DOI 10.5162/sensor2015/P5.1

Polymer planar Bragg grating sensor for 2D strain sensing

M. Rosenberger[1], W. Eisenbeil[1], S. Hessler[1], S. Belle[1], B. Schmauss[2], R. Hellmann[1]
[1] Applied Laser and Photonics Group, University of Applied Sciences Aschaffenburg,
Wuerzburger Strasse 45, 63743 Aschaffenburg, Germany,
E-mail address: manuel.rosenberger@h-ab.de
[2] Institute of Microwaves and Photonics, University of Erlangen-Nuermberg,
Cauerstrasse 9, 91058 Erlangen, Germany

Abstract

We report on the application of a 2-dimensional polymer planar Bragg grating sensor (2D PPBG) for measuring multi axial tensile and compressive strain. The 2D PPBG consists of Polymethylmethacrylate including two integrated planar Bragg gratings twisted against each other by an angle of 40°. These Bragg gratings are sequentially written into the polymer substrate by applying a rapid fabrication technique. After connecting a single mode fiber to each integrated Bragg grating, the sensing device is bonded to stainless steel and applied for tensile and compressive strain measurements. The 2D PPBG reveals a distinctive angle dependent behavior of the reflected Bragg wavelength, which in turn makes this device suitable for measuring multi axial tensile and compressive strain.

Key words: Bragg grating, polymer, multi axial strain

Introduction

Since their first fabrication by Hill et al., Bragg gratings have been subject to comprehensive investigations and are nowadays commercially available and widely spread in the field of optical sensing [1]. A Bragg grating consists of a periodical refractive index variation inside an optical waveguide and causes a wavelength selective reflection. This reflected wavelength λ_B is determined by the effective refractive index and the spatial period of the grating, thus changes of either of these parameters result in a wavelength shift usable for optical sensing. Especially, Bragg gratings inscribed into silica fibers can be used for multiple applications, e.g. as bio, temperature, or strain sensors [2]. More recently, polymers like Polymethylmethacrylate (PMMA) have been found to be suitable candidates for the fabrication of Bragg gratings, mainly due to their cost-effectiveness, availability, and excellent material properties [3]. With the focus on optical strain sensing the lower Young's Modulus and the higher breaking elongation of polymers are major advantages compared to silica [4]. In this respect, it has already been demonstrated that polymer planar Bragg gratings (PPBG) can be applied for measuring tensile and compressive strain with a single planar Bragg grating sensor [5].

In this study, we introduce a 2-dimensional PPBG for multi axial tensile and compressive strain sensing. The 2D PPBG consists of two integrated Bragg gratings which are fabricated in bulk PMMA using a rapid single writing step for each grating. After bonding the sensing device to stainless steel, we applied tensile and compressive strain from various directions and recorded the angle dependent shifts of the two reflected wavelengths. Our results remarkably demonstrate the applicability of the 2D PPBG for multi axial strain sensing.

Experimental Setup

The 2D PPBG consisting of two integrated Bragg gratings is fabricated in planar bulk PMMA which is cut to size by a CO2 laser.

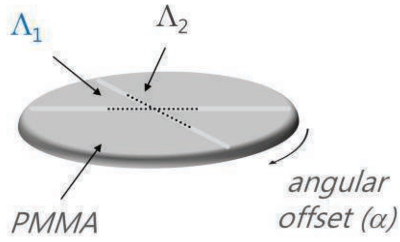
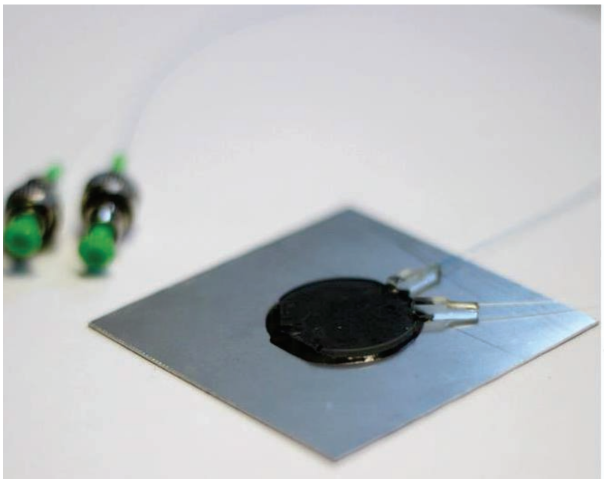


