From custom-built to ready-made photonics

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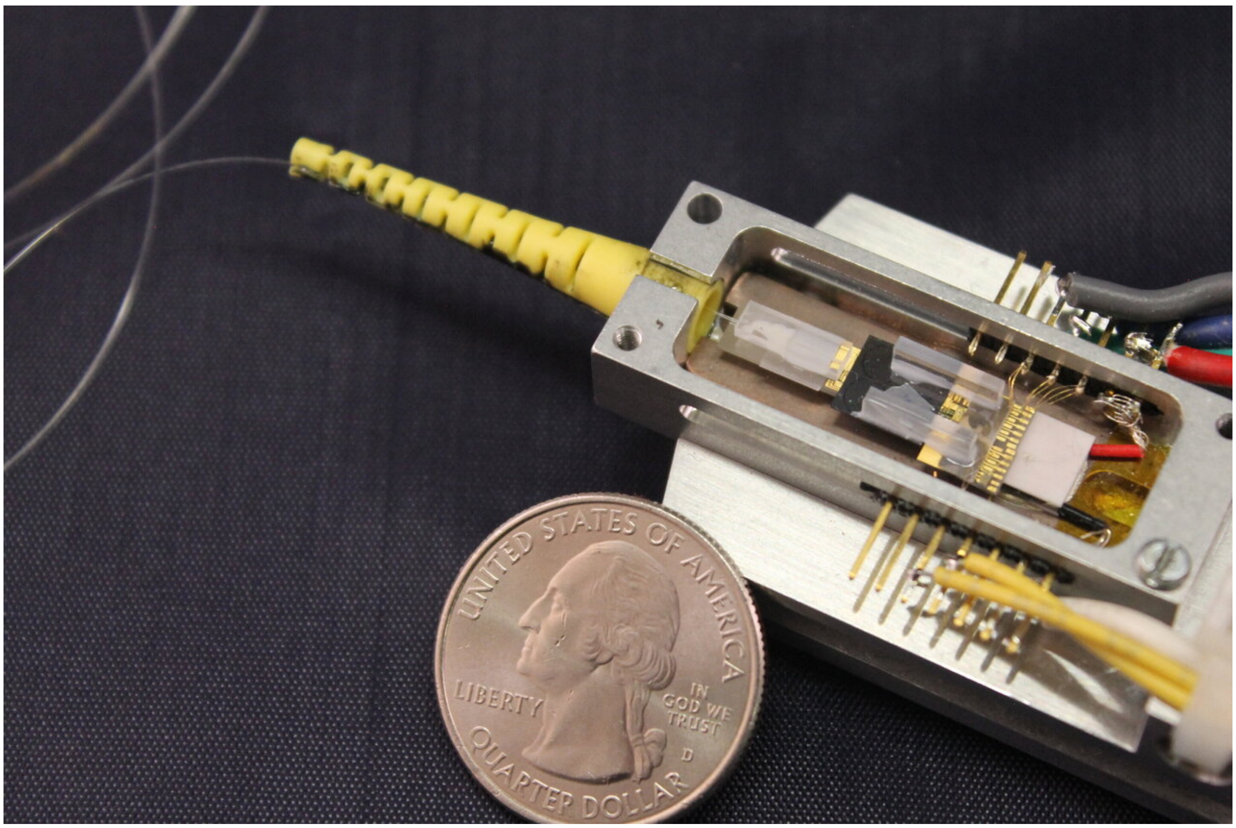

Compact silicon-nitride integrated soliton microcomb chip device in a butterfly package with a fiber output. Credit: Lin Chang (UCSB)

Information technology continues to progress at a rapid pace. However, the growing demands of data centers have pushed electrical input-output systems to their physical limit, which has created a bottleneck. Maintaining this growth will require a shift in how we build computers.

The future is optical.

Over the last decade, the field of photonics has provided a solution to the chip-to-chip bandwidth problem in the electronic world by increasing the link distance between servers with higher bandwidth, far less energy, and lower latency compared to electrical interconnects.

One element of this revolution, silicon photonics, was advanced fifteen years ago when UC Santa Barbara and Intel demonstrated silicon laser technology. This has since triggered an explosion of this field. Intel is now delivering millions of silicon photonic transceivers for data centers all around the world.

