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A Novel Mechano-Optical Sensor based on Read-out with a Si_3N_4 Grated Waveguide

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Abstract: A proof-of-concept study is reported on fabrication and characterization of a novel and compact integrated mechano-optical sensor based-on a micro-bridge suspended above a Si_3N_4 grated waveguide.

OCIS codes: (230.4685) Optical microelectromechanical devices; (130.3120) Integrated optics devices

1. Introduction

Microcantilever-based sensors can be used to detect molecular absorption of, for example, hydrogen gas, which causes changes in the surface stress [1-7], leading to deflection of the cantilever. Such a deflection can be determined by means of optical beam deflection [2], capacitance- [3], or piezo-resistance- [4] based readout. Recently, we proposed a compact integrated mechano-optical sensor using a novel and highly sensitive integrated read-out scheme to detect small deflections of a cantilever in close proximity to a grated waveguide (GWG) structure [1,2,7]. Here we present the integrated optical read-out of stress-induced micro-bridge deflections due to hydrogen gas absorption by a Pd receptor layer on top of the micro-bridge.

2. Device structure, sensing principle, and experimental

The 3D schematic structure and the cross-section of the GWG-micro-bridge device are shown in Figs. 1a and 1b. Main parts of the device are the Si_3N_4 grated waveguide and the SiO_2 bridge coated with a 30 nm thick palladium (Pd) layer for hydrogen absorption. All relevant device dimensions are depicted in the figure.

Absorption of H_2 by Pd will cause the cantilever to curl down [3-5], which narrows the GWG-cantilever gap, *g*, and leads to a stronger interaction between the cantilever and the GWG evanescent modal field, which results in a shift of the transmission spectrum. This effect can be used for the detection of cantilever displacements and, thus, the concentration of the absorbing gas (see Fig. 1c).

Integrated GWG-cantilever devices have been fabricated successfully using MEMS techniques. Details of the fabrication process were described in [1]. Instead of singly-clamped cantilevers as mentioned in [1], here we fabricated devices with a doubly-clamped cantilever and with an aimed gap of $g = 200$ nm. Initial bending of the cantilever was characterized using a white-light interferometer. The PDMS chamber placed on top of the device was connected with gas bottles (i.e., N_2 and 1% H_2-N_2 mixture) through mass flow controllers. The optical performance of the integrated device was monitored using a tunable laser source (Agilent 8164B) with a resolution of 1 pm and an InGaAs photo detector.

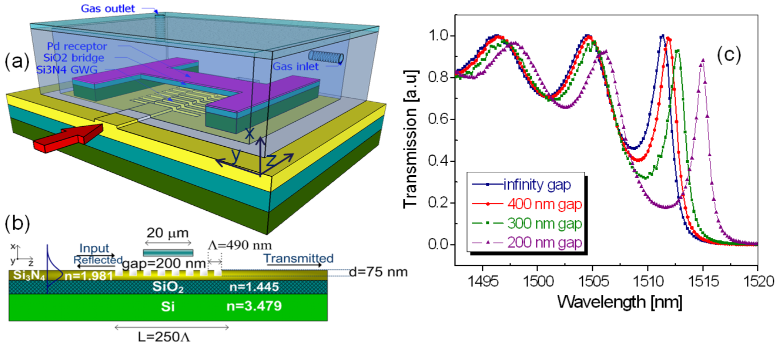

Fig. 1. (a) 3D schematic of the structure with a PDMS chamber serving as a reaction environment for H_2 sensing, (b) cross-section of the GWG-cantilever device, and (c) calculated transmission spectra for various gap sizes, illustrating the sensing principle [2].

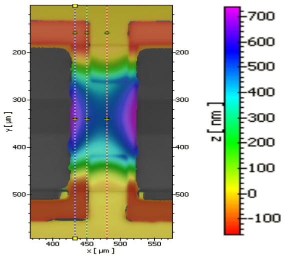

Fig. 2. Top view image of the device attained using a white-light interferometer, showing an initial up-bending of ~500 nm at the center of the micro-bridge.

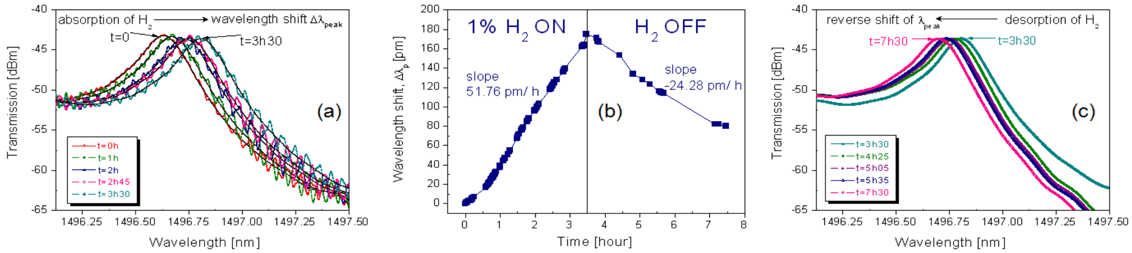

Fig. 3. Transmission curves of the device in response to the absorption (a) and desorption (c) of H_2, and the amount of wavelength shift $\Delta\lambda_p$ versus the reaction time (c).

3. Results and discussion

Figure 2 shows a top-view image of the fabricated device, as recorded with a white-light interferometer, indicating an initial bending (upwards, i.e., away from the GWG structure) of the micro-bridge of approximately 500 nm. This initial bending, which leads to a lower sensitivity at low H_2 concentrations (owing to the relatively large gap of $g \sim$ 700 nm), is due to the difference between residual stresses in the SiO_2 base layer and Pd receptor film [1].

Prior to supplying H_2 gas to the measurement chamber, N_2 gas was flushed in during 15 min with a flow rate of 0.5 sccm and optical transmission curves were captured repeatedly every minute. The results showed a stable and reproducible resonant peak at $\lambda_p = 1496.631 \pm 10^{-3}$ nm (see Fig. 3a, curve at $t = 0$), indicating that such a flow rate did not cause any side effects or mechano-optical vibrations. Noise was removed from the spectrum using low pass filtering in the Fourier domain, enabling accurate and efficient determination of changes in λ_p ($\Delta\lambda_p(t) = \lambda_p(t)- \lambda_p(t_o)$).

Next we supplied the H_2(1%)-N_2 mixture (flow rate 0.5 sccm) for a longer period of time, during which the transmission spectrum was monitored (see Fig. 3a). The shift $\Delta\lambda_p$ depends almost linearly on time, which can be explained partly by noting that the effect of the initially rapid change of the gap size, g, is compensated by lower values of $\partial\lambda_p/\partial g$ at larger gap size. After 3.5 hours the flow of the H_2 (1%)-N_2 mixture was switched off and replaced again by a pure N_2 inflow, leading to desorption, as indicated by the transmission spectra (see Fig. 3c). Figure 3b (right-hand side) shows the peak shifts during a four-hour period. It can be concluded that the desorption takes place at a much lower rate (~50%) than the absorption process and full desorption is not achieved during the monitoring period of time.

The result provides a proof of concept of a novel and compact integrated mechano-optical sensor. This result gives us a strong confidence in the feasibility of this type of sensor.

4. Conclusions

We have demonstrated H_2 sensing with a novel and compact integrated optical read-out scheme as a proof of concept for our proposed and successfully fabricated mechano-optical sensor. This new sensor type possesses a great potential as an element of a sensitive and on-chip multi-sensing system, provided that the gap between the GWG and the micro-bridge can be well controlled during fabrication.

5. Acknowledgements

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6. References

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