Tunable Slow Light in Photonic Nanostructures

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Abstract — **On-chip slow light in photonic nanostructures allows 100 ps order delay and tunability with sub-THz bandwidth. This paper reports the state-of-the-art performance of SOI slow light devices fabricated by e-beam or Si CMOS technology, related topics such as nonlinear enhancement and dynamic tuning, and its application to fast optical correlator.**

Keywords-slow light; photonic nanostructure; photonic crystal; silicon photonics; optical correlator

Slow light having a group velocity much smaller than that in vacuum has been studied in these ten years toward advanced time-domain optical signal processing (optical buffers and memories, re-timing and MUX/DMUX of optical signals, fast correlators and pump-probe systems, etc.) and enhancement of light-matter interaction (nonlinearity, phase shift, etc.). Photonic nanostructures such as photonic crystals are powerful tools that allow on-chip slow light devices [1].

We have reported slow light devices based on photonic crystal waveguides (PCWs) fabricated on SOI substrate by using *e*-beam lithography and ICP etching. The photonic crystal coupled waveguide of 250 – 700 μm length has achieved a 100 ps class delay and its tunability based on thermo-optic effects, maintaining a sub-THz bandwidth. Clear time-domain shift of picosecond optical pulses were successfully observed in the device [2]. In a lattice-shifted PCW, >40-fold enhancement of self-phase modulation and two-photon absorption was evaluated with the slow light effect [3].

The next issues are longer delay and wider tunability, stronger enhancement of nonlinearity with lower losses, more functionalities, and development of applications. For the first issue, we expect the silicon CMOS technology to provide a new class of large-scale integration. In comparison with e-beam technology, the CMOS technology allows easy integration of wire waveguides and optical coupler with fibers, as shown in Fig. 1, and ensures higher uniformity. The insertion loss can be dramatically reduced and so we can discuss practical device applications. The device length is easily elongated to millimeter order and sub-nanosecond delay and tunability will be available. For the second issue, a more efficient material beyond Si is desired. We have developed a Ag-As_2Se_3 chalcogenide glass PCW and observed more than 10-fold enhancement in third order nonlinearity than in Si [4]. The four-wave mixing was observed for < 0.5 W input peak power in a 400-μm-long PCW. It is promising to high efficiency tuning and switching based on optical Kerr effect with negligible two-photon absorption and related free carrier absorption. For the third issue, dynamic tuning of the device and optical pulse are of great interest [5]. The instantaneous change of device index changes wavelength components of optical pulses and allows the complete stopping of light and shuffling of the order of pulses. It will be experimentally demonstrated by using fast nonlinear effects as a tuning mechanism. As an application, we are considering a fast optical correlator. In conventional correlators, mechanically tunable delay line restricts data acquisition speed. Using the thermo-optic tunable delay in the PCW slow light device, 100-fold faster tunable delay is available. We achieved the correlation measurement up to 4 kHz repetition frequency [7]. It is effective for 2D and 3D data mapping of OCT and THz TDS.

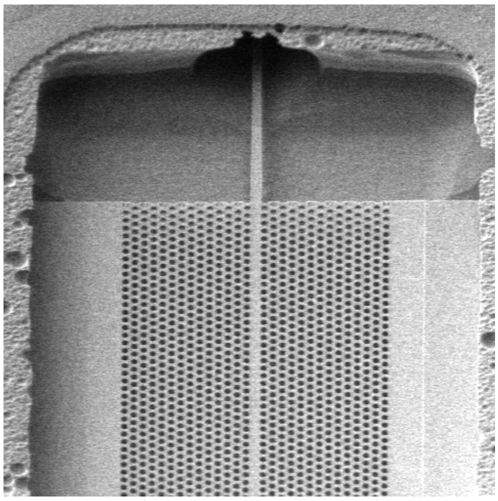

Fig. 1 Si PCW integrated with photonic wire by using CMOS technology

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This work was supported by JST-CREST project.