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Temperature Fiber-Optic Sensor with ZnO ALD Coating †

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Abstract: This study presents a microsphere-based fiber-optic sensor with a ZnO Atomic Layer Deposition (ALD) coating thickness of 100 nm for temperature measurements. Metrological properties of the sensor were investigated over the temperature range of 100 °C to 300 °C, with a 10 °C step. An interferometric signal is used to control whether the microstructure is whole. Spectrum shift of a reflected signal is used to ascertain changes in the measured parameter. With changing temperature, the peak position of a reflected signal also changes. The R^2 coefficient of the presented sensor indicates a good linear fit of over 0.99 to the obtained data. The sensitivity of the sensor investigated in this study equals 0.019 nm/°C.

Keywords: atomic layer deposition; fiber-optic; microsphere; temperature; ZnO

1. Introduction

Fiber-optic sensors have been developed and improved upon for over a decade. Due to their versatility, they are used in numerous fields, such as industry, science or medicine [1–4]. Optimization of measurement parameters plays a significant role in development of the fiber-optic sensors. While planning measurements, selection of the sensor is a crucial element, depending on their purpose and conditions in which they will perform. Based on the type of sensor, diversity of designs and parameters can be optimized: adjustable cavity length, structure modification [5–8], as well as metrological properties, such as: resolution, precision, sensitivity, accuracy [9,10]. Many researchers contribute to the determination of the properties and parameters of various materials and structures [11,12].

This study investigates sensing abilities of the microsphere-based fiber-optic sensor with a 100-nm ZnO Atomic Layer Deposition (ALD) coating during temperature measurements.

2. Materials and Methods

Measurements were performed using a sensor made of a standard single-mode telecommunication optical fiber (SMF-28, Thorlabs Inc., Newton, NJ, USA) with a microsphere structure produced at the end of the fiber, using a fiber-optic splicer (FSU975, Ericsson, Sweden). The obtained microsphere has a diameter of 245 μm. After the manufacturing of the microsphere, the ZnO coating of 100 nm thickness was deposited on its surface by Atomic Layer Deposition (ALD) method. Detailed description of the deposition process is presented elsewhere [13,14].

To assess quality of the structure and the deposited ZnO ALD coating of 100 nm thickness, it was then investigated under a Scanning Electron Microscope (SEM, Phenom XL G2, Thermo Fisher Scientific, Waltham, MA, USA), the results of which are shown in Figure 1.

Figure 1. SEM image of the microsphere-sensor with a 100-nm ZnO Atomic Layer Deposition (ALD) coating. Magnification of 1000×.

The image shows the device with a magnification of 1000× and it can be seen that the structure exhibits excellent roundness. Furthermore, the presence of ZnO coating is apparent.

Moreover, metrological properties of the sensor were validated by performing experimental measurements. During investigation, the sensor is placed in a temperature calibrator (ETC-400A, Ametek, Berwyn, PA, USA), which was increased from 100 °C to 300 °C, with a 10 °C step. The temperature was stabilized for 3 min, at each step, allowing the sensor to adjust to altered conditions. The measurements were executed using a light source with a center wavelength of 1310 nm ± 20 nm (SLD-1310-18-W, FiberLabs Inc., Fujimino, Japan). The signal was propagated through a 2:1 50/50% optical coupler (G657A, CELLCO, Kobylanka, Poland) to the sensor head coated with a 100-nm ZnO ALD coating, which is highly reflective, allowing the wave to superpose, therefore inciting interference as shown in Figure 2.

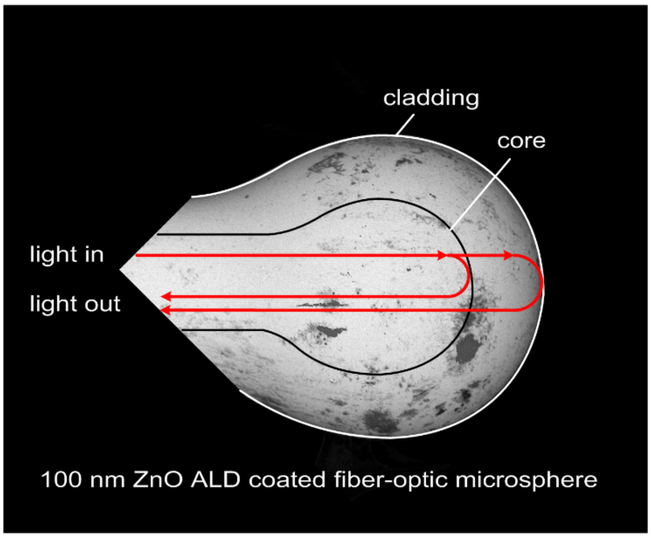

Figure 2. Principle of operation of a microsphere-based fiber-optic sensor.

By obtaining interference, the integrity of the structure can be monitored, ensuring the sensor is not damaged. The reflected signal is then collected by Optical Spectrum Analyzer (OSA, Ando AQ6319, Yokohama, Japan). Depending on the position of the spectral peak of the signal, temperature can be determined.

3. Results and Discussion

This section presents results, which were acquired from the measurements performed with the setup shown above.