Now, a collaboration between UC Santa Barbara, Caltech, and EPFL have made another revolutionary discovery in the field. The group managed to simplify and condense a complex optical system onto a single silicon photonic chip. The achievement, published in *Nature*, significantly lowers the cost of production and allows for easy integration with traditional, silicon chip production.

"The entire internet is driven by photonics now," says John Bowers, who holds the Fred Kavli Chair in Nanotechnology at UC Santa Barbara and directs the campus's Institute for Energy Efficiency and led the collaborative research effort.

Despite the great success of photonics in the internet's backbone, there are still challenges. The explosion of data traffic also means growing requirements for the data rates that silicon photonic chip can handle. So far, most efficient way to address this demand is to use multicolor laser lights to transmit information: the more laser colors, the more information can be carried.

But this poses a problem for integrated lasers, which can generate only one color of laser light at a time. "You might literally need fifty or more lasers in that chip for that purpose," says Bowers. And using fifty lasers is expensive and inefficient in terms of power. Also, noise and heat can cause the frequency of light that each laser produces to fluctuate. Finally, with multiple lasers, the frequencies can even drift into each other, much like early radio stations did.

A solution can be found in the technology of "optical frequency combs", which are collections of equally spaced frequencies of laser light. Plotting the frequencies reveals spikes and dips that resemble a hair comb—hence the name.

Generating combs used to require bulky and expensive equipment, but this can be now managed using the recently emerged microresonator-based soliton frequency combs, which are miniaturized frequency comb sources built on CMOS photonic chips. Using this "integrated photonics" approach, the collaborating team has developed the smallest comb generator in the world, which essentially resolves all of these issues.

The system is rather simple, consisting of a commercially available feedback laser and a silicon nitride photonic chip. "What we have is a source that generates all these colors out of one laser and one chip," says Bowers. "That's what's significant about this."

The simple structure means small scale, less power, and lower cost. The entire setup now fits in a package smaller than a match box whose overall price and power consumption are smaller than previous systems.

The new technology is also much more convenient to operate. Previously, generating a stable comb had been a tricky endeavor. Researchers would have to adjust frequency and power just right to produce a coherent soliton comb, and even then, the process was not guaranteed to generate a comb every time. "The new approach makes the process as easy as switching on a room light," says Kerry Vahala, Professor of Applied Physics and Information Science and Technology at Caltech, where the new soliton generation scheme was discovered.

"What is remarkable about the result is the full photonic integration and reproducibility with which frequency combs can be generated on demand," adds Tobias J. Kippenberg, Professor of Physics at EPFL who leads the Laboratory and Photonics and Quantum Measurement (LPQM), and whose laboratory first observed microcombs more than a decade ago.

The EPFL team has provided the ultralow-loss silicon nitride photonic chips, which were fabricated in at EPFL Center of MicroNanoTechnology (CMi) and serve as the key component for soliton comb generation. The low-loss silicon nitride photonics technology has been commercialized via the lab startup LIGENTEC.

The "magic" behind all these improvements lies in an interesting physical phenomenon: when the pump laser and resonator are integrated, their interaction forms a highly coupled system that is self-injection-locking and simultaneously generates "solitons"—pulses that circulate indefinitely inside the resonator and give rise to optical frequency combs.

The new technology is expected to have an extensive impact on photonics. In addition to addressing the demands of multicolor light sources in communication-related products, it also opens up a lot of new opportunities in many applications. One example is optical clocks, which provide the most accurate time standard in the world and are used in a number of applications, from navigation to measuring physical constants.

"Optical clocks used to be large, heavy, and expensive," says Bowers. "There are only a few in the world. With integrated photonics, we can make something that could fit in a wristwatch, and you could afford it."

"Low-noise integrated optical microcombs will enable a new generation of optical clocks, communications and sensors," says Gordon Keeler, the project's manager at the Defense Advanced Research Projects Agency (DARPA). "We should see more compact, more sensitive GPS receivers coming out of this approach."

All in all, the future looks bright for photonics. "It is the key step to transfer the frequency comb technology from the laboratory to the real world," says Bowers. "It will change photonics and our daily lives."

More information: Integrated turnkey soliton microcombs, *Nature* (2020). DOI: 10.1038/s41586-020-2358-x , www.nature.com/articles/s41586-020-2358-x

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