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By V. Geudens et al.

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Femtosecond laser written Bragg grating sensors with passive fiber alignment structures in fused silica

Viktor Geudens
Centre for Microsystems Technology (CMST), Department of Electronics and Information Systems (ELIS)
Ghent University - imec,
Gent, Belgium
viktor.geudens@ugent.be

Jeroen Missinne
Centre for Microsystems Technology (CMST), Department of Electronics and Information Systems (ELIS)
Ghent University - imec,
Gent, Belgium
jeroen.missinne@ugent.be

Geert Van Steenberge
Centre for Microsystems Technology (CMST), Department of Electronics and Information Systems (ELIS)
Ghent University - imec,
Gent, Belgium
geert.vansteenberge@ugent.be

***Abstract*—V-grooves as passive alignment structures allow for easy and cost-efficient packaging of planar optical sensors. Micron-scale tolerances for alignment can be met during fabrication, eliminating the need for accurate alignment tools during assembly. Mechanical stability of the structure is verified with a temperature test.**

Keywords—V-groove, packaging, Bragg grating waveguide, femtosecond laser, fused silica

I. INTRODUCTION

Femtosecond laser inscription technology enables the creation of complex photonic circuits in glass substrates, such as fused silica. Common to photonic integrated circuits (PICs) on silicon or planar lightwave circuits (PLCs), packaging to external components with the help of optical fibers remains challenging. This paper investigates the monolithical integration of V-grooves as passive alignment structures with Bragg grating waveguide sensors. Based on the sensor's response, the fabrication tolerances are investigated. A temperature test is performed to verify the mechanical stability.

II. METHODS

For the experiments, an ytterbium doped fiber laser (Satsuma, Amplitude Systèmes) with an output wavelength of 1030 nm and a pulse width shorter than 400 fs is used. The light is linearly polarized. A second harmonic generation crystal frequency doubles the wavelength to 515 nm. The laser light is focussed tranversely into the substrate using an aspherical lens with a numerical aperture of 0.55. The fused silica substrate is moved using a motorized xy-stage, while the focus depth of the laser light can be adjusted with motorized stage to which the focussing objective is attached.

The designed sample consists of a 5 mm long V-groove followed by a 3 mm waveguide to end in a 15 mm long Bragg grating waveguide. For investigating the coupling without alignment structure, the V-groove is replaced by a waveguide of the same length.

The first step in the fabrication process is to create the laser lines in the fused silica substrate. The Bragg gratings and V-grooves are defined in a single laser step. Subsequently, the substrate is submerged in an etching solution.

Regular waveguides are formed by using a pulse energy of 300 nJ, a pulse repetition rate of 500 kHz and a translation speed of 0.5 mm/s [4]. In the case of Bragg grating waveguides, the same pulse energy and pulse repetition rate are used, with an external modulation of 500 Hz with a duty cycle of 60 %. For a target Bragg grating wavelength of 1550 nm, a translation speed of 268.166 μm/s is found [1].

The V-grooves are created by femtosecond laser irradiation followed by chemical etching (FLICE). In order to reduce the time required to write the V-groove, only the contour is written. During etching, the bulk of the V-groove will be lifted out of the substrate, creating the wanted structure [3]. The pulse repetition rate for the fabrication of V-grooves is again 500 kHz. A lower pulse energy of 100 nJ is used together with a higher translation speed of 10 mm/s and 1 mm/s for the sides and bottom, and end facet, repectively. For all structures, the laser was polarized perpendicular to the writing direction, to enhance etching. After the laser step, the substrate is submerged in a 30 wt% KOH solution for 4 hours at a temperature of 85 °C. A magnetic stirrer ensures that the etchant is being sufficiently refreshed, and able to penetrate along the contours of the V-groove.

III. RESULTS AND DISCUSSION

Figure 1 depicts a fully assembled sensor where an optical fiber is attached to the sample with the help of a V-groove. A glass plate on top is added for additional mechanical support. Characterization was performed by fixating the sample with a vacuum chuck, and aligning the fiber with the structures on the sample with the help of a motorized xyz-stage with submicron precision. For read-out a FBG-scan 608 interrogator with a resolution of 1 pm was used. The light of the interrogator was unpolarized.