Figure 3 shows normalized values of the measured signal response for the microsphere-based sensor with a 100-nm ZnO ALD coating, at 100 °C and 300 °C to preserve readability of the plot. In rising the temperature, spectral peak of the reflected signal shifts toward lower values of the wavelength. The envelope, however, remains similar for each temperature. In addition, interference fringes visible in the Figure inform about the integrity of the sensor head structure, which allows the monitoring of its condition in real-time.

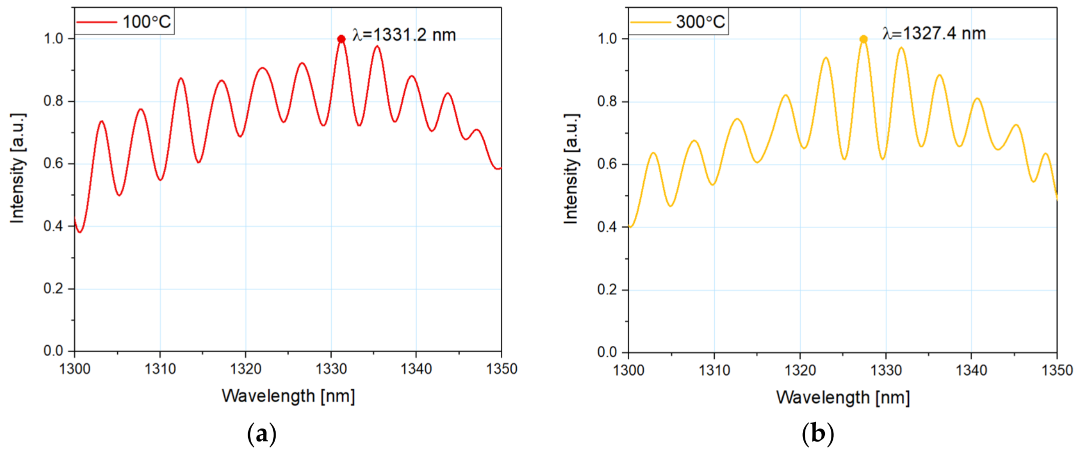

Figure 3. The normalized measured response of the reflected signal for the microsphere-based sensor with 100-nm ZnO ALD coating at: (**a**) 100 °C and (**b**) 300 °C.

Dependence of the peak wavelength position on the temperature can be observed in Figure 4. Moreover, theoretical linear fit is also presented, as well as coefficient R^2, which equals 0.99176, being determined to confirm fitness of the obtained data to the theoretical model. Furthermore, the results presented in Figure 4 allowed to calculate the sensitivity of the microsphere-based sensor with a 100-nm ZnO ALD coating—0.019 nm/°C.

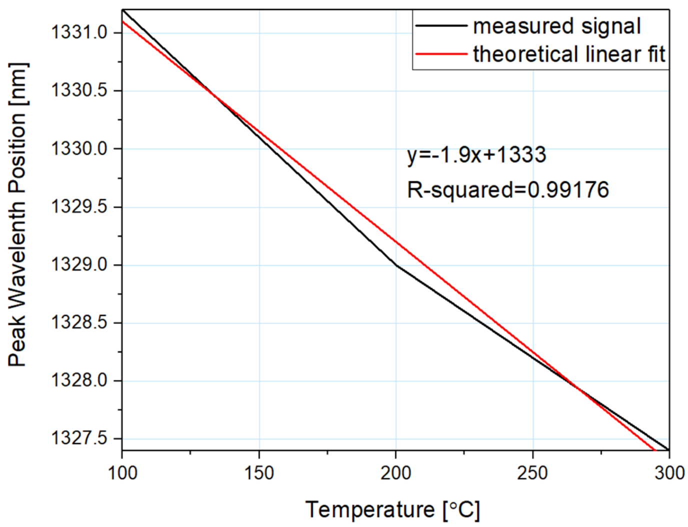

Figure 4. Dependence of the spectral shift of a reflected signal on the temperature.

The spectrum changes its peak wavelength position when the temperature is altered. The higher the temperature, the spectrum shift is constant throughout whole range of roughly 2 nm per 100 °C. By following linear regression, it is possible to determine the position of the reflected signal peak for each measured temperature.

4. Conclusions

Microsphere-based sensors are ideal for long-term and remote measurements of parameters such as temperature or refractive index due to their ability to constantly monitor the integrity of the sensor head. The study presents a 100-nm ZnO ALD coating on the surface of a microsphere-based fiber-optic sensor for temperature measurements. Selection of an optimal coating is crucial for long-term and remote measurements. While devising the measurements, it is important to select proper parameters of the fiber-optic sensor coating for optimal efficiency. The sensor with a 100-nm ZnO ALD coating exhibits a close match between measurement data and theoretical linear fit, which is confirmed by an R^2 coefficient of over 0.99. The sensitivity of the sensor with a 100-nm coating equals 0.019 nm/°C. Additionally, for the microsphere-based sensor with a 100-nm ZnO ALD coating, changes of temperature can be observed based on the spectral shift, which coincides with rise of the temperature. The sensor also indicates its proper operation by inciting interference.

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Conflicts of Interest: The authors declare no conflict of interest.

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