Electronics and photonics united

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A method for integrating photonic devices with state-of-the-art nanoelectronics overcomes previous limitations. The approach shows promise for realizing high-speed, low-power optoelectronic technology.

The integration of electronic and photonic circuits on a single silicon chip could enable unprecedented functions and performance in computing, communications and sensing at a low cost. But this goal has been hindered by the fact that most electronic circuits use bulk silicon substrates, whereas photonic circuits typically require silicon-on-insulator platforms. In a paper in *Nature*, Atabaki *et al.*1 report the first fabrication of photonic devices on a bulk silicon substrate, together with millions of electronic devices known as transistors. The work paves the way for the mass production of optoelectronic systems on chips.

Photonics is prevalent in almost every aspect of day-to-day life — from smartphones and display screens to lighting and medical devices. It is often considered to be the 'electronics of the twenty-first century'. Although silicon is not an ideal photonics material (for example, lasers cannot be built from silicon), many factors have made it the main candidate for applications that require large numbers of photonic devices2. These factors include the high natural abundance of silicon, its widespread use in electronics, its optical transparency over a wide range of wavelengths and the availability of silicon-fabrication facilities that are used in micro- and nanoelectronics.

Thanks to intense research activity over the past 15 years, there have been many breakthroughs in the field of silicon photonics. Examples include hybrid silicon lasers3, various types of modulator4 (devices that convert electronic information into optical signals), high-speed light detectors5 (photodetectors) and complex optoelectronic circuits6. Several companies currently sell products based on silicon photonics chips, and many more are poised to do so in the near future.

In the electronics industry, complementary-metal-oxide-semiconductor (CMOS) technology is used to create computer processors and memory, communication chips and image sensors. This technology is based on silicon and depends on the ability to cram a large number of transistors and electronic circuits on to a single chip. Similarly, the integration of large numbers of electronic and photonic circuits on a single chip is crucial for meeting the requirements of computer processors and communication links in data centres, in terms of data-transmission rates, power consumption, scalability and complexity.

The main challenge for such integration has been the incompatibility of the material platforms used in silicon electronics and photonics. CMOS technology uses either bulk silicon substrates or thin silicon-on-insulator wafers6. The former is by far the most dominant platform because of its abundant supply chain and low cost. By contrast, silicon photonics usually requires thick silicon-on-insulator wafers that have a limited supply chain and are too expensive for many applications, such as computer memory. A long-term goal has therefore been to integrate electronic and photonic components using standard CMOS-manufacturing techniques and material platforms, without affecting the performance of such components.

Atabaki and colleagues have made a breakthrough in this regard by decoupling the formation of photonic devices from that of transistors, and by successfully incorporating these photonic devices into bulk silicon CMOS chips. The authors used standard CMOS-manufacturing methods, and introduced only a few changes to the fabrication process to create areas dedicated to photonic devices in the bulk silicon. The devices were integrated during the processing of the transistors. This involved the addition of isolated patches (islands) of the insulator material silicon dioxide to the bulk silicon and the deposition of a thin film of polycrystalline silicon on top. Photonic devices were fabricated in this silicon-on-insulator region, whereas transistors were formed in standard bulk silicon regions on the CMOS chip (Fig. 1).

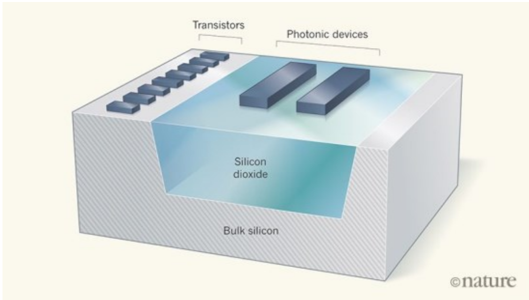

Figure 1 | Optoelectronic integration. Atabaki *et al.*1 report a technique for integrating electronic and photonic devices on a single silicon microchip. The authors added isolated patches (islands) of the insulator material silicon dioxide to a bulk silicon substrate — for simplicity, a single island is shown here. They then deposited a thin film of polycrystalline silicon on top. Photonic devices and electronic devices known as transistors were fabricated from this film; the former in the silicon-on-insulator region and the latter in the bulk silicon. (Adapted from Fig. 1b of ref. 1.)

Although the electronic and photonic properties of crystalline silicon are superior to those of polycrystalline silicon, because the former has a more uniform structure, it is not possible to grow crystalline silicon on top of silicon dioxide. Atabaki *et al.* therefore opted for polycrystalline silicon, which is relatively cheap and readily available because it is used in transistor fabrication. The authors used this material to create various photonic components, including waveguides (structures that enable light propagation on chips), optical filters known as micro-ring resonators, vertical grating couplers (for coupling light between waveguides and optical fibres), high-speed modulators and photodetectors.

The performance of these components was similar to or better than previous demonstrations in polycrystalline silicon7–9. But, more importantly, the performance was unaffected by the fact that such components operated next to electronic-circuit blocks composed of millions of CMOS transistors. Consequently, the authors' silicon-photonics chips can achieve many of the goals of systems that require multiple chips, with substantial cost, scalability and performance advantages.

Atabaki and colleagues' results are impressive, but there are several aspects that could be improved. For example, optical loss in the waveguides could be reduced, and the filtering of light in the micro-ring resonators and the coupling efficiency of the vertical grating couplers could be increased. The authors suggest that optical loss might be minimized by refining the polishing process that they used to reduce the roughness of the silicon dioxide islands and the polycrystalline-silicon film. Such an improvement would lead to chips that have better photodetector sensitivity, lower voltage requirements and lower power consumption — all of which are crucial for the realization of efficient on-chip optoelectronic systems.

Further optimization of the polycrystalline-silicon film could enhance the speed of the modulators and photodetectors, which is paramount for future optical connections that can transmit data at rates of multi-terabytes per second. Atabaki *et al.* fabricated their silicon photonics chips using a technology based on 65-nanometre transistors, and it will be interesting to see whether their approach can be extended to smaller scales at which an even greater density of transistors can be integrated. Future work could also examine how the approach could be used for optical connections inside microprocessors.

Although there are several challenges to be overcome, the authors' work is a milestone on the path towards the mass production of on-chip optoelectronic systems. We can expect an exciting period of development of such systems, and their demonstration for a host of applications. In the future, they might be as ubiquitous as today's electronic microchips.

Source:
Nature **556**, 316-318 (2018); *doi: 10.1038/d41586-018-04443-3*