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Line Beam Scanner using Slow-Light Waveguides in Si Photonics

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Abstract

We demonstrate a line beam scanner which radiates slow light from a Si photonic crystal waveguide. 10-fold wider beam scanning, compared with simple diffraction grating's, is obtained with a narrow width of the line beam.

1. Introduction

Recently, non-mechanical beam steering devices are being studied actively toward various applications, such as LiDARs, displays, and readers. The diffraction grating type [1] and optical phased array type [2] have been studied toward a compact size and high reliability. However, their number of resolution points, which is one of the most important performance parameters for beam scanners, are smaller than required values or more than one hundred because of their small steering angle, large beam divergence, and/or generation of multi-beams. For example, the diffraction grating only gives a steering angle of several degrees even for the wide range of wavelength scanning such as several tens of nanometers. The phased array type only exhibits a beam broadened to 1 degree. In this context, a VCSEL-type multilayer waveguide has been employed to achieve a large number of resolution points over 1,000, in which slow light generated in the waveguide enhances the angular dispersion [3].

In this study, we demonstrate a line beam scanner, which potentially achieves higher performance than those of previous works. It radiates a guided mode of photonic crystal waveguide (PCW) through a diffraction grating and forms a line beam with narrow and wide divergence in the longitudinal and lateral directions, respectively. Similarly to the aforementioned VCSEL-type waveguide, it achieves a wide beam scanning thanks to the slow light effect. Since the device is able to fabricated by Si CMOS process and used at $\lambda \sim 1.5$ μm, it will allow the integration with other components, mass production, and eye-safe operation, which is suitable particularly for LiDAR applications.

2. Device

Figure 1 shows the proposed device consisting of SiO_2-cladded PCW with a surface diffraction grating. The PCW maintains a slow light mode, which is coupled to the grating and radiated out to the free space gradually in the upper oblique direction. The radiation angle θ is controlled by changing the wavelength and/or refractive index of the PCW. θ is determined by the propagation constant β of the slow-light mode, which largely changes with the change of wavelength λ and material refractive index *n* [3,4].

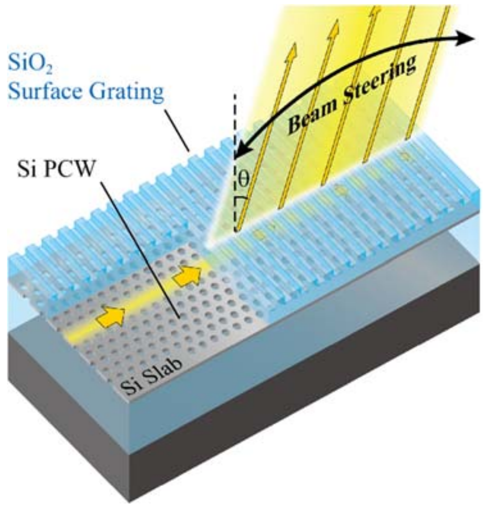

Fig.1 Surface grating loaded slow-light beam steering device.

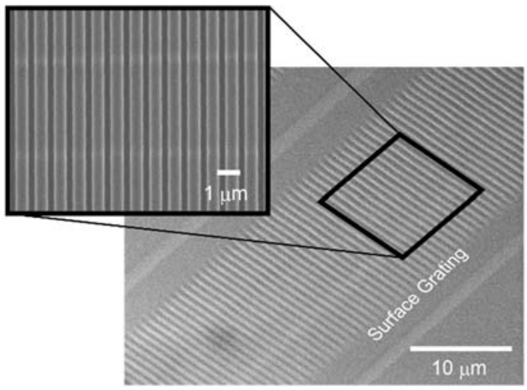

Fig. 2 SEM image of fabricated device.

3. Experiment

In the experiment, we actually employed two types of PCW: one is a standard PCW and the other is lattice-shifted PCW (LSPCW) which shows the low-dispersion characteristics [5]. They were fabricated by CMOS process with KrF excimer exposure. The lattice constant was set at 400 nm and the thickness of the upper-cladding was 2 μm. Next, the SiO_2 cladding except at the spot-size converters (SSCs) for the end-fire optical coupling was thinned to approximately 300 nm via CHF_3 ICP plasma etching. Then, by using focused ion beam (FIB), the diffraction grating with a period of 800 nm and a depth of 180 nm was formed on the surface of the SiO_2 cladding over the length of 96 μm or 192 μm along with the propagation direction (these lengths were limited by the processing region of the used FIB machine), as shown in Fig. 2.

Figure 3 shows the far-field pattern (FFP) of the radiated beam observed when laser light was launched on the PCW through the SSC (FFPs at different wavelengths are overlaid). Each beam exhibits a line pattern because the beam radiated from the narrow PCW spread widely in the direction normal to the propagation. It will become a spot profile if a cylindrical collimate lens is inserted. Let us focus on the profile in the direction parallel to the propagation. Each pattern exhibits a sharp and single peak beam profile. The radiation angle θ varied with the wavelength.

We measured n_g, θ and beam divergence (FWHM) $\Delta\theta$ by changing λ. For the first LSPCW sample with a grating length of 96 μm and $n_g = 19$, the variation of θ was 26° in the wavelength range of 36 nm, maintaining $\Delta\theta = 0.36°$ on average. For the second LSPCW sample with a grating length of 192 μm and $n_g = 25$, and the variation of θ was 23° in the wavelength range of 26 nm (angular dispersion $d\theta/d\lambda$ is seven times larger than normal diffractive grating's [1]) and the averaged $\Delta\theta$ was narrowed to 0.30°. For the third sample with the same grating length and $n_g = 19$, the variation of θ was 26° and average $\Delta\theta$ was 0.24°. The number of resolution points is 90. $\Delta\theta$ depends on the grating length and its uniformity, but now it is rather limited by the processing region of the FIB as well as the pixel size of used InGaAs camera. We expect a one order larger number of resolution points by improving the process and measurement setup.

Acknowledgment

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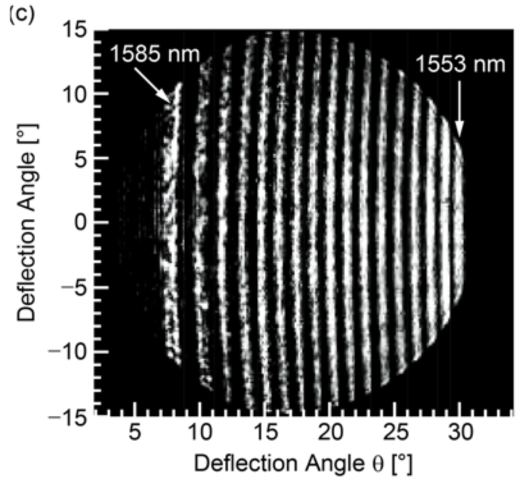

Fig. 3 Overlay of far field patterns of line beams radiated from the slow-light waveguide at different wavelength with a 2-nm spacing.