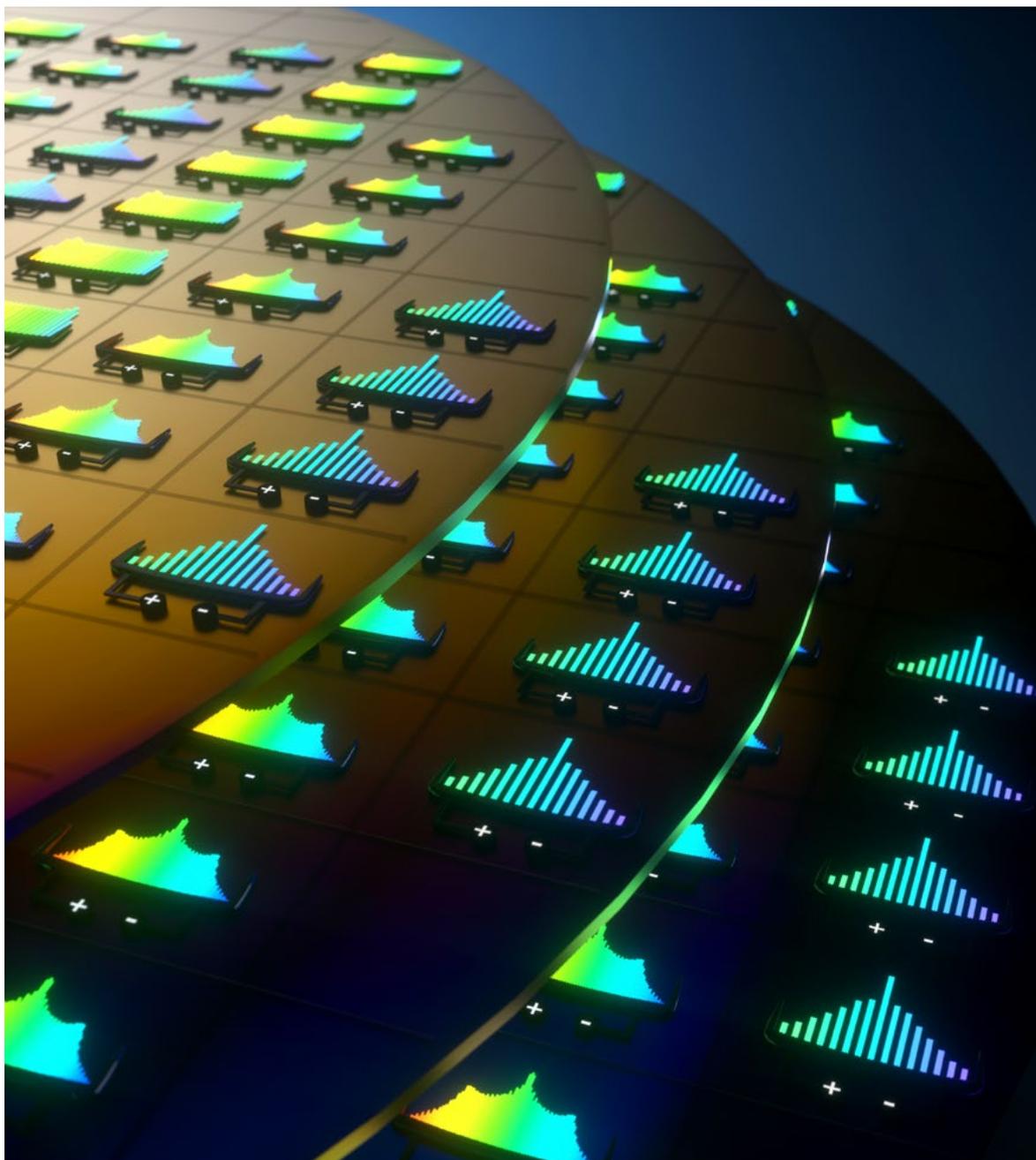


Concept illustration depicts how thousands of integrated frequency microcombs might be manufactured at scale on silicon wafers.
Illustration by Brian Long.



The First
**COMMERCIALY SCALABLE
INTEGRATED LASER
AND MICROCOMB**
on a Single Chip

The Bowers lab and collaborators develop long-awaited breakthrough technology

Fifteen years ago, **John Bowers**, professor in UC Santa Barbara's Departments of Materials, and Electrical and Computer Engineering, pioneered a method for integrating a laser onto a silicon wafer. The technology has been widely deployed in combination with other silicon photonics devices to replace the copper-wire interconnects that formerly linked servers at data centers, dramatically increasing energy efficiency, an important endeavor at a time when data traffic is growing by roughly 25 percent per year.

