Ultra-Compact Optical True Time Delay Lines Featuring Fishbone-Like One-Dimensional Photonic Crystal Waveguide

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Abstract: An ultra-compact on-chip optical true-time-delay line features the slow light enhanced fishbone-like one-dimensional photonic crystal waveguide is proposed. A delay time of 65 ps/mm which corresponds to group index of 19.47 is observed experimentally.
OCIS codes: (060.5625) Radio frequency photonics; (130.5296) Photonic crystal waveguides.

Phased array antenna(PAA) [1] is an array of antenna elements controlled by phase shifters. Through changing the relative phase difference or time delay between adjacent elements, constructive inference is formed at desired directions. Therefore, a beam of radio frequency (RF) wave can be steered to different directions without physically turning the antenna. Due to the narrow bandwidth of electrical phase shifters, RF waves at different frequencies are steered toward different directions. This phenomenon is referred as beam squint effect. It significantly limits the bandwidth of PAA systems.

On-chip silicon based optical true time delay lines (OTTDL) [2-3] has become a promising alternative to address the beam squint issue. Besides, it has additional advantages such as strong EMI immunity, low loss for large delay, and fully integrated on single silicon chip. Slow light fishbone-like (FL) one-dimensional (1D) photonic crystal waveguide (PCW) has been reported with lower optical propagation loss due to less etched surface area overlapped with optical mode compared to two-dimensional (2D) PCW. Furthermore, FL 1D PCW is less susceptible to fabrication variations compared to 2D PCW, making it a good candidate for on-chip OTTDL [4]. In this paper, we experimentally demonstrated an on-chip wavelength tunable OTTDL featuring FL 1D PCWs, which can be used in microwave applications such as multi-frequency PAAs. The proposed TTD module based on FL 1D PCW provides compact footprint, low loss, and slow light enhancement, making it a promising technology for high performance, large bandwidth RF devices.

Fig. 1. (a) shows the schematic of the FL 1D PCW. The slow light effect is generated by periodically arranged sidewalls along the propagation direction and the light is confined in the vertical directions through index guiding. The geometrical parameters are optimized with 3D plane wave expansion method targeting at generating large time delay with a compact footprint. The structure supports both quasi-TE and quai-TM modes, but quasi-TE mode is selected due to its stronger slow light effect. The simulation results show the slow light effect with group index greater than 20 at 1565 nm with and strong GVD up to -1.5×107 ps/(nm•km) as shown in Fig. 1. (b). Fig. 1. (c) shows that adding a set of group index taper FL 1D PCW and silicon strip waveguide helps to reduce Fresnel reflection and increase the coupling efficiency to 72%.

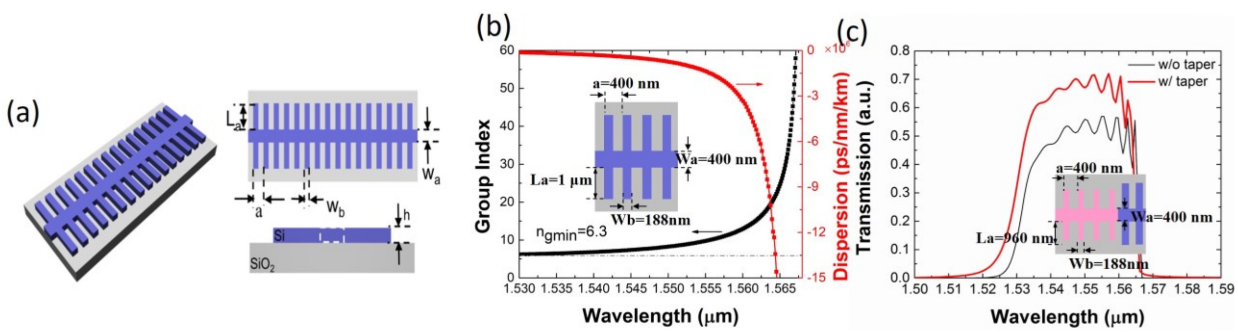

Fig. 1. (a) Schematic plot of the proposed FL 1D PCW. (b) Simulation results of group index and dispersion versus wavelength. (c) Simulated transmission curve of the FL 1D PCW.

