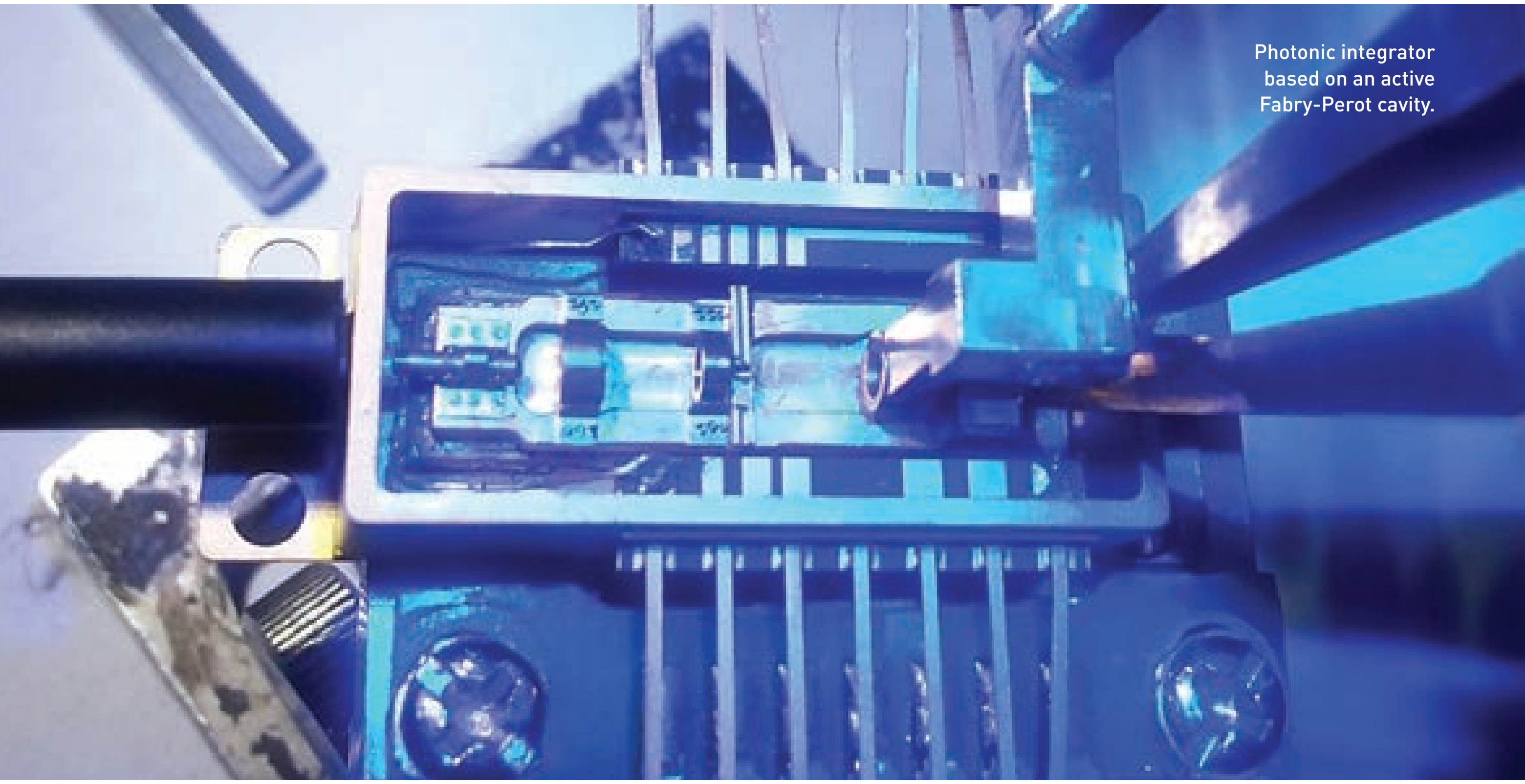

Ming Li, IS-CAS

OPTICAL ENGINEERING

Advances in **All-Optical Circuits**

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New photonic temporal integrators could push past some of the processing-speed limitations of electronic approaches.

All-optical signal processing attracts much attention because of its potential to overcome the bandwidth and speed bottlenecks of electronic circuits. Many all-optical signal processing techniques already show up in a wide range of applications, like ultrafast telecommunications, optical computing, microwave photonics and biophotonics. These techniques offer processing bandwidths up to several THz—significantly faster than their electronic counterparts.

