photonics tech briefs:

Photonic Crystals Show Promise for Wiring Optical Chips

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Wiring in an electronic circuit is relatively easy; photons, on the other hand, require more subtle persuasion to change direction.

Photonische Kristalle sind vielversprechend bei der Verdrahtung optischer Chips

Die Verdrahtung einer elektronischen Schaltung ist verhältnismäßig einfach, Photonen dagegen erfordern subtilere Arten der Überredung, um Ihre Richtung zu ändern.

Des cristaux photoniques prometteurs pour le câblage de puces optiques

Monter un circuit électronique est relativement facile mais les photons de leur côté exigent une méthode subtile pour changer de direction.

I cristalli fotonici appaiono promettenti per il "cablaggio" dei *chips* ottici

Cablare un circuito elettronico e' relativamente agevole; i fotoni, al contrario, per cambiare direzione hanno bisogno di un'opera di persuasione piu' raffinata.

If you place a conducting path — typically made of copper, aluminium or silver — on your chip or circuit board, the electrons will follow that path. But changing the direction of photons is more complicated. In established integrated optics, there are two techniques for bending light. Adiabatic deflection uses a very gentle curved waveguide, and the "photonic wire" method uses mirror surfaces based on total internal reflection. Adiabatic components offer low loss but are generally very large. Photonic wire components are much smaller but have much higher loss.

Photonic crystals may offer a third way to connect optical components, potentially delivering the low loss of adiabatic components and matching the small size of total-internal-reflection-based devices. The best minds in photonics, working in universities and in industries around the world, are trying to solve the problems that remain. If they are successful, the photonic crystal is likely to make a huge impact not only on optical circuits for telecommunications applications, but also as an interconnect technology for semiconductor chips. An electronic signal will typically travel at just 10 per cent of the speed of light on the surface of an integrated circuit, but an optical signal will travel three to six times this speed, enabling faster electronic chips, even as the chip size increases.

A typical photonic crystal waveguide consists of a GaAs layer sandwiched between AlGaAs layers, with holes etched through in a triangular lattice pattern. At certain wavelengths, interference effects prohibit photons from propagating through these lattice regions, just as electrons are kept out of the bandgap energy region of a semiconductor. In the structure, some holes are missing (a so-called "line defect"), allowing light to travel along the line of missing holes, but the lattice prevents it from escaping sideways.

When a Y junction is implemented, the light can only go forward into the Y branches, be reflected or be scattered up- or downward (Figure 1). The photonic crystal lattice eliminates all "in-plane" losses. Eliminating

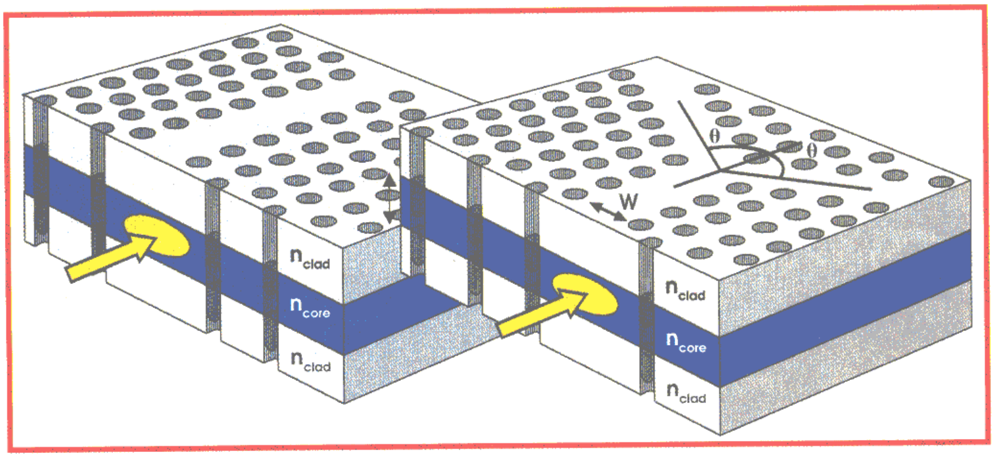

Figure 1. In this schematic of a photonic crystal waveguide (left), a GaAs layer (blue) is sandwiched between AlGaAs layers (grey). Holes are etched through the layers in a triangular lattice pattern. When a Y junction is added (right), the light can only move forward into the Y branches, be reflected or be scattered up or down.

