Design of a Novel, Cost-Effective Wide Field-Of-View Surface-Normal Optical Phased Array

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Abstract: We propose a novel surface-normal slow-light photonic crystal waveguide optical phased array that can provide high speed (~MHz), wide angle (>45degreex45degree) beam scanning capability, with a reduced fabrication effort.

OCIS codes: 010.3310 Laser beam transmission; 060.2605 Free-space optical communication; Holographic optical elements; 130.0250 Optoelectronics; 130.5296 Photonic crystal waveguides; 250.3140 Integrated optoelectronic circuits; 250.5300 Photonic integrated circuits; 350.4238 Nanophotonics and photonic crystals

Optical beam steering using optical phased array (OPA) represents an enabling technology that makes possible simple, affordable, and lightweight laser beam steering with precise stabilization, random access pointing and programmable multiple simultaneous beams [1]. Over the last few decades, intensive efforts have been made to develop OPAs based on liquid crystals [2]; cascaded microlens arrays [3], optical waveguides using polymers, GaAs/AlGaAs [4], Silicon [5], Lithium Niobate [6], Lithium Tantalate [7], Optical MEMs [8] etc and to improve OPA performance. Until now, no technology has been able to satisfy simultaneously the requirements of fabrication feasibility, high speed and large angle beam steering, and thus be able to be widely implemented in various systems.

In this paper, we propose a drastically novel light weight and compact surface normal two-dimensional slow-light photonic crystal waveguide optical phased array (OPA) that can provide large angle, high speed and non-mechanical steering of laser beam as illustrated in Fig. 1. Unlike conventional thinking, where the waveguides in a photonic integrated circuit (PIC) are always built parallel to the substrate, which will require N lithographically defined waveguide layers to provide a NxN phased array, the proposed structure can be vertically integrated in one lithography layer, thus significantly increasing the yield > 90%. The design is based on a silicon platform and is entirely compatible with the CMOS fabrication technique. The $1xN^2$ surface normal fanout beams for the OPA input are realized through waveguide hologram coupling as shown in Fig. 1(a), where 2D surface normal fanout beams are created [9,10]. The 2D array of radiating elements is made of vertically fabricated photonic crystal waveguides operating at the infrared region within 1.1 to 2.0 micron. Note that, other wavelength range of operation can be performed by choosing an appropriate substrate material other than silicon.

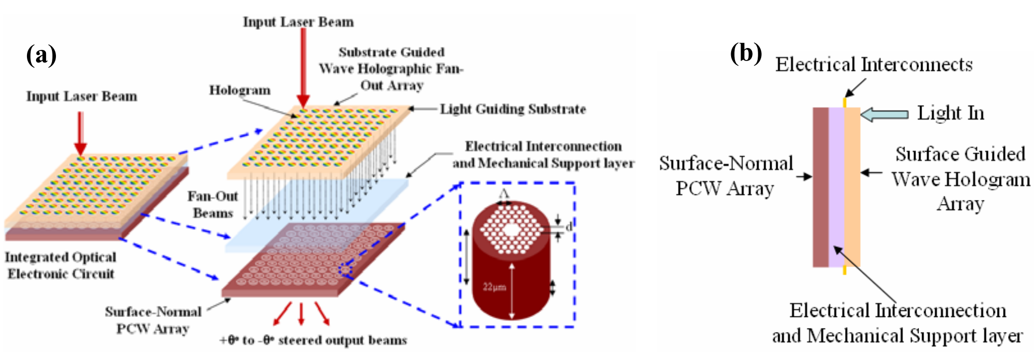


Fig. 1 (a) The schematic of the proposed NxN OPA with vertically integrated slow light photonic crystal waveguide array that is capable of providing the needed phase delay within ~20 micron thickness. The input surface normal beams are provided through an integrated photonic circuit with a 2D waveguide hologram array [9,10]. An enlarged view of one pixel is also shown (b) Cross sectional view of the different layers forming the OPA

