ADVANCED PROCESSING USING A 1950 NM FEMTOSECOND LASER

CHRISTOPH WUNDERLING & STEFANIE TERTELMANN

Quartz sand is the industrial feedstock for two essential materials in industry – silicon and fused silica. The former is of particular importance because silicon products enable megatrends like digitisation and electromobility. Material processing is still a challenging task. For example, established lasers with wavelengths around 1 µm are suitable for processing silicon due to the high absorption at this wavelength, but mainly on the surface. The absorption coefficient is a limiting value when processing silicon inside or on the backside is necessary. In this article, the processing possibilites of silicon using an InnoLas Photonics femtosecond laser with a wavelength of 1950 nm are presented and two exemplary applications are shown – the modification inside silicon and the selective laser-induced etching of fused silica.

Quartz sand – an essential base material for today's industrial products

Whether products are for medical technology, microchips, batteries for electric vehicles or solar cells, quartz sand is an important basic raw material for their manufacture. The reason for this is that fused silica and silicon can be produced from the material. Silicon in particular is a material of great economic importance for numerous key technologies, but it is only regionally produced and requires energy-intensive manufacturing processes. Due to the increasing global demand, driven by megatrends such as digitisation or electromobility, the material must therefore be used as efficiently as possible. To this end, laser processes have been established to provide highly-precise processing and good quality of the process result.

Trends in development of ultra-short pulsed lasers

Extremely precise laser processing of these high-end materials is possible using ultra-short laser pulses. The interaction of the pulse and the material is in the range of pico- or femtoseconds which means that all the energy is focused in the processing zone for a very short time. Consequently, the intensive interaction significantly reduces the heat input into the material compared to short- or long-pulsed laser sources. But there are still some challenges to overcome. One of them is the achievable processing speed which significantly affects the cycle time of the manufacturing process. The second is, especially in case of silicon processing, the wavelength-dependent absorption of laser radiation and consequently the flexibility of processing materials on the surface, inside the material or on the backside. In the past there have been two significant trends in the development of ultra-short pulsed lasers to solve these problems.

The first trend is the scaling of average power, because using high pulse energies at high repetition rates can increase the productivity of the manufacturing process. Low cycle times are especially necessary in high-volume production as it is state-of-the-art in microelectronics or in battery production for example.

The second trend is the development of laser sources emitting laser radiation at non-usual wavelengths – besides UV, green or infrared around 1030 nm – in order to improve the efficiency of existing laser processes or to enable even new ways of manufacturing. The material-adapted wavelength can be used to control the absorbance and transmittance of the laser radiation in the material.

Wavelength-dependent potential in laser processing

For many applications, such as laser welding, cutting, surface texturing or marking, the absorption of the laser beam is limited to an area near the surface due to a high reflectivity and low transmittance of the established laser wavelengths. In these cases, increasing the absorbance is one approach to improve process efficiency or process speed of established manufacturing processes. This can be made by choosing an appropriate wavelength, increasing the roughness of the irradiated surface or optimising the material composition, to give just some examples. But all the mentioned processes have one aspect in common – the absorption of the laser radiation is limited to the surface area.

When processing materials inside or on the backside and when any damage on the material's surface should be avoided, wavelengths with a high transmittance are necessary. One example, which is still challenging, is the processing of silicon, for example wafer stealth dicing or inscribing of well controlled volume modifications like waveguides. For theses processes, multi photon absorption becomes relevant to control the location of absorption. Due to the high intensity of the laser pulse, this specific absorption mechanism guarantees that the laser beam interacts locally with the material, especially at the beam waist, even when the wavelength-specific absorbance of the material is very low. For silicon, the transmittance is significantly increased and the absorption is decreased when using wavelengths above approximately 1250 nm [1].

