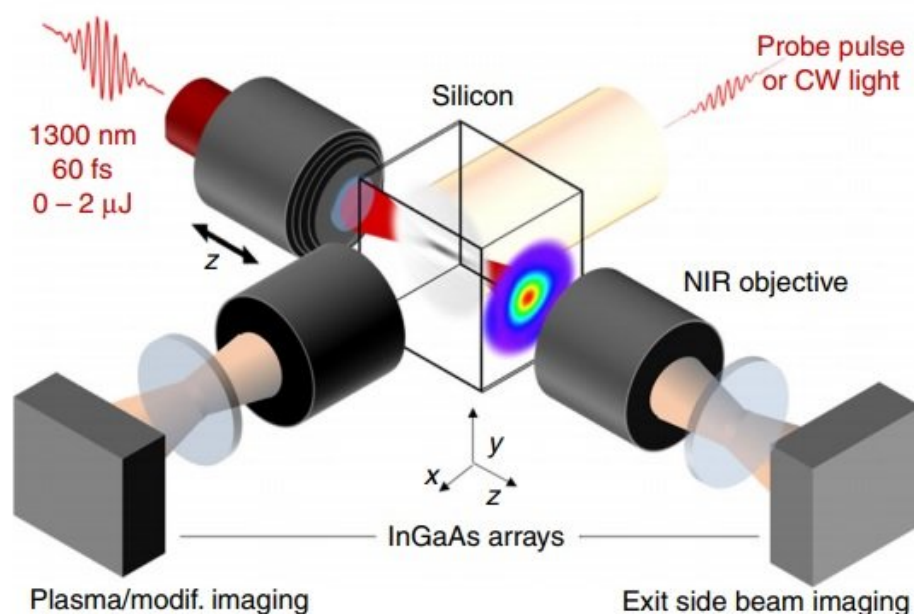


Scientists reach milestone in 3-D laser writing in bulk silicon

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Experimental setup of using 60-femtosecond laser pulses for laser writing in silicon. Credit: Chanal et al. Published in *Nature Communications*

(Phys.org)—It has taken more than 20 years, but researchers have demonstrated for the first time that femtosecond lasers can be used to structurally manipulate bulk silicon for high-precision applications. Since the late '90s, researchers have been using the ultrashort pulses of

femtosecond lasers to write into bulk materials with wide band gaps, which are typically insulators. But until now, precise ultrafast laser writing has not been possible for materials with narrow band gaps, such as silicon and other semiconductors.

The researchers expect that the results will open the doors to 3D [laser](#) writing for [silicon photonics](#) applications, as well as for studying new physics in semiconductors.

The scientists, Margaux Chanal et al., from institutes in France, Qatar, Russia, and Greece, have published their paper "Crossing the threshold of ultrafast laser writing in bulk silicon" in a recent issue of *Nature Communications*.

In previous attempts at ultrafast laser writing in bulk silicon, scientists found that femtosecond lasers simply weren't capable of structurally manipulating the bulk silicon, even when the [laser energy](#) was increased to the highest pulse intensity technologically possible.

In the new study, the researchers found that, fortunately, there is no physical limit that prevents ultrafast laser-induced structural manipulations of bulk silicon. Instead, they found that the laser energy has to be delivered in the medium in an abrupt way in order to minimize losses from nonlinear absorption. This finding revealed that the problem of all past efforts arose from the laser's small numerical aperture (NA), which refers to the range of angles over which focused laser light can be delivered. The researchers calculated that, in order to achieve the desired results, it would be necessary to obtain extreme NA values that have so far not been realized in this area.

In order to reach these extreme NA values, the researchers borrowed a technique from advanced microscopy called solid-immersion microscopy. The idea is similar to the commonly used liquid-immersion

microscopy, in which a small drop of oil is placed on the slide. As oil has a larger refractive index than air, the oil reduces the amount of optical refraction (bending of light) as the light travels between the slide and the microscope lens. This, in turn, increases the NA and the associated microscope's resolution (the NA for a microscope measures the range of angles over which light is collected rather than delivered). The difference with solid-immersion microscopy is that a solid material with a high refractive index is used instead of a liquid.

In the new study, the researchers used silicon spheres as the solid-immersion medium. They found that, when focusing the laser at the center of a sphere, they could completely suppress refraction and greatly increase the NA. The extreme NA values allowed the laser pulses to achieve sufficient ionization to break chemical bonds in the silicon, which in turn causes permanent structural changes in the material.

"The in-depth understanding of the physics of the interaction and propagation of [ultrashort laser pulses](#) in low-[band-gap](#) semiconductors, like silicon, enabled us to solve this long-standing problem and achieve controlled material structural modifications, appropriate for applications," coauthor Stelios Tzortzakis, at the Texas A&M University at Qatar, FORTH, and the University of Crete in Greece, told *Phys.org*. "Even more, the localized energy deposition in the medium results in out-of-equilibrium phases with extreme thermal and pressure gradients that can enable the creation and study of new states of matter, previously unreachable in laboratory environments."

In the future, the researchers plan to further push the boundaries of this approach by borrowing another microscopy technique called 4-Pi arrangement. This concept involves crossing multiple laser pulses with extreme NA values at the centers of spheres, which may lead to even greater possibilities in ultrafast laser writing in bulk silicon and other semiconductors.

"3D laser writing applicable to silicon may drastically change how things are designed and fabricated in the important field of silicon photonics," said coauthor David Grojo at CNRS/Aix-Marseille University in France. "Silicon photonics is seen as the next revolution of microelectronics using light at the chips level for ultimate speed data processing. However, it remains today a 2D world because of the planar lithographic methods used for fabrication (SOI technology). With our method we can envision the equivalent of a 3D printer for rapid prototyping of any innovative architecture. This will make possible for [silicon](#) photonics specialists to design things in 3D that must represent a real booster for the emergence of disruptive technologies and new concepts."

More information: Margaux Chanal et al. "Crossing the threshold of ultrafast laser writing in bulk silicon." *Nature Communications*. DOI: [10.1038/s41467-017-00907-8](https://doi.org/10.1038/s41467-017-00907-8)

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