Fig. 2: Graphical representation of a 2D polymer planar Bragg grating in PMMA substrate



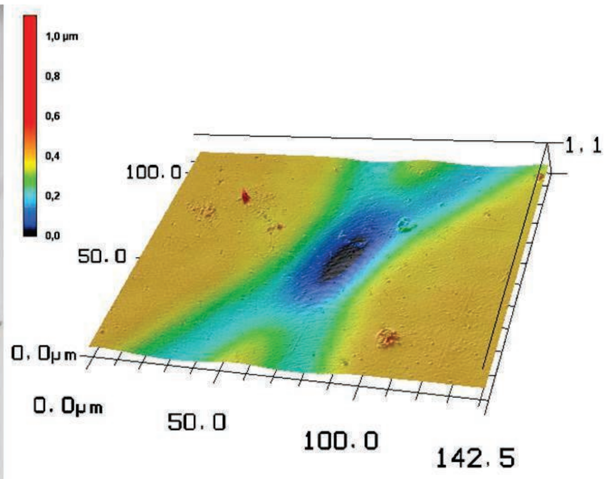


Fig. 2. (a) 2D PPBG sensor chip bonded to stainless steel. (b) Laser scanning microscopy image of the intersection of the two integrated Bragg gratings.

The end faces of the sensing device are polished with an advanced preparation system to the point of surface quality suitable for optical fiber coupling. The integrated Bragg gratings are inscribed using a KrF excimer laser illuminating a stacked mask configuration consisting of an amplitude and a phase mask.

Based on the stacked mask configuration both, the integrated waveguide and the Bragg grating are simultaneously written into the PMMA substrate. A detailed description of the fabrication process of a PPBG can be found elsewhere [6]. Following the fabrication of the first grating, the PMMA substrate is rotated by a freely selectable angle α and subsequently a second grating is inscribed. Figure 1 illustrates the design of the 2D PPBG in a PMMA substrate. In this specific case, the two intersecting Bragg gratings with different grating periods, namely 1036.79 nm (Λ_1) and 1053 nm (Λ_2), are oriented in an angle of 40° to one another to obtain distinct wavelength shifts for each grating.

After connecting a single mode fiber to each of the two gratings using UV curable glue, the PPBG can be connected to a standard optical interrogation system via a 2x2-50/50 coupler. Subsequently, the sensing device is bonded to a stainless steel plate and loaded with increasing tensile and compressive strain. Starting with tensile strain of 30 N the 2D PPBG is unloaded before being compressed by -30 N. Subsequently, the applied force is amplified to ±50 N, ±80 N, and ±100 N, respectively.

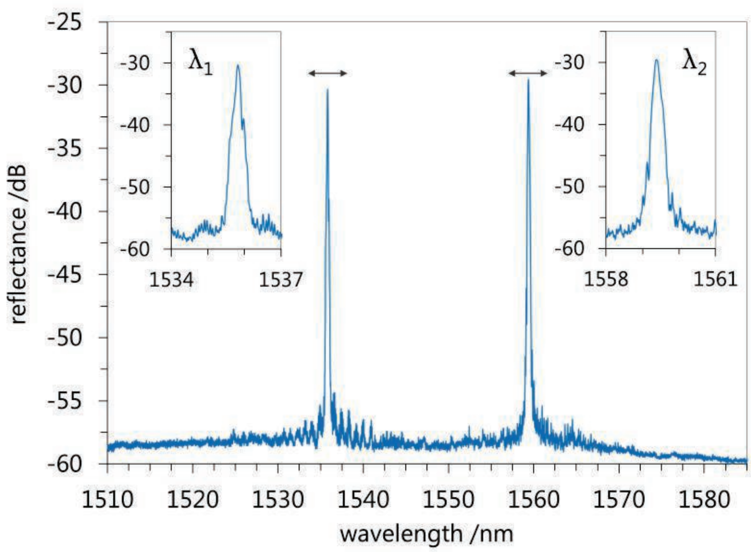


Fig. 3: Reflected spectrum of the 2D polymer planar Bragg grating.