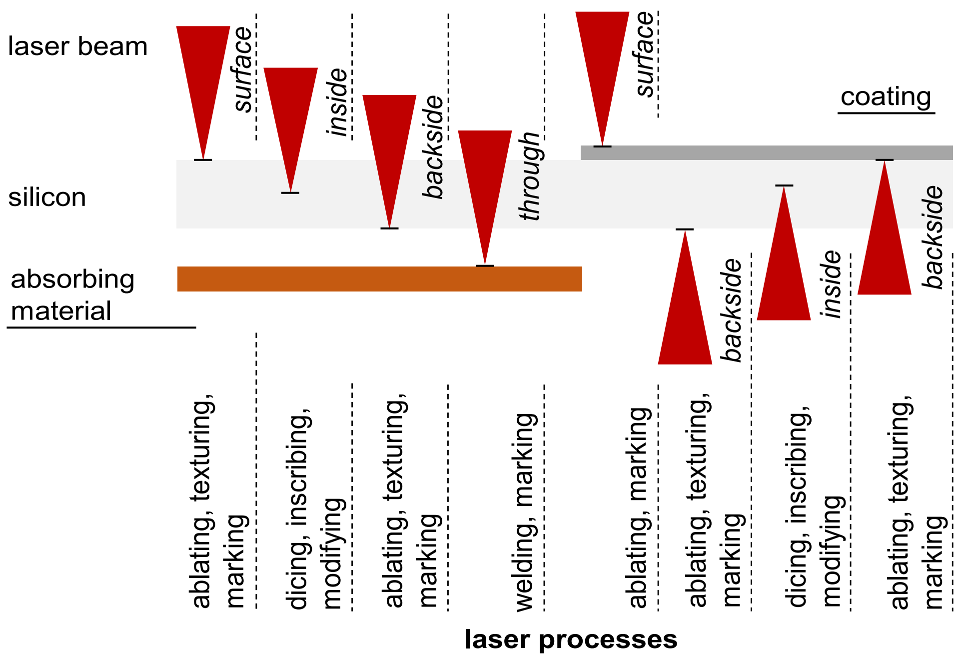

Figure 1: Potential laser material processes using a 1950 nm femtosecond laser

A laser emitting radiation with such wavelengths can be used as a flexible tool which can be seen in Figure 1. Depending on whether the silicon wafer is coated or not, the location of processing can be precisely controlled and many laser processes can be performed. Modifying silicon in the inside, processing on the backside, transmission welding to another material or marking through silicon are examples for that. Two exemplary processes were investigated and are described below in more detail. The first refers directly to silicon processing, and the second to selective laser-induced etching of fused silica. For both processes, the micro-machining system FemtoLab from the company Workshop of Photonics was used to evaluate the feasibility.

Inside-modification of silicon using a 1950 nm femtosecond laser

Wavelengths in the range of 1064 nm to 2350 nm were investigated experimentally and numerically in order to create modifications in the bulk material. It was proven that wavelengths around 2000 nm and higher are more favorable compared to conventional wavelengths around 515 nm, 1030 nm, or even 1550 nm [2]. This is due to the optical behaviour of the material, as already described. In Figure 2, a microscope image of a broken silicon wafer is shown. The 700 µm thick bulk material was modified using a 1950 nm femtosecond laser from InnoLas Photonics GmbH. The silicon wafer was moved by high-precision linear translation stages, creating lines starting on the backside of the sample and changing the z-position between the lines. On the surface, the wafer was scribed and then broken mechanically. The inserted modifications supported a defined breakage of the wafer with an excellent edge quality, as can be seen in Figure 2.