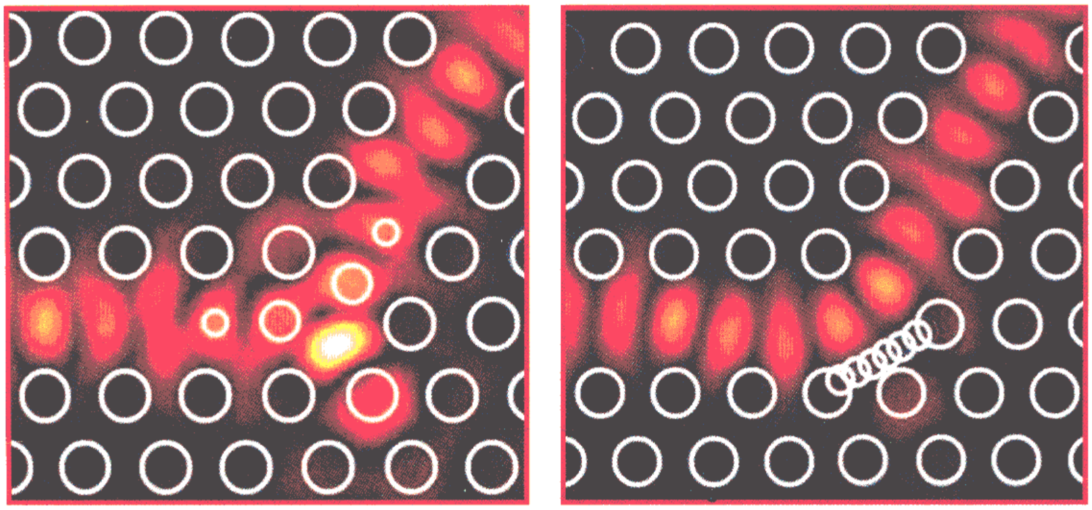

Figure 2. Light can be bent in two ways: by using a resonance effect (far left) or a "steering" effect (left).

backreflection and vertical scattering are the key challenges in designing a photonic crystal circuit. A successful design must have high transmission and a wide bandwidth, implying low reflectivity and low out-of-plane scattering of the light. It also must be easy to manufacture. Enormous progress has been made in the past year, with many groups reporting very low loss circuit components, such as the Y junction.

To support this research, Photon Design has developed a tool under the auspices of the European research project Picco. CrystalWave was built from the ground up for the design, layout and simulation of photonic crystals.

Many researchers in photonic crystals had put forward designs involving resonances (Figure 2, left). CrystalWave simulations based on the finite difference time domain algorithm have been instrumental in a move away from such resonant designs and toward the use of "steering" mechanisms (Figure 2, right). The resonances act as antennae radiating losses up and down. They also significantly reduce the optical bandwidth. This understanding of the need to avoid photon localization has been a key factor in the improvement in photonic crystal circuit efficiency over the past 18 months.

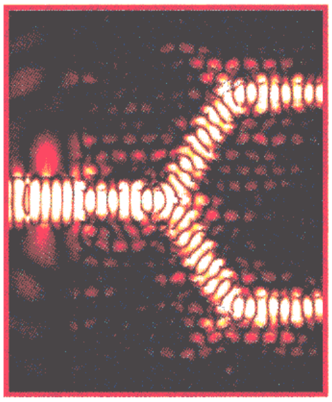

Figure 3. The 3-D finite difference time domain method was used to simulate a photonic crystal Y junction. The device was made in GaAs/AlGaAs with a hole spacing of 0.428 μm and a hole diameter of 0.26 μm, yielding an operational wavelength of around 1.55 μm.

The design of a photonic crystal circuit element is not a trivial exercise — many parameters must be optimized simultaneously, and there is no simple way to calculate what each value should be. This is a very laborious task to do manually. Thus, an automatic optimization algorithm is of enormous benefit to the designer. In a simulation of a Y junction, the automatic optimization was performed using a fast-frequency-domain algorithm in two dimensions and verified using the 3-D finite difference time domain method (Figure 3).

The design exhibits an ultralow loss of just 2 per cent in two dimensions, and the device, manufactured using GaAs/AlGaAs technology by the University of St. Andrews in the UK, has demonstrated efficiencies of ~90 per cent. It also exhibits a world-record bandwidth with a response almost flat over 50 nm (the measurement window) around 1.55 μm — something that has been difficult to achieve with high efficiency.

The tools used to design the above structure are now integrated into the CrystalWave environment. An integrated band-structure calculator based on the plane-wave expansion method is available to study the properties of the lattice — a first step in any photonic crystal design. An ultrafast frequency domain simulation algorithm coupled to an automatic optimization tool is used to produce initial designs. This algorithm, capable of evaluating thousands of designs an hour, is the key to efficient automatic optimization. A highly efficient finite difference time domain engine then verifies the designs in three dimensions. The integration of these tools into one package reduces what was previously a task of multiple man-months to one of a few days.

Photonic crystal technology continues to evolve by leaps and bounds. Though even higher efficiencies than those reported here will be required for large circuits, this rapid advancement is likely to bring photonic crystals into real-life applications in the next couple of years. CrystalWave and the competing products that are likely to follow make the design of what is a sometimes temperamental technology almost as routine as conventional integrated optics.

In recognition of the potential importance of this technology, the European Union has just awarded €2 million for a new project, FunFox (Functional Photonic Crystal Devices for Metropolitan Optical Networks). This project includes industrials Alcatel and Photon Design, the University of St. Andrews, the Centre National de la Recherche Scientifique in Orsay, France, and five other leading research labs. It will address the use of photonic crystals to miniaturize and improve semiconductor optoelectronic devices needed in the metropolitan core and access optical networks. ☐

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