DOI 10.5162/sensor2015/P5.1

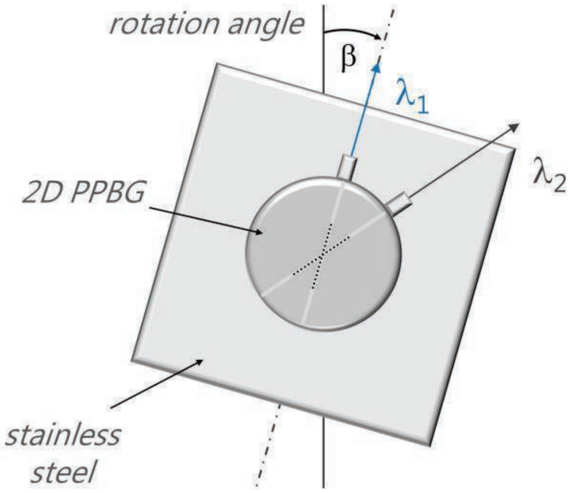


Fig. 4: Schematic illustration of the 2D PPBG and its orientation to the direction of the load transmission.

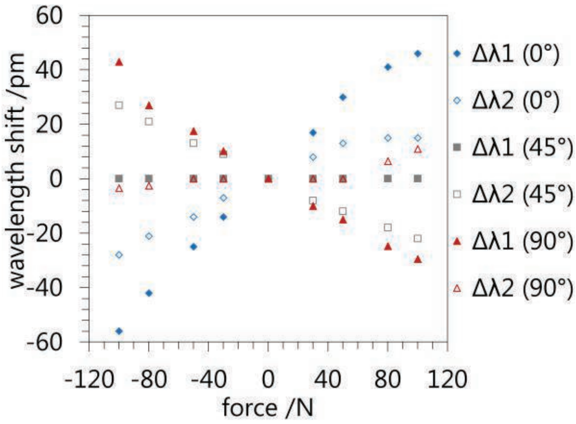


Fig. 5: Wavelength shift of the two Bragg wavelengths during tensile and compressive strain at different angles.

To evaluate the behavior of the 2D PPBG, we stepwise rotated the sensor and applied the same automated testing scheme at different angles. Please note that at an orientation of 0° the force is applied alongside to Λ_1 and with an angular offset (40°) to Λ_2. Based on these results the sensitivity of the 2D PPBG is determined for each angle. The applied Bragg grating interrogation system consists of a tunable laser diode emitting a wavelength spectrum of 1550±40 nm, a circulator and a photodiode.

Results

Figure 2a shows a picture of the 2D PPBG on top of the square stainless steel plate which exhibits a lateral length of 55 mm and a thickness of 6 mm. Figure 2b displays an image of the intersection of the two integrated Bragg gratings which is recorded using a laser scanning microscope. Evidently, the intercepting region shows a higher degree of surface degradation due to the dual UV illumination as compared to the remaining waveguide regions. However, this degradation has no effect on the reflected spectrum of the 2D PPBG which is depicted in figure 3. Based on the grating period of the first grating (Λ_1=1036.79 nm) the first reflected wavelength shows a maximum reflected intensity at 1535.8 nm, while the second grating (Λ_2=1053 nm) exhibits a Bragg wavelength at 1559.4 nm. Figure 4 shows a schematic illustration of the 2D PPBG including the angle β by which the sensing device is rotated. The behavior of the two twisted Bragg gratings towards tensile and compressive strain is

