3-D-printed silicon chips with ultrafast trains of laser pulses

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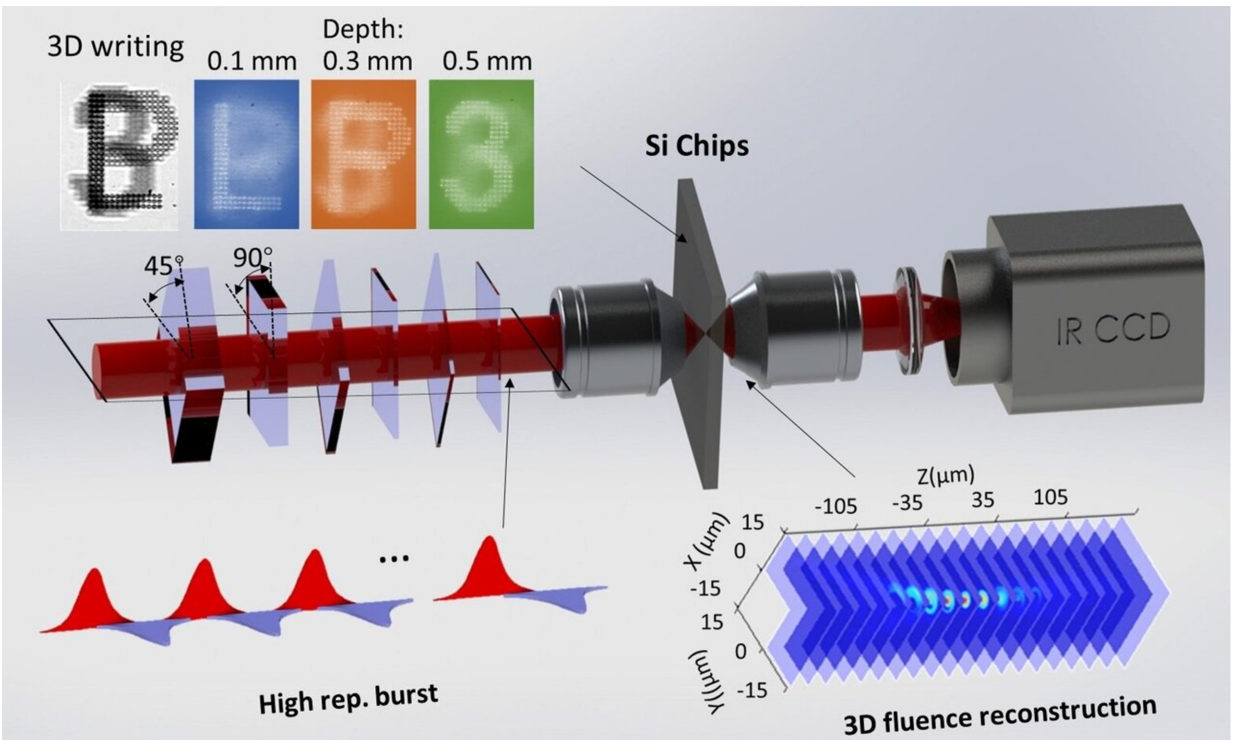

Researchers demonstrate multi-layer writing deep inside silicon by using tightly focused ultrashort pulses at THz-repetition-rate. Credit: LP3-CNRS.

As the basis of the electronics industry, silicon influences most people's daily lives. The powerful Si-based devices in homes are still fabricated by an optical method: lithography. Despite decades of developments and huge investments, the industry confronts a mounting challenge to ultrahigh-density integration.

Lithographic methods are, by nature, 2-D planar manufacturing technologies, while rapidly growing demands make it necessary to extend the created structures from 2-D to 3-D. One consequence is that tedious, complex and costly cycles are required to assemble devices with 3-D architectures. A potential solution to this problem is another optical method—ultrafast laser 3-D writing—which could directly add functionalities anywhere in a silicon chip.

Direct ultrafast laser writing first showed its potential 20 years ago, with the first waveguides fabricated in glass. With the ability to produce material modifications anywhere in the 3-D space, this technique has rapidly developed as a unique tool to form micro-devices with optical, fluidic, or mechanical functionalities, and even hybrid lab-on-chip systems.

However, there have been no similar developments so far in electronics materials because all relevant materials are opaque to light pulses. Although silicon is as opaque as a metal for most lasers, it becomes transparent in the infrared region of the spectrum (>1.1 μm). This, combined with the advent of new laser technologies, has inspired solutions to create 3-D structures inside silicon.

While tightly focused, intense laser light pulses can, in principle, destroy any transparent materials, most narrow-gap semiconductors constitute an exception. The intrinsic propagation nonlinearities associated with these materials prevent the high space-time confinement of laser energy. A consequence is that all attempts to achieve internal structuring of silicon via ultrafast lasers failed, until a recent proof-of-concept experiment relying on hyper-focused beams (Chanal et al. *Nat. Commun*. 2017. 8(1):1-6.).

For a more practical solution, we have identified a new approach exploiting trains of ultrashort laser pulses in a recent study. The solution relies on a simple, elegant, and robust in-line optical arrangement to generate trains of repeated pulses at unprecedented rates. The rates of these intense light bursts, up to 5.6 THz, are so high that they enable unique capabilities for pulse-to-pulse energy accumulation as well as progressive thermal bandgap closure before any diffusion process comes into play.

Space-resolved measurements inside silicon directly display the net increase in the level of space-time energy localization with this new method. The improvement is also supported by high-performance laser writing experiments using this method that would be otherwise impossible. The unique benefits of ultrafast bursts can provide a new route to meet the challenges of 3-D laser writing inside silicon. Interestingly, the generated repetition rates are so high that it makes the method applicable to any other narrow bandgap materials.

We believe this holds the potential for drastically changing how semiconductors are designed and fabricated. While there is still a long way to go to deliver a mass-production technology, we can today envision the development of the equivalent of a 3-D printer for rapid prototyping of 3-D semiconductor devices. This may be crucial for a sector in constant evolution to meet new market demands.

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More information: Andong Wang, et al. Ultrafast Laser Writing Deep inside Silicon with THz-Repetition-Rate Trains of Pulses, Research (2020). DOI: 10.34133/2020/8149764

Bio:

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