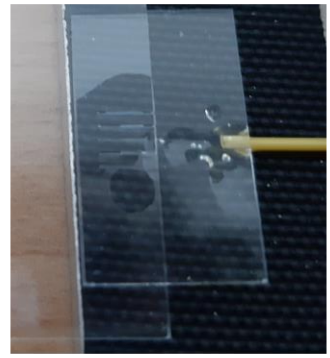

Figure 1: fully assembled sensor with optical fiber glued into V-groove.

A. Tolerances

The influence of vertical and horizontal offset of the fiber with respect to the Bragg grating sensor is studied. Figures 2 and 3 summarizes the experimental results where the difference in reflectivity from the optimal position is plotted in function the offset, ranging from -10 µm to +10 µm for vertical offset and -12 µm to +14 µm for horizontal offset, with steps of 1 µm and 2 µm, respectively.

In the case of vertical offset, there is a large asymmetry. This can be accounted to the elliptical shape of the laser-modified region in the glass. This asymmetrical response leads asymmetrical 1 dB tolerances of 1.2 µm and 2 µm for positive and negative offset, respectively. In contrast to the horizontal offset, the behaviour is more symmetric. Hence, the same 1 dB tolerance of about 2.2 µm is obtained for both negative and positive offset. This result is comparable to the 1dB tolerance of coupling 2 SMF, which is 2.5 µm [5].

B. Temperature sensing

V-grooves, compared to gluing a fiber to the facet of the sample, provide more mechanical support in the sense that the fiber is partly integrated on the substate, and less likely to break off. Moreover, there are less degrees of freedom for the fiber to move. To test how well the fiber stays in place, a temperature test is performed to verify that the alignment is maintained for readout of the sensor. Using a hotplate, the temperature was ramped up from 15 °C to 60 °C and back down to 15 °C. The results in Figure 4 show the wavelength of the reflectivity peak. During the characterization process, the reflectivity reduced less than 1 dB, confirming that alignment is maintained. A sensitivity of 9.35 pm/°C, which corresponds well to the theoretical expecation of 10.3 pm/°C, is found.

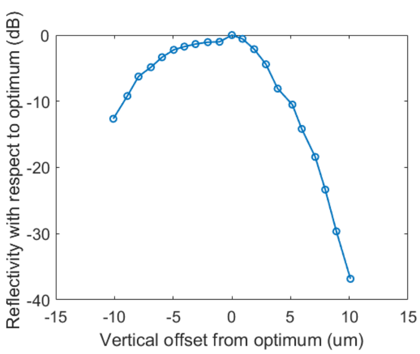

Figure 2: The vertical offset from the optimum position shows an assymmetrical 1 dB tolerance window of [-2, 1.2] µm

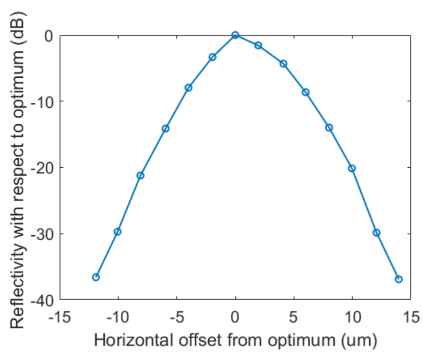

Figure 3: The lateral offset from the optimum position shows a symmetrical 1 dB tolerance window of [-2.2, 2.2] µm

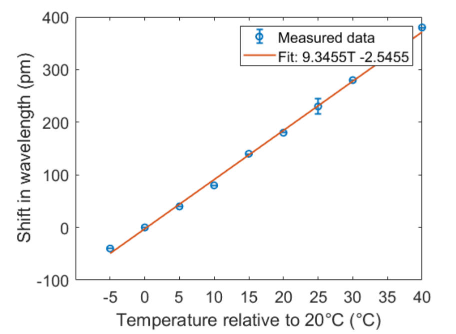

Figure 4: Temperature sensitivity of Bragg grating sensor.

IV. CONCLUSION

The monolithical integration of V-grooves with Bragg grating waveguide sensors allows for more easily packaging of sensors writting in planar substrates, and omits the nessecity of accurate active alignment tools. The results show that 1 dB tolerance window of [-2, 1.2] µm and [-2.2, 2.2] µm for vertical and horizontal offset, respectively. The mechanical stability was verified with a temperature test, and a sensitivity of 9.35 pm/°C was found.

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