Arrayed waveguide grating of $70 \times 60\ \mu m^2$ size based on Si photonic wire waveguides

K. Sasaki, F. Ohno, A. Motegi and T. Baba

A miniature arrayed waveguide grating of $70 \times 60\ \mu m^2$ size consisting of Si photonic wire waveguides was designed using complete modelling in the finite-difference time-domain simulation. The device was fabricated onto a silicon-on-insulator substrate and evaluated in the wavelength range around 1.55 µm. The clear demultiplexing characteristics were observed with a channel spacing of 11 nm and a loss of less than 1 dB.

Introduction: The Si photonic wire waveguide (PWW) [1–6], which has an ultra-high relative refractive index difference Δ between the Si core and low index claddings, allows sharp bends and various μ-components. Therefore, it is expected to be the key element for dense photonic integrated circuits. Presently, arrayed waveguide gratings (AWGs) based on silica waveguides are widely used as high performance multi/demultiplexers. However, their size is typically as large as $10\ cm^2$ owing to their low Δ. The InP-based high mesa waveguide and the Si PWW reduce the size to the order of mm^2 and $(100\ \mu m)^2$ order, respectively. Previously, we reported the first PWW AWG of $110 \times 90\ \mu m^2$ size and observed the preliminary demultiplexing function [5].

However, the adjacent channel crosstalk was as large as -5 dB and the excess loss was more than 10 dB even excluding the coupling loss with the external optical setup. These were considered to be caused by the unwanted scattering and resonance inside the device. In this Letter, we demonstrate a smaller PWW AWG. By the complete modelling in the finite-difference time-domain (FDTD) simulation, we optimised the AWG for reducing the scattering and resonance, and obtained much better demultiplexing characteristics.

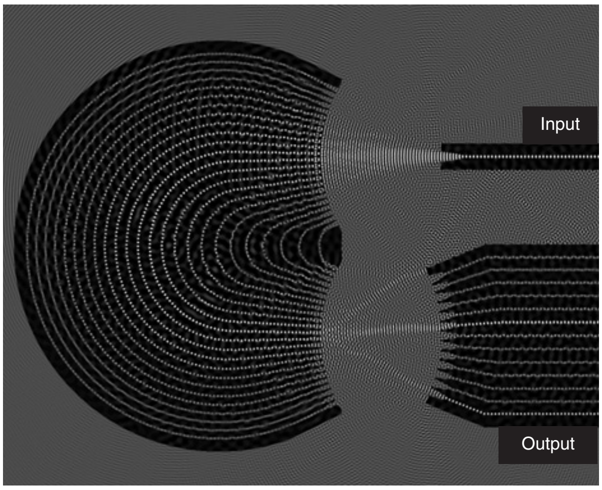

Fig. 1 *Field distribution of light in AWG simulated by FDTD method*

Design: This Letter fundamentally discusses the PWW with an Si core of 0.32 µm thickness and ~0.45 µm width, which satisfy the singlemode condition at the wavelength $\lambda = 1.55\ \mu m$. The detail of the AWG was designed through the FDTD simulation for the indices of Si and air of 3.46 and 1.0, respectively, and the transverse electric (TE) polarisation. Fig. 1 shows the simulated field distribution for the designed device. Incident light from the input waveguide is converted to the Gaussian beam in the first slab waveguide, coupled with arrayed waveguides, and focused to the output waveguides in the second slab waveguide. The slab waveguides with a focal length of 25 µm are opened to the outer region to eliminate internal reflection. The arrayed waveguides consist of smoothly curved waveguides whose pitch and length difference between adjacent guides are 1.0 and 6.06 µm, respectively. The pitch of I/O waveguides is 1.6 µm. According to the simple design principle of AWGs, these conditions correspond to a diffraction order of 10, a channel spacing $\Delta\lambda$ of 11 nm, and a free spectral range (FSR) of ~85 nm. To obtain the smooth mode conversion to/from the Gaussian beam, parabolic tapers of 1.3 µm width and 3.0 µm length are inserted between the I/O waveguides and slab waveguides. To reduce the connection loss between arrayed waveguides and slab waveguides, parabolic tapers of 1.0 µm width and 3.0 µm length are also inserted. The total size of the AWG is $70 \times 60\ \mu m^2$, which is smaller than half of the previous one [5].

