MICROPHOTONIC DEVICES

The polarization gates open

For optical devices to be truly useful, they must be able to control light of any polarization. A group at MIT has now made this possible, bringing us a step closer to unlocking the potential of on-chip optics.

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Scalable integration of photonic devices has long been a revolution on the horizon. The ability to mass-produce arrays of optical components integrated onto a single wafer promises dramatic improvements in the cost, performance and complexity of light-based technology. In contrast to the current labour-intensive hand assembly of optical devices, integration could put photonics on the kind of Moore's law trajectory that has made microelectronics pervasive.

Researchers have just overcome one of the remaining obstacles to this enticing goal on page 57 of this issue[1]. Barwicz and colleagues have demonstrated the ability to make devices that confine light on a microscopic scale and, in addition, are 'polarization-transparent': that is, an incoming light signal is processed correctly even if it has a randomly oriented electric field. Specifically, Barwicz and co-workers present an add–drop filter, a device that can pull out a signal at one wavelength from a communication line densely packed with many different wavelengths. The device can separate closely spaced (130 GHz) channels very cleanly and maintains polarization-transparency over a broad range (60 nm) of wavelengths — the kind of device you would expect to find on a next-generation telecommunications chip.

This breakthrough has come at an exciting time in the field of microphotonics. In just a few years, several major hurdles have been overcome. One barrier was the profound incompatibility between materials that are good at generating or modulating light and those that make good electrical devices. Scientists have now coaxed different materials to work together, for example by bonding optical-gain media onto silicon wafers used in standard electronics[2]. In other work, attempts to endow silicon — the staple of the microelectronic world — with the ability to control light are paying off, resulting in compact silicon modulators[3,4].

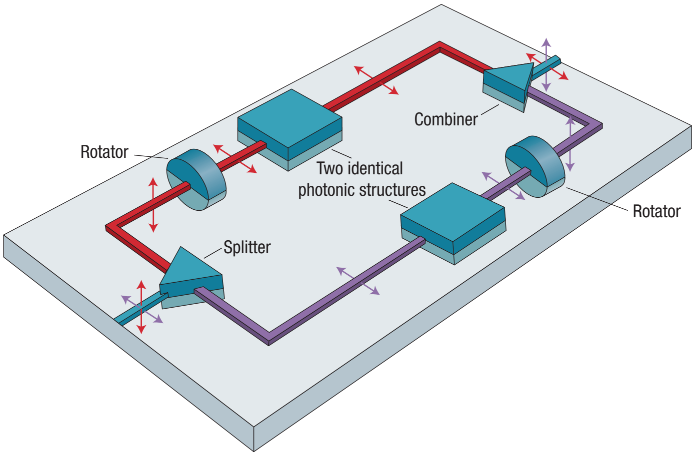

Figure 1 Polarization-transparent devices. Using the polarization-diversity approach shown, the two polarization components of the incoming light wave are separated, sent through two identical photonic structures (add–drop filters in this case), and combined at the output. The overall device has an almost identical filter response to orthogonal input polarizations, even though individual photonic elements are extremely polarization sensitive.

Even simpler structures that merely move light around a microphotonic chip can unfortunately be difficult to implement, because of their sensitivity to manufacturing errors. For dense integration into optical devices, waveguides must confine light within submicrometre dimensions using materials with a high refractive index. But even slight imperfections in the dimensions or surface roughness of waveguide structures can lead to crippling light losses.

If the light entering such a structure is randomly polarized, this inherent sensitivity becomes an even bigger problem. Arbitrary input polarization is often unavoidable, especially if light couples to the device through an optical fibre as is the case in many applications. A recent theoretical analysis[5] showed that even if components could be fabricated with atomic-level precision, this would still not be enough to achieve polarization transparency for some devices. Subnanometre imperfections in modules such as add–drop filters can lead to different polarization contributions being filtered in different ways. The need for better than atomic precision puts severe limitations on the structures that can be made.

This apparent impasse has not stopped Barwicz and colleagues[1]. They use a technique called polarization diversity, in which light (of a random polarization) is split into its orthogonally polarized components travelling in separate arms of a photonic circuit (see Fig. 1). By rotating the polarization state in one of these arms, a single polarization is achieved on the chip as a whole. The two beams then pass through identical sets of polarization-sensitive structures and are recombined at the output. In this way, the researchers force polarization-sensitive structures (in this case distinct add–drop filters) to behave in a polarization-transparent way, offering an almost identical response to the different input polarizations.

