On-chip optical isolation

Nature Photonics spoke to Zongfu Yu and Shanhui Fan from Stanford University about their proposed 'one-way valve for light' that suits integration on a photonic silicon chip.

Tell us about optical isolators.

An optical isolator is a device that allows light to travel only in one direction, blocking any transmission in the opposite direction. In optical fibre communications networks it is an essential device, basically preventing interference between different parts of network equipment.

What is the motivation for an on-chip isolator?

If you want to integrate a lot of components together you need to have a way to prevent interference between them, especially in terms of backscattering, which can lead to coherent interference. Such interference can give you very complicated parasitic responses of the network. In fibre networks it is essential to have that kind of isolator functionality. As researchers push towards very large-scale on-chip networks, optical isolation on the chip scale is becoming increasingly important.

Why is it so hard to make an isolator that suits chip-scale integration?

A number of routes towards on-chip optical isolation have formed over the past few decades. One direction is the use of magneto-optical materials on-chip but common magneto-optic materials such as yttrium iron garnet, found in optical isolators based on the Faraday effect, are not the type of materials that are amenable to semiconductor chip fabrication. Also, the most popular semiconductors in electronics and photonics, such as silicon or GaAs, are not magneto-optically active. People are trying to get around this by various means such as wafer-bonding yttrium iron garnet thin-films onto a silicon waveguide, developing magnetically doped semiconductors that show magneto-optical effects and trying to create magneto-optical photonic crystals.

One of the promising recent approaches was to use optical micro-resonators to greatly enhance magneto-optical effects, but these materials systems are still fairly non-standard and not ideal. The difficulty with on-chip magneto-optics has been very well recognized and so there has been a lot of work on trying to figure out a way to get optical isolation without using any magneto-optical materials.

One approach is to use optically nonlinear structures to achieve isolation. The main difficulty here is that nonlinear effects are typically power-dependent so you only have isolation at some particular power level. That is a real issue because if you build an optical network you actually don't know what the noise will be, and this results in only partial isolation. Our aim was to have a linear scheme that is independent of amplitude and phase of the signals.

Zongfu Yu (left) and Shanhui Fan.

How does your non-magnetic and linear scheme work?

The question we asked was whether it is possible to use a travelling refractive-index modulation to produce isolation. In this case you break the symmetry in space (left–right) as well as in time (forwards–backwards) so reciprocity is broken. Basically light propagating in one direction will see a different refractive-index profile from counter-propagating light.

The fact that this modulation breaks reciprocity is known, and was widely used, for example in phase modulators in optical gyroscopes. In the typical modulation schemes used there, they use intra-band transitions, and that scheme generates modulation side-bands that are undesirable for an isolator. Our photonic interband transition developed here overcomes this difficulty. What we show is that if you have a phase-matched transition, non-reciprocal between two bands, there is no other phase-matched process allowed. As a result, you can achieve very clean isolation.

How small could the isolator be?

All isolators in which the non-reciprocal part is largely lossless need to include a filter. The standard optical Faraday rotator needs a polarization filter to block out the reflected light whose polarization has been rotated. The total size of that type of isolator is of the order of millimetres to centimetres. The overall footprint of our device, including the modulation region and the mode filter, could be less than ten wavelengths squared.

What kind of performance can we expect and how could your design be made?

The operating wavelength is theoretically arbitrary. We have a realistic design for 1.55 μm wavelength — this gives a bandwidth exceeding 1 THz with more than 40 dB isolation. Insertion loss is not really an issue; it could be effectively reduced by mode-matching. The main loss comes from the modulation itself. The more strongly you modulate, the more loss you get. At least this is the case with silicon, where you inject carriers and in doing so you modulate the refractive index but also introduce intrinsic loss. For the kind of refractive-index modulations we are talking about, propagation over the millimetre range is probably not an issue.

Our device could be realized in a ring-resonator or a straight waveguide, which is probably easier to make. The main thing is not the particular shape of the waveguide, but achieving the modulation. There are a number of schemes we are actively thinking about for demonstrating that — for example, a carrier-induced scheme, as described in the paper, or an acoustic scheme.

What is the next step?

For on-chip integrated photonics in general, the issue of dynamics is very important. Typically when people think about dynamic devices, they think about tunable or reconfigurable properties, like changing the frequency of a spectral filter. However, if you modulate dynamically, the functionality you can accomplish is much greater than just a tunable device. We are very interested in new functionalities enabled by on-chip photonic structures that change their properties as a function of time. In our view, this is a very rich field that is waiting to be explored.

INTERVIEW BY DAVID PILE

Zongfu Yu and Shanhui Fan have a Letter on their on-chip optical isolator on page 91 of this issue.