Fabrication and measurement: Similar to those in [5], the AWG was fabricated on silicon-on-insulator substrate by *e*-beam lithography, pattern transferred to Cr mask and CF_4 inductively coupled plasma etching. Fig. 2 shows the top view of the device. In the measurement, tunable laser light was coupled into the input waveguide. Here, a linearly tapered input end was placed to reduce the internal Fabry-Perot resonance. The light output was observed by infrared camera and measured by an optical power meter. The propagation loss of the linear PWW fabricated simultaneously was measured to be 12 dB/mm. This large loss was caused by the irregular scattering at etched sidewalls [2]. However, it was not a serious problem in the very compact AWG. Fig. 3 shows the transmission spectrum of TE polarisation for each output waveguide. The clear Gaussian spectrum was obtained with $\Delta\lambda = 11$ nm, an adjacent channel crosstalk of -13 dB, and an oscillation by the Fabry-Perot resonance of 0.9 dB. In addition, the FSR was measured to be 92 nm, which is close to the theoretical value. Different peak intensities between channels were caused mainly by the small focusing error in the slab waveguides. We confirmed this from the almost uniform spectra, when we adjusted slightly the focal length for another device without an input taper. The vertical axis of Fig. 3 shows the normalised intensity, when another PWW with a length equal to the average path length in the AWG is used as a reference. The maximum value was $+0.3$ dB. It can be explained by a lower loss in the slab waveguides of the AWG. Taking account of the propagation loss of the PWW, output light from the AWG can be $+0.6$ dB higher than the reference, if the slab waveguide loss and other excess losses are sufficiently low. Even considering the average loss at the arrayed waveguides, the total loss of the AWG excluding I/O waveguides is finally estimated to be less than 1 dB. For the transverse magnetic polarisation, the transmission peak red-shifted by 2.1 nm. This shift will be removed by the fine structural tuning of the arrayed waveguides.

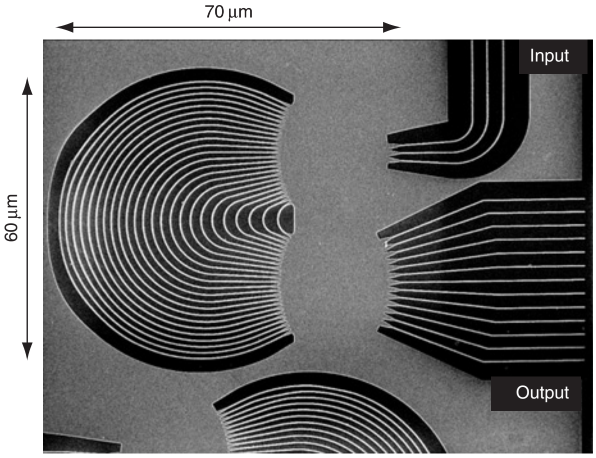

Fig. 2 *Scanning electron micrograph of fabricated AWG*

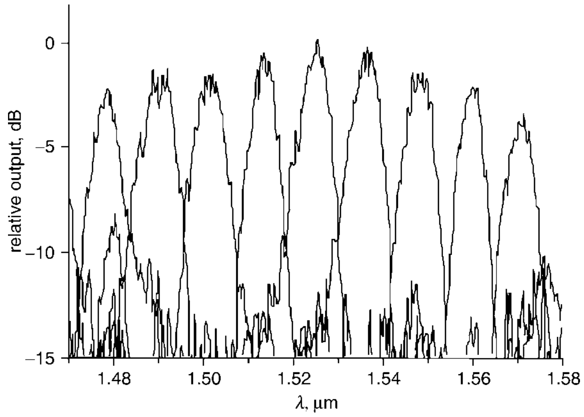

Fig. 3 *Transmission spectra*

Conclusion: We have demonstrated an Si PWW AWG of 70 × 60 μm^2 size with a channel spacing of 11 nm, a crosstalk of −13 dB, an oscillation by the Fabry-Perot resonance of 0.9 dB, and a total device loss of less than 1 dB. This AWG will have practical applications as demultiplexers and monochromators, if the crosstalk is further reduced to less than −20 dB.

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