Integrated corner mirrors as a platform for miniaturized planar strain sensing

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***Abstract*—Corner mirrors provide a route to create more compact two dimensional strain rosettes. Based on silica-on-silicon, our device fabrication utilizes physical micromachining and direct UV writing. A grating based loss technique has shown our corner mirrors to have excess losses of 1.15dB for TM polarization.**

Keywords-component; Strain sensor; Planar Integrated Optics; Bragg Gratings;

I. INTRODUCTION

Corner mirrors can be used to provide a route to achieve higher density optical components on an integrated chip. However the ability to redirected light and expose evanescent fields at the point of turning, provides an alternative geometry for a range of integrated devices. These include: optofludic switches, plasmon couplers and strain sensors. In our work we create a device utilizing Bragg gratings and a corner mirror to allow interrogation of strain in two axes in a compact integrated package. Bragg grating based strain rosettes have been demonstrated in fibers, however these devices can be bulky in order to accommodate the fiber bend radius (~1mm) [1]. Correctly placing the fiber Bragg gratings can also be difficult due to their cylindrical shape and usually employs the need for separate packaging to ensure the correct angle between the gratings is obtained (e.g. the Delta rosette) [1]. Our device combines the waveguides, several Bragg gratings and a corner mirror in a 2x2cm footprint, allowing strain to be sensed in confined space with a single optical connection. Previously integrated corner mirrors have been demonstrated in Si_3N_4/SiO_2 multilayer hollow waveguides with losses of TE 1.0dB and TM 0.8dB [2] and in SiO_2 TE 1.48dB and TM 1.08dB [3] all losses are measured at 1550nm. In previous work we have reported a device containing a pair of corner mirrors with average individual insertion loss of ~0.96dB for TM [4]. A schematic of the corner mirror device is shown in Fig. 1. The strain can be sensed in both direction x and y, see Fig.1, through the strain-optic effect tuning the Bragg grating central wavelength preferentially for the grating parallel to the applied strain. In other work, by our group, we have shown that three point bending achieves 280pmN^{-1} Bragg grating wavelength tuning for the TM polarization at 1550nm [5].

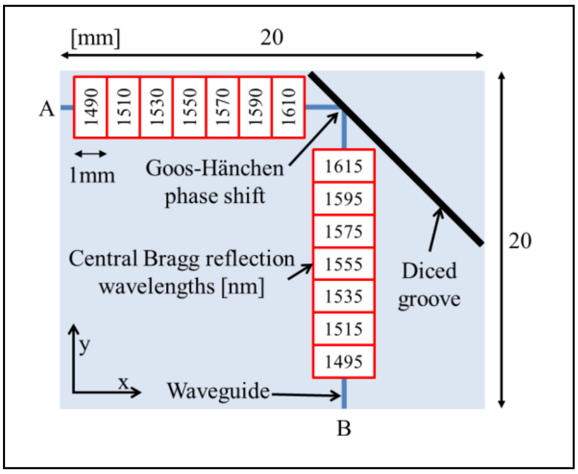

Figure 1. Schematic of corner mirror device, showing the order of the Bragg grating central wavelengths.

II. DEVICE FABRICATION AND CHARACTERIZATION

Our fabrication technique for silica corner mirrors utilizes physical micromachining using a commercially available precision dicing saw. Waveguides and Bragg grating are inscribed into silica-on-silicon substrates by direct UV writing (DUVW). DUVW creates single mode integrated channel waveguides, with low loss waveguides propagation (typically around 0.24dBcm^{-1}) [6] and allows us to produce Bragg gratings within the telecommunications C-band (1525-1565nm). These complementary techniques are suited to rapid prototyping and small batch production of silica integrated optic devices without the need for cleanroom processing. The corner mirror demonstrated in this work, as shown in Fig. 2, was fabricated by dicing a groove through the silica into the silicon. The groove was formed using a diamond impregnated nickel bonded blade (55mm diameter) at 20krpm with a translation speed of 0.1mms^{-1}. Investigation of grooves diced with these parameters have been measured to a give surface roughness (S_a) of around 19nm. Channel waveguides and Bragg gratings are then directly inscribed into the planar core layer, the groove location is detected precisely by monitoring the reflected UV laser light from the sample.

