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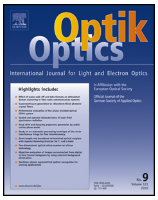

Original research article

Optimization of parameters for packaged long-period fiber grating

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ABSTRACT

The micro-electromechanical systems (MEMS) process and packaging with polydimethylsiloxane (PDMS) polymer materials are important technologies in semiconductor industries. In this study, we propose using the L9 orthogonal array to determine the optimal parameters for an optical fiber sensor packaged with PDMS. According to analysis of variance results, the optimal parameters are as follows: a grating with a diameter of 60 μm, a period of 650 μm, and a length of 2.5 cm, as well as a photoresist structure with a width of 2 mm. The results of a large-the-best (LTB) analysis indicated that the expected sensitivity value of a sensor with those parameters would be around 0.0345 dB $/\mu\varepsilon$. After testing and verification, the sensitivity results indicated a mean sensitivity of 0.0339 dB $/\mu\varepsilon$, with the deviation in sensitivity being less than 0.14%.

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1. Introduction

Grating structures are important [1] not only in fiber optics but also in integrated optics. Static and dynamic waveguide gratings for light coupling between the TE and TM modes of planar waveguides were first demonstrated by Alferness in 1982 [2]. A long-period fiber grating (LPFG) can couple the forward propagating core mode to one or a few of the forward propagating cladding modes [3]. A segment of long-period fiber grating (LPFG) that can selectively filter the fundamental mode in few-mode optical fiber is proposed in this study [4]. By applying an appropriate surrounding material and an apodized configuration of LPFG, high fundamental mode loss and low high-order core mode loss can be achieved simultaneously [5]. Furthermore, LPFGs are widely used for strain, temperature, and chemical sensing applications [6,7]. The use of LPFGs in sensing technologies is particularly popular because these gratings are relatively easy to fabricate [8]. Moreover, through the use of optimized waveguide and grating parameters, sensors with high degrees of sensitivity have been produced [9].

Taguchi methods [10] have been widely utilized in engineering analysis and consist of the planning of experiments with the objective of acquiring data in a controlled way. In industry, Taguchi's robust design methods constitute a powerful tool for the design of high-quality systems. In addition to the S/N ratio, a statistical analysis of variance (ANOVA) can be employed to indicate the impact of process parameters on the sensitivity of packaged LPFG (PLPFG) for strain measurement

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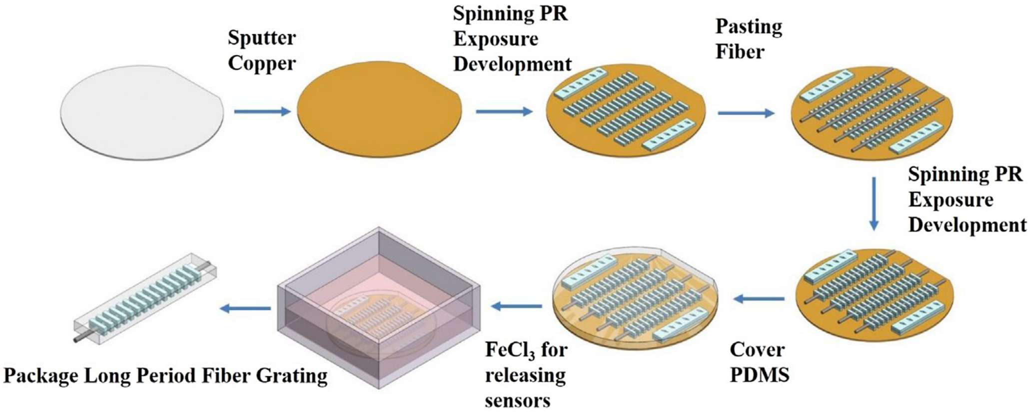

Fig. 1. The production process of the packaged long-period fiber grating (PLPFG) strain sensor.

[11]. Furthermore, Taguchi's matrix method is typically used to the extent possible to provide cost savings and quality improvements via the optimization of parameters. In this study, we propose using the L9 orthogonal array to determine the optimal parameters for PLPFG used for strain measurement. The grating parameters are also optimized in order to achieve a good contrast between the grating period and the resonance wavelength in the 1.5 m region and in order to better sense the external medium refractive index over a wide range [12].

2. Working principle of PLPFG sensors

When light is transmitted in a PLPFG, the periodic refractive index grating structure generates a resonant attenuation dip in the spectrum, as indicated in the coupled mode theory [8]. The resonant attenuation dip (transmission loss) is calculated as

$$\mathrm{T} = cos^2\left(\kappa_{co-cl}^{ac} L\right) \tag{1}$$

Where L indicates the length of the LPFG and κ_{co-cl}^{ac} is the AC component of the coupling coefficient between the core and cladding modes. The transmission loss of an LPFG can be deduced from the AC component of the coupling coefficient between the core and the cladding. Transmission loss is a function of κ_{co-cl}^{ac}, which is proportional to the amplitude of refractive index changes due to the periodical variation of the strain field. When loading is supported, κ_{co-cl}^{ac} will change according to the strain-optics effect. From the above formula, it can be seen that the transmission loss of a PLPFG is related to the coupling coefficient and grating length.

3. Experimental method

3.1. Production process and fabrication of the PLPFG

The lithography and etching processes were adopted as the process for fabricating the PLPFG strain sensor. Before starting the fabrication process, copper was deposited via sputtering on a 4-inch wafer. The single mode optical fiber length of 30 cm and stripped 3 cm used to etched region, the optical fiber was etched from 125 to 60, 66, 72 μm, respectively, with buffer oxide etching (BOE) solution at a temperature of 40 °. Next, the negative photoresist SU-8 3050 was spun onto the wafer as the base layer. Then, the coated wafer was placed on a heating plate in order to carry out a soft bake (SB) operation. After the SB operation, the exposure process was performed using an ABM alignment system ATI-1248 (365 nm, 210 mW/cm^2). The exposure machine was used to carry out an exposure operation with a plastic mask. The plastic mask was designed with periods of 650, 660, and 670 μm in order to achieve a resonant wavelength with a transmission dip of about 1550 nm. Then, the wafer was placed on a hot plate to carry out a post-exposure baking (PEB) operation. Finally, after the above operations were completed, the photoresist was immersed in a developing solution to obtain the designed bottom periodic structure. The four parameters (that is, the diameter, period, and length of the grating, and the width of the photoresist structure) are the important factors and were thus the factors considered for parameter optimization by the L9 orthogonal array. PLPFG was produced 2 sets to strain test by every experimental No. parameter. The production process of the PLPFG strain sensor is shown in Fig. 1, while the schematics of the PLPFG are shown in Fig. 2.

3.2. The experimental setup for the strain sensing

The sensitivity of a PLPFG sensor is closely related to the fiber diameter and the etch time for the MEMS process of the LPFG photoresist structure. The sensitivity can be increased by etching the fiber to a smaller diameter to increase the effective

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