Wavelength-Tunable on-Chip True Time Delay Lines Based on Photonic Crystal Waveguides for X-Band Phased Array Antenna Applications

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The authors would like to acknowledge the Air Force Office of Scientific Research (AFOSR) for supporting this work under the Multi-disciplinary University Research Initiative (MURI) program (Grant No. FA 9550-08-1-039), monitored by Dr. Gernot Pomrenke.

Abstract: We demonstrate on-chip tunable true-time-delay (TTD) lines based on photonics crystal waveguides. Measurement results show a maximum time delay of 260pS with a 3mm PCW.

OCIS codes: (230.5298) Photonic crystals; (040.6040) Silicon; (130.5296) Photonic crystal waveguides; (350.4238) Nanophotonics and photonic crystals; (130.3120) Integrated optics devices; (250.5300) Photonic integrated circuits; (130.0130) Integrated optics.

1. Introduction

Photonic crystal waveguides (PCWs) offer strong optical confinement and slow light enhanced interactions, which enable many miniaturized and highly efficient devices [1-3]. Broadband phased array antenna (PAA) requires true-time-delay (TTD) lines to provide constant and proportional time delays between adjacent delay lines across the entire operation bandwidth. PCWs with strong dispersions and slow light effect provide an ideal platform for building highly compact, chip scale TTD lines [4]. These devices shall provide large bandwidth, small footprint, and tunable time delay. In this work, we experimentally demonstrate a continuously tunable time delay system operated in microwave X-Band (8~12GHz), which provide 0~90 degree steering with 1.3cm PAA element spacing.

2. Design and fabrication

The schematic of the PAA using PCW TTD beamformer is shown in Fig. 1(a). A 1*4 multi-mode interference coupler (MMI) [5] is used to split light equally into four channels of same total length L. Each channel consists of silicon strip waveguides and PCWs [6] with proportional lengths. Channel-1 contain only strip waveguide. Channel-2, 3, and 4 contain strip waveguide and 1mm, 2mm, and 3mm-long PCWs. This configuration creates proportional relative time delay 0, τ, 2τ, and 3τ in channel-1~4, respectively. Micrographs of the 1*4 MMI and four channel TTD beamformers are shown in Fig. 1(b). The enlarged view of the 1*4 MMI, S bends, and slow light PCWs (blue) with photonic crystal taper (green) [6] regions are shown in Fig. 1(c), (d), and (e),(f), respectively.

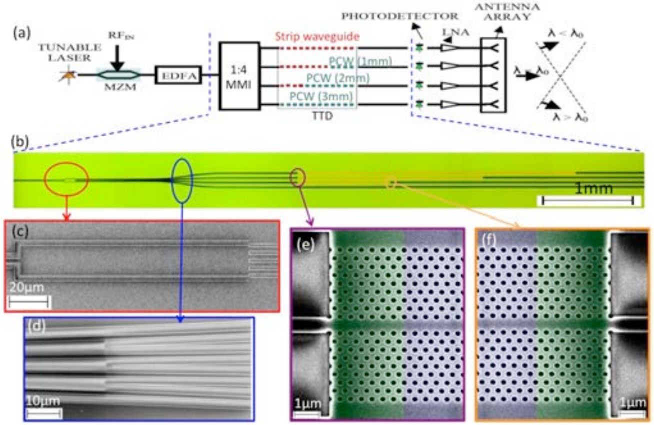

Fig. 1. Schematic of the TTD beamformer based on a 1*4 MMI and PCWs.

To minimize the coupling loss into the slow light structure, we utilize two group index tapers at the strip-PCW interfaces [6, 7], which reduce the coupling loss of the PCW to ~1.3dB/facet. Significant reduction of slow light coupling loss allows us to measure time delay closer to the band edge, which can lead to significantly larger delay time. The devices were fabricated on silicon-on-insulator (SOI) wafers with 230nm top silicon layer and 3μm buried oxide (BOX). Details of the fabrication procedures are described in [2].

3. Measurements

The modulation phase shift method was used to measure the time delay of the TTD lines. An RF signal from a vector network analyzer was modulated onto the optical carrier using a Mach-Zehnder Modulator. The phase of S21 of each device was measured with a vector network analyzer in microwave X-band (8~12GHz). Measurement results of all four channels are shown in Fig. 2. These measurements were normalized to the strip waveguide channel (channel-1) to show the relative phase change in channels that contain different lengths of PCWs. Highly linear phase-frequency relation is seen in all channels, which shows the signature of TTD. The time delay (τ) in the PCWs can be derived from the equation: $\tau = \Delta\Phi/\Delta\omega$, where $\Delta\Phi$ represents the changes of phase in the measurement frequency range $\Delta\omega$. The maximum time delays obtained are 64.9pS, 126.3pS, and 216.7pS for channel-2, 3, and 4, respectively. The achievable steering angle for a PAA using these TTD lines can be calculated as $\theta = sin^{-1}\left(\tau/c \cdot d\right)$, which means 0~90 degree steering angle can be achieved with 1.3cm element spacing.

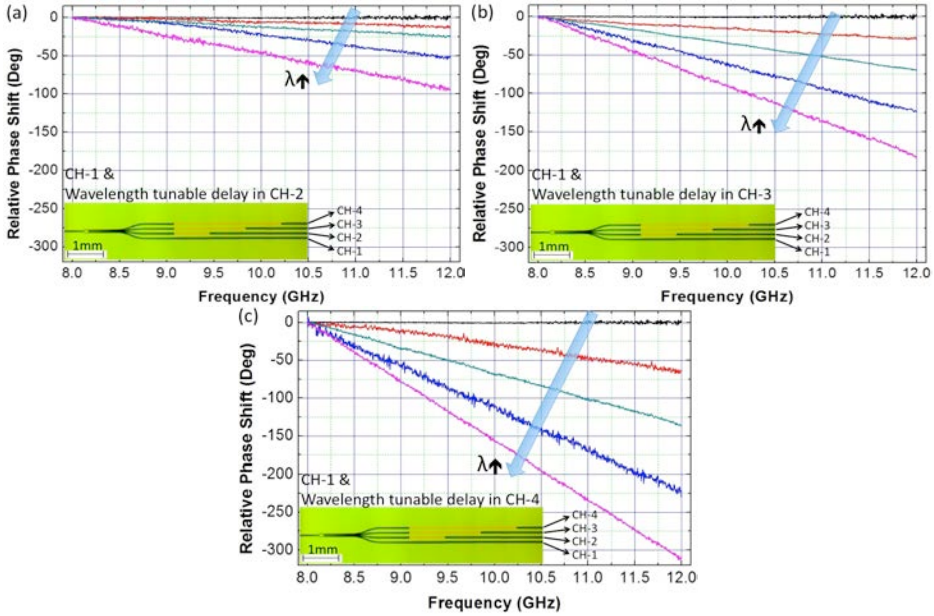

Fig. 2. Measurement results of phase vs. frequency relation for (a) channel-2, (b) channel-3, and (c) channel-4. Measurement results were normalized to the strip waveguide (channel-1). The horizontal line (black) in (a), (b), and (c) represents the normalized phase shift of channel-1

4. Conclusion

We experimentally demonstrate a chip scale four-channel TTD beamformer based on slow light photonic crystal waveguides. The implementation of photonic crystal tapers enables device operation near the band edge slow region. The measurements show continuously and wavelength tunable time delay up to 216.7pS. The large time delay is sufficient to provide steering angle from 0 to 90 degree for a X-Band phased array antenna system with 1.3cm element spacing.

5. References

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