency and a small through-hole taper.

Compared with mechanical drilling, laser glass drilling is contactless, uses no consumables, can cut any shape and does not cause pollution. For example, using an infrared picosecond laser to drill a 1 mm aperture hole on the substrate glass, the glass chipping edge is observed to be within 30 µm with a microscope (**Fig. 3b – c**). Other laser drilling samples are shown in **Fig. 3d – g**.

In addition to the glass used in 3C products, the market demand for glass back for solar panels is dramatically increasing, parallel to the development of the photovoltaic industry. The back glass generally needs to have three holes, some of them may be irregularly shaped, which is not easily achieved by traditional mechanical punch drilling due to low efficiency and poor quality. At present, fiber lasers are being used to drill photovoltaic glass. Picosecond lasers combined with chemical wet etching can produce micro-holes with a large deep-width ratio without cracks.

Surface layer removal

Laser surface layer removal mainly uses a high-energy laser beam to quickly gasify or strip the surface layer. Normally, we would select a laser wavelength which shows a higher absorption rate for the layer to be removed than that of the base substrate. Meanwhile, the laser energy density is adjusted to be above the damage threshold of the removal layer but avoiding causing damage to the substrate under the layer. The traditional methods of film removal include mechanical grinding, chemical corrosion and others, which have inevitable shortcomings such as poor accuracy, easy damage to the glass substrate or causing environmental issues. Driven by the demand of energy saving and emission reduction, low-e glass shows a high growth trend in China, and lasers are also being introduced to remove the dielectric film layer or heat insulation films in specific areas on windshields or sunroof (**Fig. 4b**). It is also used for the selective removal of passivation/insulation layers on semiconductor materials.

Industrial-grade picosecond lasers have also been widely used in semiconductor wafer processing, display panel cutting, perovskite

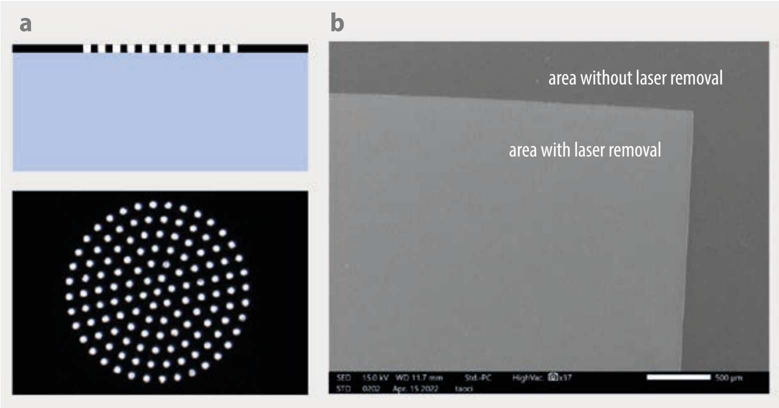

Fig. 4 UV picosecond lasers can remove deco (a), the black color indicates the deco layer. The image of functional thin film removal on glass (b) was taken by a scanning electron microscope.

film scribing and other industries. With the improvement of laser pulse energy, average power and stability, they will make further progress to realize high-precision and high-efficiency laser processing in new energy lithium batteries, the photovoltaic silicon industry, the military, and aerospace science and technology.

Shenzhen JPT Opto-electronics focuses on the development of laser sources, its JPT-PS-IR series industrial grade infrared picosecond laser, based on MOPA structure and rubidium-doped yttrium vanadate crystal, can achieve 2 mJ pulse energy output. JPT's industrial grade green picosecond laser can achieve 50 W output average power, and the UV picosecond laser can achieve an average power output of more than 30 W. These parameters can meet the above-mentioned processing requirements. JPT has accumulated rich experience in brittle materials processing, FPC circuit board cutting, medical stainless steel surface modification and others. The company engages in large R&D investment for picosecond, femtosecond mode-locking technology, femtosecond chirp pulse amplification technology and high power, high energy density laser products, which are expected to create new laser application fields under the premise of meeting high-precision processing requirements, and promote the further improvement of laser processing efficiency.

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