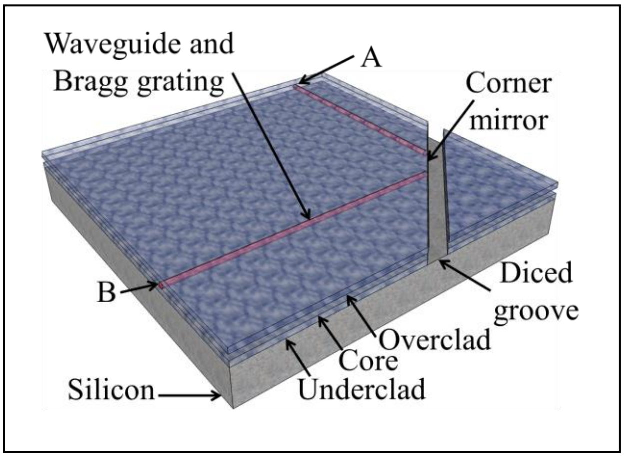

Figure 2. Schematic of corner mirror showing the silica planar layers and silicon substrate.

Once the groove has been detected the sample is rotated by 90° and the Goos-Hänchen phase shift is accounted for [7] by an appropriate offset.

$$S_{TE} = \left(\frac{\lambda}{\pi n_{eff}}\right)\frac{\tan\alpha_c}{(\sin^2\alpha - \sin^2\alpha_c)^{1/2}}, \qquad S_{TM} = \frac{S_{TE}}{(\sin^2\alpha_c)}. \quad (1)$$

Where S_{TE} is the Goos-Hänchen phase shift for the TE polarization, S_{TM} is the Goos-Hänchen phase shift for the TM polarization, λ is the wavelength of interest, n_{eff} is effective refractive index, α_c is the critical angle and α is the angle at which the waveguide intersects the mirror. For a wavelength of 1550nm, an effective refractive index of 1.448, a critical angle of 43.7° and at 45° waveguide / mirror intersection, the Goos-Hänchen phase shift is calculated to be 2.1µm and 4.5µm for TE and TM respectively. As the sample is offset from the center of the rotation stage, Eulerian angles along with an offset (the stage center) are utilized to ensure the point at which the waveguide must start (after the Goos-Hänchen phase shift) is returned to. Bragg gratings are inscribed before and after the corner mirror, as shown in Fig. 1.

The wide spectral range (1490-1615 nm) of Bragg gratings gives a non-destructive, ratiometric route for measuring the loss of the corner mirror [6]. The device was characterized using a broadband SLED source (1480-1630nm), an optical spectrum analyzer, 50/50 coupler and a polarizer where TE and TM polarizations can be independently interrogated. Reflection spectra, see Fig. 3, were collected sequentially from facets A and B (see Fig. 1). The Bragg gratings are fitted using a Gaussian fitting algorithm by which the ratio of their amplitudes are taken and from which the insertion loss of the mirror can be calculated, as shown in Fig. 4. By using the technique described in [6], an insertion loss of the corner mirror can be calculated. For wavelengths between 1490nm and 1615nm the insertion loss of the corner mirror is 1.15dB for the TM mode and 1.63dB for the TE mode. These results are comparable to those previously obtained and to those achieved in silica [3]. We shall present our latest results in the application of this corner mirror to applied two dimensional strain.

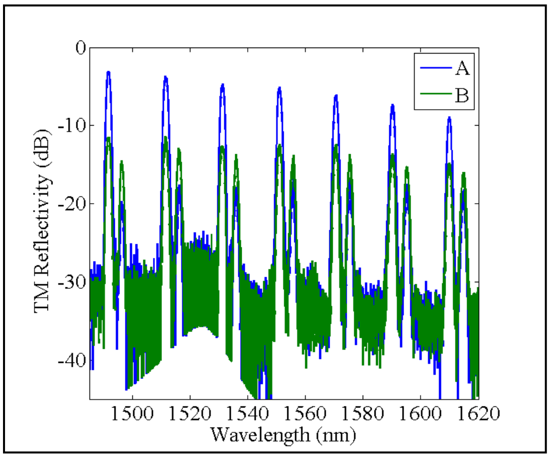

Figure 3. TM Reflection spectra collected from facet A and B of the corner mirror device.

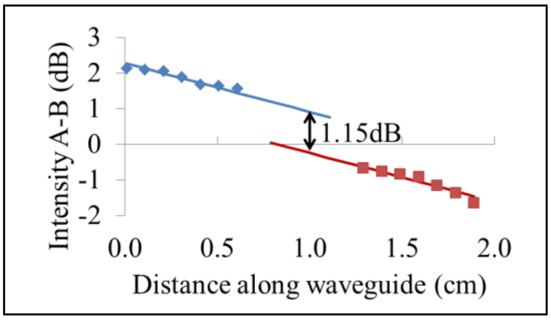

Figure 4. Ratio of reflected power of each Bragg grating relative to its chip position. The corresponding central Bragg wavelengths from left to right follow the order from facet A to B as shown in Fig. 1.

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