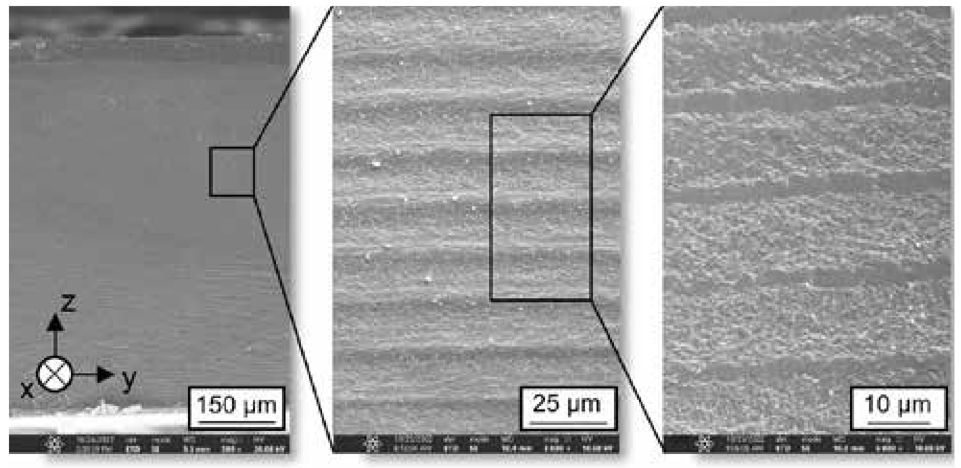

Figure 2: Broken edge of a 700-µm-thick silicon wafer at different magnifications pre-modified in the plane of fracture using a femtosecond laser with a wavelength of 1950 nm

Selective laser-induced etching of fused silica using a 1950 nm femtosecond laser

In addition to the experiments on silicon, the ultra-short laser source was used to create sub-surface modifications in fused silica, as can be seen in Figure 3. The material properties were changed in such a way that the modified areas were affected much faster than the untreated ones during a subsequent etching process. The resulting holes had a very stable geometry and a high-quality edge with a roughness Ra of less than 0.2 µm was achieved. The change in diameter comparing top and bottom of the 1.5 mm-thick glass sample was about 0.5 %, which means that the taper is less than 0.8 ‰.

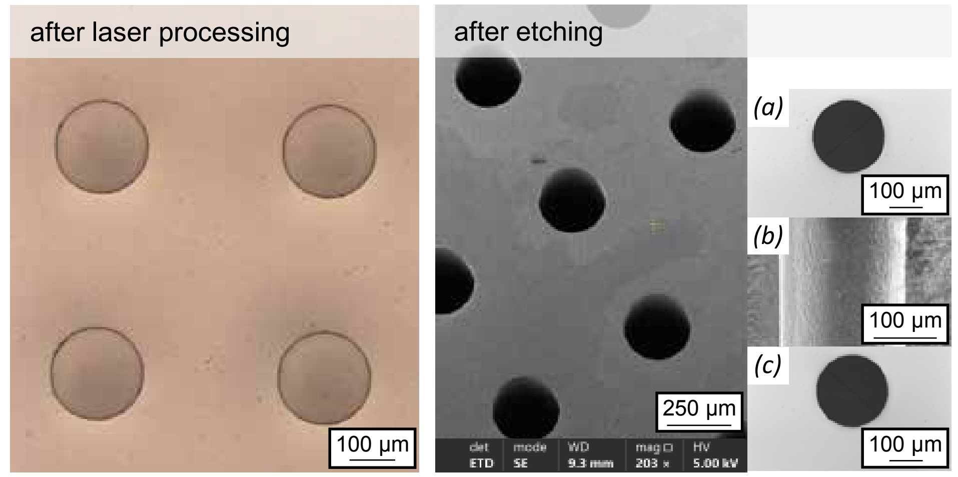

Figure 3: Surface of fused silica after laser pre-treatment using a 1950 nm femtosecond laser and holes after etching in top view (a), cross section (b) and bottom view (c)

Conclusion

Femtosecond lasers emitting a wavelength around 2000 nm can extend the possibilites of laser manufacturing for high-end materials. Lasers which are appropriate for industrial usage start to enter the market. A femtosecond laser emitting laser radiation with a maximum average output power of 8 W and with a wavelength of 1950 nm is an appropriate tool for many industrial manufacturing processes. In this study, it was used to modify silicon and fused silica in the inside which are just two exemplary processes that can be performed.

References

[1] Mühlbauer, M. Dünne kristalline Silizium-Wafer-Solarzelle mit Glasträger stabilisiert. Dissertation. FernUniversität Hagen. Hagen 2009.

[2] Richter, R. A. et al. Sub-surface modifications in silicon with ultra-short pulsed lasers above 2 µm. Journal of the Optical Society of America B 37 (2020) 9. pp. 2543–2556.

Acknowledgements

Many thanks to Workshop of Photonics for performing the experiments and the great collaboration.

Contact: Christoph Wunderling
christoph.wunderling@innolas-photonics.com
www.innolas-photonics.com

Christoph Wunderling is a sales manager at InnoLas Photonics GmbH focusing on femtosecond lasers, their applications and strategic development.

SEE OBSERVATIONS P28