Such an approach is conceptually rather simple: as each filter receives only one polarization, its mismatched response to the other polarization does not matter. However, to implement this known approach, the team had to overcome some technological challenges. Not least, polarization diversity calls for extra complexity and the design of new elements in addition to the microrings that do the filtering. One such component is an elegant polarization splitter and rotator, which manipulates light in an intricate three-dimensional structure that can be constructed from just two flat silicon layers. Moreover, the filters in the device must be very nearly identical so that they offer the same response, otherwise the overall device will process the two incoming polarizations differently.

This advance is a culmination of several refinements that have been made in recent years, pulling together clever designs and fabrication techniques. By integrating these new building blocks, Barwicz and co-workers not only address the specific needs of polarization diversity, but they also move a step closer to producing sophisticated optical devices with improved functionality.

The emerging silicon photonics toolbox is impressive, and its ability to put optics on a chip with standard silicon electronics already has enormous potential. Nevertheless, tantalizing questions remain about the development of light sources that are compatible with silicon. In the meantime, non-silicon platforms are showing promise for optical integration[6]. Regardless of the eventual winner, in order to substantially change the way optical networks are made — and get other applications such as light-based computing and sensors moving — we will need to bring together the capabilities demonstrated at MIT and other research labs. With exciting improvements in the pipeline, the long-awaited impact of integrated photonics should be arriving soon.

References

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SILICON PHOTONICS

An exercise in self control

Controlling light with light using devices small enough to fit on a chip is tricky, but it is crucial for any integrated all-optical logic scheme. Scientists have now produced modulators that control light at breakneck speeds, bringing the vision of all-optical chips closer to reality.

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We all expect fast, free-flowing data whenever and wherever we connect with the world. Optical devices built onto microelectronic chips[1–4] could bring us computers that process and deliver information faster than ever before. A possible path along this route is to construct purely light-based networks on a single chip, in which electro–optic components are replaced by their faster photonic counterparts, and a key ingredient for this is the all-optical modulator, which controls one light signal with another. As reported in *Nature Materials*, Michael Hochberg and collaborators have now successfully demonstrated all-optical modulation at unprecedented speeds, suggesting that chip-scale all-optical networks are indeed within reach[5].

Within the coming decade, the circuitry embodied by a rack of today's network servers will in theory fit onto a single silicon chip half the size of a postage stamp. But can we really expect the available bandwidth to continue to increase? This is not clear. One of the bandwidth bottlenecks is the type of interconnect that feeds processors within computers and servers: existing copper interconnecting wires are becoming incapable of handling today's overwhelming tides of data because they create too much heat. By replacing electrical interconnects with optical ones, we could create radically new flexible architectures capable of processing large amounts of information while dissipating acceptably small amounts of heat. And by implanting the photonic technology on silicon wafers[6,7] (as opposed to other, more traditional substrates such as gallium arsenide and indium phosphate), manufacturers can use the same methods and equipment they now use for ordinary integrated circuits.

Over the past 20 years most progress in silicon photonics has been targeted towards making passive devices — waveguides, filters and the like — in which the flow of light is predetermined by the geometry of the structure. It was only very recently that efficient active devices such as modulators, which work by controlling light transmission externally, were shown to be feasible on a silicon platform, thanks to advances in nanofabrication techniques. Such devices operate through the so-called plasma-dispersion effect[8], in which changes in electrical-carrier concentration affect the overall optical behaviour.

Electro–optic modulators control light using electrical signals — essentially they take small changes in the optical properties of a material (which arise in response to an electric field) and translate them into an intensity change in the light. Although such modulation has been demonstrated at gigahertz speeds, the question is can we go further and faster by modulating one light wave with another? All-optical modulators and switches that exploit an effect similar to the one used in previously demonstrated electro–optic modulators[9] have been built, but the speed of such devices is limited by how fast carriers can be moved across the photonic structures (a speed now in the gigahertz domain). Until now, this limitation seemed to be a fundamental one.

Hochberg and colleagues at Caltech and the University of Washington have broken this speed limit. Instead of relying on carrier-induced effects, they exploit the Kerr phenomenon — whereby an