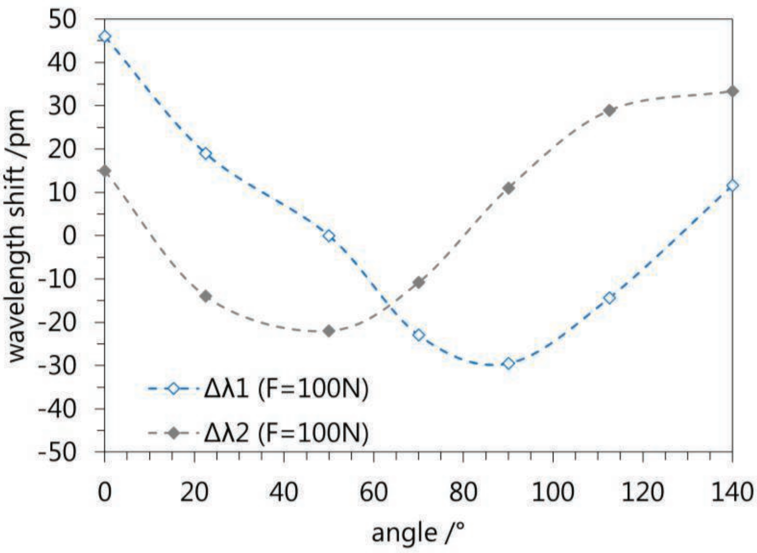


Fig. 6: Wavelength shift of both reflected wavelengths at different angles β at a distinct force of 100 N.

DOI 10.5162/sensor2015/P5.1

shown in figure 5 for three different orientations of the mechanical load. Apparently, the sensing device exhibits a strong angle dependence, yet with a linear shift of the Bragg wavelength versus tensile and compressive strain for each orientation. At an angle of 0° the reflected wavelength λ_1 shows a maximum redshift during tensile and a blue shift during compressive strain, while λ_2 possesses a reduced sensitivity. However at an angle of 45°, λ_1 exhibits no wavelength shift during mechanical loading. A rotation of the 2D PPBG by 90° results in an inverse behavior compared to 0°, which means that tensile strain results in a blue and compressive strain in a redshift of the Bragg wavelength. A detailed presentation of the angle dependent sensitivity of the 2D PPBG during tensile and compressive strain is given in figure 6, in which the induced wavelength shift of λ_1 and λ_2 at different angles β for an applied force of 100 N is shown. The angle α between the inscribed Bragg gratings is responsible for the ratio of the two wavelength shifts. Therefore, the offset of the wavelength shifts can be customized by adjusting the angular offset α during the fabrication process.

In conclusion, we demonstrated the fabrication and application of a multi-axial optical strain sensor. The device is based on two integrated planar Bragg gratings with an angular offset of 40° which are inscribed in a polymer substrate using a rapid single writing step. Being bonded to stainless steel and loaded with tensile and compressive strain at various angles, the two Bragg gratings of the 2D PPBG reveal an angle dependent linear sensitivity with a distinct offset which is based on the angle between the two gratings. This, in turn, makes the 2D polymer planar Bragg grating a promising candidate for multi axial strain sensing.

References

[1] K. O. Hill, Y. Fujii, D. C. Johnson, B. S. Kawasaki, Applied Physics Letters, 32, 647–649 (1978); doi: 10.1063/1.89881

[2] K. Hill, G. Meltz, Journal of Lightwave Technology 15(8), 1263–1276 (1997); doi: 10.1109/50.618320

[3] H. Ma, A.K.-Y. Jen, L. R. Dalton, Advanced Materials, 14 (19), 1339-1365 (2002); doi: 10.1002/1521-4095(20021002)14:19<1339::AID-ADMA1339>3.0.CO;2-O

[4] G. Rajan, B. Liu, Y Luo, E. Ambikairajah, G.D. Peng, IEEE Sen. J. 13, 1794-1800 (2013); doi: 10.1109/JSEN.2013.2242883

[5] M. Rosenberger, S. Hessler, S. Belle, B. Schmauss, R. Hellmann, Optics Express, 22(5), 5483-5490 (2014); doi: 10.1364/OE.20.027288

[6] M. Rosenberger, G. Koller, S. Belle, B. Schmauss, R. Hellmann, Optics Express 20(25), 27288-27296 (2012); doi: 10.1364/OE.22.005483M.