A four channel TTD device based on FL 1D PCW was fabricated on SOI wafer with 220 nm device layer by e-beam lithography and reactive ion etching as the scanning electron microscope images shown in Fig. 2. (a). Fig. 2.

(b) shows the transmission spectrum of a 500µm long FL 1D PCW and the loss can be low as 3.7 dB. An unbalanced Mach-Zehnder interferometer (MZI) fabricated on the same chip with one arm of 500 µm long FS 1D PCW and the other arm of 500 um long silicon strip waveguide is tested for calculate the group index of the FL 1D PCW as shown in Fig. 2(c). The calculated group index at the photonic bandgap is 31.6.

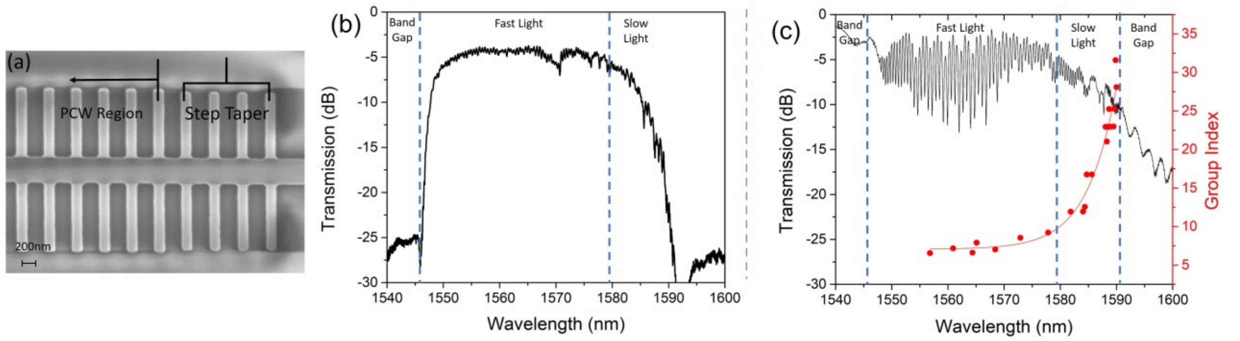

Fig. 2. Wavelength continuously tunable time delay measurement setup for FL 1D PCW TTD lines. TLS: Tunable laser source

The delay time of each channel with different FL 1D PCW length from 1 to 3mm was determined from the phase of S21 parameters versus frequency data using VNA as the testing setup shown in Fig. 3(a). A delay time of 65 ps/mm which corresponds to group index of 19.47 is observed experimentally at 1579nm, as shown in Fig. 3(b-d).

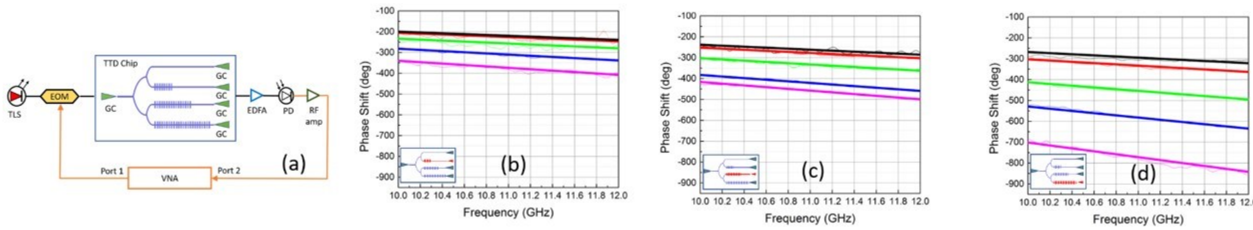

Fig. 3. (a)Time delay measurement setup for FL 1D PCW TTD lines. TLS: Tunable laser source (b-d) S21 phase versus frequency plots for 1mm, 2mm, and 3mm long FL 1D PCW.

In conclusion, we present a FL 1D PCW based true-time delay line. A delay time of 65 ps/mm has been observed experimentally. This component can be used in a wide range of RF systems to widen the RF bandwidth.

This research is supported by Airforce Office of Scientific Research(AFOSR) Small Business Innovation Research (SBIR) Program (Contract #: FA9550-C-16-0033).

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