To build an all-optical signal-processing and computing platform, we need to replace electronic circuit components with photonic counterparts, and thereby emulate processes and structures in the electronic domain using photonic technologies. Recently, all-optical temporal differentiators and integrators, and real-time Fourier and Hilbert transformers have been tested in the lab using fiber and integrated optics platforms, with bandwidths two to four orders higher than those of electronic equivalents.

We have recently demonstrated two kinds of all-optical temporal integrators. Each design is capable of calculating the time integral of an arbitrary optical temporal waveform and has the potential to reach processing speeds well beyond the capabilities of electronic

CIRCUIT PERFORMANCE COMPARISON

DIFFERENTIATOR BANDWIDTH

Electronic: **<1 GHz**

Photonic: **>25 THz**

INTEGRATOR BANDWIDTH

Electronic: **<1 GHz**

Photonic: **>200 GHz**

integrators. An all-optical temporal integrator could be used to realize arbitrary waveform generation, all-optical memory units and programmable differential-equation solvers, among other applications.

Active Fabry-Perot cavity integrator

One of our proposed all-optical temporal integrators is based on numerical modeling of an active Fabry-Perot (FP) cavity. The gain medium in the FP cavity is a semiconductor optical amplifier (SOA) with a high gain coefficient. The length of its integration time window is widely tunable and could be extended to be infinitely long by properly setting the injection current. This feature is important because it could greatly extend memory time when used for creating random access memory (RAM).

SOAs can be easily integrated with other semiconductor devices, such as lasers, modulators and photodetectors in photonic integrated circuits; this is another critical feature for achieving integrated all-optical signal-processing circuits with complex functionality.

Based on the use of an FP cavity with nearly feasible parameters, such as net modal gain and gain recovery speed, we successfully demonstrated a photonic temporal integrator with an integration time window of 160 ns and an operational bandwidth of 180 GHz. We calculated the time-bandwidth product of the simulated photonic temporal integrator to be 28,800—about two orders of magnitude higher than any previously reported result that we know of.

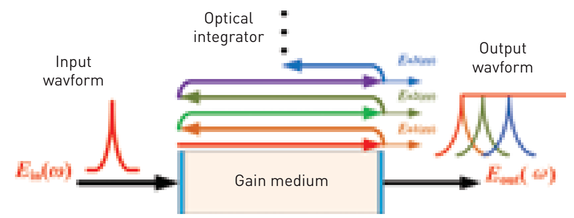
Active ring cavity integrator

Our second proposed all-optical temporal integrator includes a ring structure coupled with two bypass waveguides in an InP-InGaAsP material system consisting of SOAs and current-injection phase modulators (PMs).

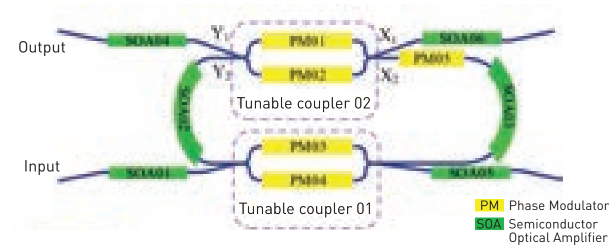
During experimental testing, we modulated an input signal from an electronic arbitrary waveform generator onto a tunable laser. When we tuned the carrier wavelength to match the operation wavelength of the all-optical integrator, the output integrated waveform was converted into an electrical signal in a photodetector, which was then measured in a high-speed sampling oscilloscope. Within the ring, two SOAs were incorporated to compensate for the insertion loss.

We reported an experimental integration time window as long as 6,331 ps, an order of magnitude longer than any other photonic integrator we could find. In addition, there is a current injection PM in the ring for wavelength tuning. We believe our demonstration is the first report of an all-optical temporal integrator with an ultra-long integration time window and an ultra-wide tunable operation wavelength.

FABRY-PEROT CAVITY



ACTIVE RING CAVITY



Next steps

Despite promising experimental results, our two integrators suffer from relatively low processing speeds—they still exceed electronic integrator performance, but perform well below the full theoretical potential of an all-optical solution. This limitation is due to the relatively long cavity of our designs. We are working on improving our designs for future demonstrations.

Nevertheless, our proposed integrators provide noteworthy integration time windows and represent an important step toward realizing efficient all-optical signal-processing circuits capable of overcoming the limitation in integration time window, bandwidth and power consumption imposed by electronics. OPN

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To Learn More ...

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