For several years, the Bowers group has collaborated with the group of Tobias J. Kippenberg at the Swiss Federal Institute of Technology (EPFL), within the Defense Advanced Research Projects Agency's (DARPA) Direct On-Chip Digital Optical Synthesizer program. The Kippenberg group discovered "microcombs," a series of parallel, low-noise, highly stable laser lines. Each of the many lines of the laser comb can carry information, extensively multiplying the amount of data that can be sent by a single laser.

Recently, several teams demonstrated very compact combs made by placing a semiconductor laser chip and a separate silicon nitride ring-resonator chip very close together. However, the laser and the resonator were still separate devices, made independently and then placed close to each other perfectly aligned, a costly and time-consuming process that is not scalable.

The Bowers lab has worked with the Kippenberg lab to develop an *integrated* on-chip semiconductor laser and resonator capable of producing a laser microcomb. A paper titled "Laser soliton microcombs heterogeneously integrated on silicon," published last summer in the

This research enables semiconductor lasers to be integrated seamlessly with low-loss nonlinear optical micro-resonators, "low-loss" referring to the fact that the light can travel in the waveguide without losing a significant amount of its intensity over distance. No optical coupling is required, and the device is entirely electrically controlled.

Importantly, the new technology lends itself to commercial-scale production, because thousands of devices can be made from a single wafer using industry-standard complementary metal-oxide-semiconductor (CMOS)-compatible techniques. "Our approach paves the way for large-volume, low-cost manufacturing of chip-based frequency combs for next-generation high-capacity transceivers, datacenters, space, and mobile platforms," the researchers say in the paper.

The key challenge in making the device was the fact that the semiconductor laser and the resonator, which generates the comb, had to be built on different material platforms. The lasers can be made only with materials from the III and V groups on the Periodic Table, such as indium phosphide, and the best combs can be made only from silicon nitride. "So, we had to find a way to put them together on a single wafer," Xiang explains.

Working sequentially on the same wafer, the researchers leveraged UCSB's heterogeneous integration process for making high-performance lasers on silicon substrate and the ability of their EPFL collaborators to make record ultra-low-loss high-Q silicon nitride micro-resonators using a "photonic damascene process" they developed. The wafer-scale process — in contrast to making individual devices and then combining them one by one — enables thousands

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journal *Science*, describes their success as the first to achieve that goal.

Soliton microcombs are optical frequency combs that emit mutually coherent laser lines — lines in constant, unchanging phase relative to each other. The technology is applied in optical timing, metrology, and sensing. Recent field demonstrations have included applications in multi-terabit-per-second optical communications, ultrafast light detection and ranging (LiDAR), neuromorphic computing, and astrophysical spectrometer calibration for planet searching, to name several. It is a powerful tool, but one that normally requires exceptionally high power and expensive lasers and sophisticated optical coupling to function.

The working principle of a laser microcomb, explains lead author **Chao Xiang**, who earned his PhD in Bowers's lab in May and is now a postdoctoral researcher there, is that a distributed feedback (DFB) laser produces one laser line. That line then passes through an optical phase controller and enters the micro-ring resonator, which causes the power intensity to increase as the light travels around the ring. If the intensity reaches a certain threshold, non-linear optical effects occur, causing the one laser line to create two additional identical lines, one on either side of it. Each of those two "side lines" creates others, leading to a cascade of laser-line generation. "You end up with a series of mutually coherent frequency combs [so-called because the parallel laser lines resemble the teeth of a comb]," Xiang says — and a vastly expanded ability to transmit data.

of devices to be made from a single 100-mm-diameter wafer, a production level that can be scaled up further on the industry standard 200-mm- or 300-mm-diameter substrate.

"The field of optical comb generation is very exciting and moving very fast," says Bowers, the Fred Kavli Chair in Nanotechnology and the director of the College of Engineering's Institute for Energy Efficiency. "The missing element has been a self-contained chip that includes both the pump laser and the optical resonator. We demonstrated that key element, which should open up rapid adoption of this technology."

"I think this work is going to become very big," says Xiang, adding that the potential of the new soliton laser technology reminds him of how the development of putting lasers on silicon fifteen years ago led to enormous progress both in research and in industrial commercialization of silicon photonics. "That transformative technology has been commercialized, and Intel ships millions of transceiver products per year. Future silicon photonics incorporating co-packaged optics will likely be a strong driver for higher-capacity transceivers using a large number of optical channels.

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