Ultracompact photonic crystal integrated circuits: connecting tiny devices to achieve high-performances

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Abstract: PhC technology is expected to play an important role in the future of optical telecommunication devices. Results relevant to the design and fabrication of a 4×25 Gbit/s WDM Receiver and of a 100 Gbit/s OTDM Receiver are presented.

Introduction. In the last years, the rapid advances in science and technology, with the disrupting advent of Internet in daily life, have transformed significantly the world of communication and computing. The demands of consumers for higher speeds and greater capacities appear unending. Photonic chips are set to play an important role in the development of future communication and information technologies. Photons (carriers of optical signals) have important fundamental properties that make them superior to electrons (carriers of electrical signals) for representing and transmitting data, as demonstrated by long distance communication networks. However, as the bandwidth increases, the advantages of optics even holds for very short transmission distances, such as between high-speed processors in a computer, and ultimately, across individual computer chips. Although electronics continues to remain unbeaten for performing high-level data processing (such as that performed by modern computers), the growth in performance is today falling short of earlier predictions: electrical interconnects, in fact, are the key factor limiting the speed and the integration level of electronic circuits. Faster switching is possible with current transistor technology, but it takes too much power and generates too much heat to send information across the chip at higher data rates. Photonics has therefore a crucial role to play in global interconnects, but this is a difficult challenge as, to be competitive, the size and power consumption of traditional photonic devices must be reduced by more than two orders of magnitude. Photonic Crystals (PhCs) based technology seems to address these issues and be able to provide devices capable of meeting these challenges. In the framework of the European Project COPERNICUS, researches of different institutions developed the technology needed to provide 100 Gbit/s WDM and OTDM receivers based on PhCs. The main steps needed to get devices that can satisfy these challenging specifications and ensure the required performances, are summarized in the following.

Modeling. Effective designs for complex devices as the ones based on PhCs requires accurate theoretical modeling and simulation tools. To achieve the expected results, a wide range of steady-state and time-domain approaches have been developed. In particular, the Finite Difference in the Time Domain (FDTD) has proven to be accurate for simulating linear responses of the investigated components[1]. However, other approaches were pursued, in particular for nonlinear modeling[2] and coupling with electrical/thermal simulations[3].

Material Engineering. For device fabrication, III-V semiconductor PhC membranes have been used[4,5]. This platform is ideally suited for both wavelength filtering/routing, high-speed/low power optical switching and detection. In particular, GaAs and InP technology were pursued. GaAs has the key advantage of a short carrier lifetime, which is attractive for AOGs, whereas InP is compatible with active telecom devices such as InGaAs photodetectors/laser/amplifiers. For the planar technology, both air-bridged and Benzocyclobutene (BCB)-encapsulated PhC membranes were pursued. The former for AOGs[6], whereas the latter for WDM devices with integrated photodetectors[7].

Device Fabrication and Measurements. Fig. 1 (on the left) shows an example of a 4-channel WDM Receiver. The fabrication of this component required the design of both the key elements (the PhC cavities) and the optical circuitry (waveguides, bends, tapers). Optimizations of each component is fundamental to guarantee a device that satisfies the challenging specifications and ensures the required performances. The same figure reports also (on the right) the eye diagram evaluations at the different ports of the receiver[8].

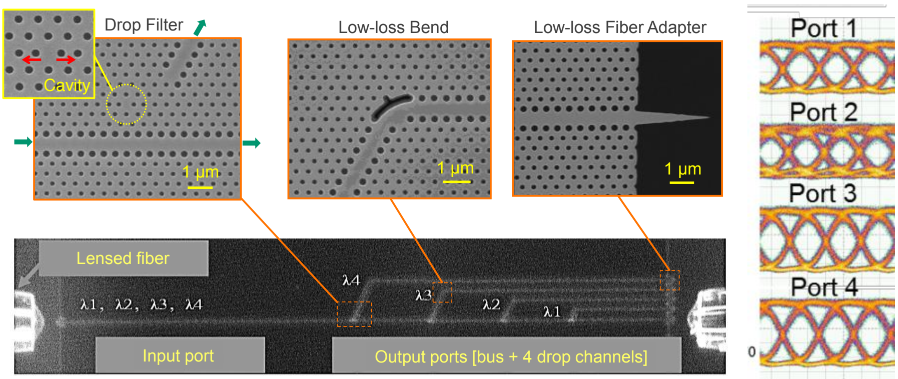

Fig. 1 Image of the 4-channel WDM demultiplexer (left) with magnifications of the resonant cavity, low-loss bend and fiber adapter. Eye diagrams of 100 Gbit/s signal after demultiplexing into 4×25 Gbit/s signals (right).

The All Optical gate (AOG) is the key component of the OTDM Receiver. The basic principle of the AOG is the optically induced spectral shift of a microcavity, which is configured to operate as a band-pass filter. Through this mechanism, the transmission spectrum near the cavity resonance is dynamically controlled. Different configurations for this device have been investigated. The left panel of Fig. 2 shows a layout based on two H0 coupled cavities on a PhC air-suspended InP membrane[6]. Switching obtained on a non-degenerate pump-probe experiment (pump shifted of about 10 nm from the signal) is also illustrated (center-left panel). Measurements showed that this AOG follows a clock of 20 Gbit/s. An alternative configuration based on a hybrid III-V photonic crystal nanobeam cavity on a silicon on insulator (SOI) waveguide[9] is reported in the center-right panel of the same figure. A switching time of 12 ps, with an energy of 40 fJ, has been measured (Fig. 2 on the right).

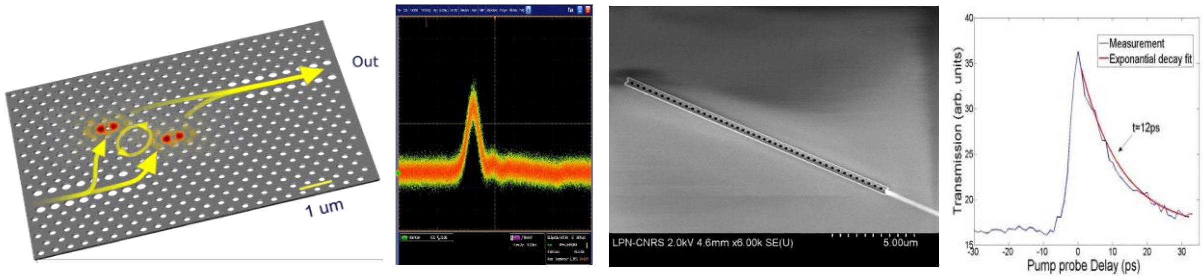

Fig. 2: On the left: layout of the two coupled H0 cavities forming the PhC "molecule" AOG and (center-left) response to a single short pulse in non-degenerate pump-probe measurement of the nonlinear dynamics. Center-right: two-port AOG based on a hybrid III-V PhC nanobeam cavity on a (SOI) waveguide and switch demonstration on a degenerate pump-probe experiment (on the right).

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