By engineering the band structure of the pixel, via controlling the structural parameters such as period (Λ) and diameter of air holes (d) [indicated in Fig. 1(a)], it is possible to obtain a slow light effect or a region within the guided mode where the group velocity approaches zero, as shown in Fig. 2(a). The low group velocity slows down the photons sufficiently, thereby increasing the effective interaction length of light with substrate material. The structural parameters of the PCW are chosen as $\Lambda = 0.678\mu m$ and $d = 0.89\Lambda$ to achieve slow light near 1670nm, as shown in Fig. 2(b). Note that a group index exceeding 400 can be achieved. The group index curves calculated at different temperatures are shown in Fig. 2(c). It can be seen from the figure that there is a pronounced change in position of the group index curves as the temperature is varied from 300K to 550K in steps of 25K increments. Thus, at any given wavelength, a large group index change can be achieved in the different slow light PCW structures via perturbing the refractive index of silicon due to the large thermo-optic (TO) effect (Silicon has a large TO coefficient of ~2.4x10^{-4}/K.), thus achieving the given required phase shift for beam steering. The phase shift generated ($\Delta\phi$) by changing the group index by Δn_g, in a length L of the PCW is given by

$$\Delta\phi = \left(\frac{2\pi}{\lambda_0}\right)(\Delta n_g)(L) \tag{1}$$

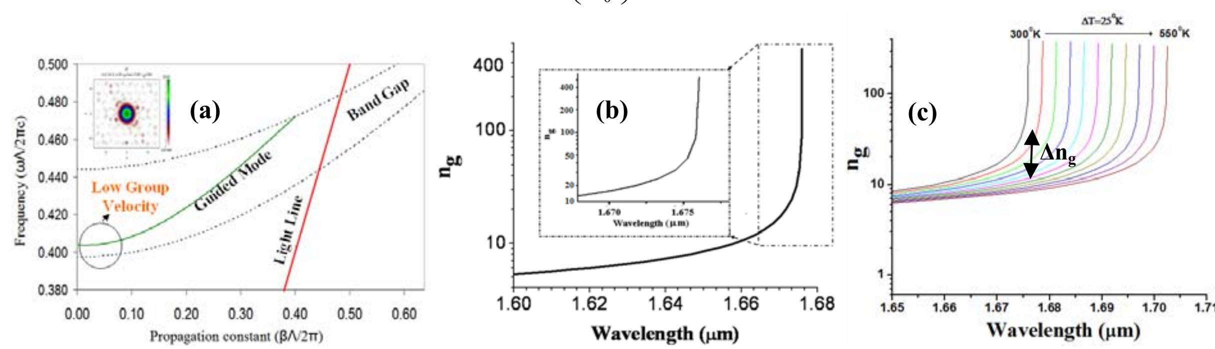


Fig. 2. (a) Slow light region that provides huge index change within very short waveguide length (note that dω/dk is the group velocity and n_g =c/(dω/dk), (b) Calculated group index of PCW structure as a function of wavelength. Inset shows the expanded view of the slow light region, (c) Dependence of group index curve on temperature of pixel. The shifting of curve causes a change in the group index at a given wavelength.

In order to show the feasibility of the approach, we have perfomed preliminary deep RIE fabrication of a PCW lattice in a silicon substrate, as shown in Fig. 3(a). The period is 200μm. The hole diameter is 100μm at the top and 140μm at the bottom. The depth of the holes is 500μm. This design can work at ~0.75THz. We are currently working on achieving the design for operation at ~1.67μm. We also recorded and tested a 8x8 surface normal holographic fan out array, as shown in Fig. 3(b). The diffraction efficiency among the 64 outputs is within 1%.

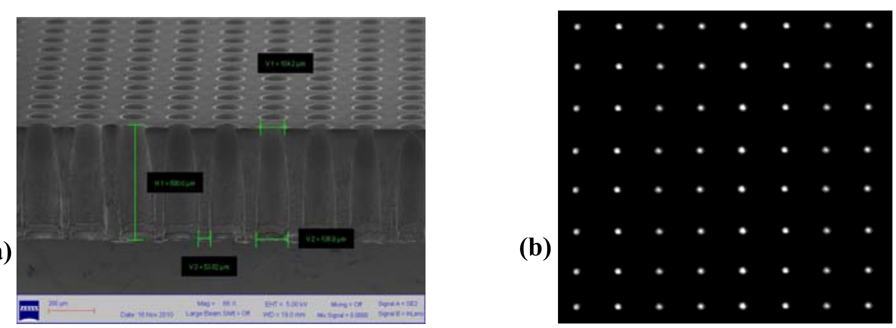
(a)  (b)

Fig. 3 (a) SEM picture of a deep RIE fabricated Photonic Crystal Array in silicon. The taper provides good impedance matching between PCW and free space. (b) IR-CCD image of the output from a fabricated 8x8 holographic fanout array. The uniformity in the output is within 1%.

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