

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.

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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.

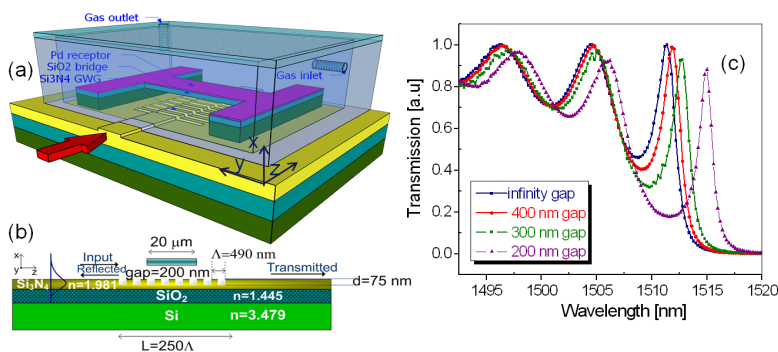


Fig. 1. (a) 3D schematic of the structure with a PDMS chamber serving as a reaction environment for H_2 sensing, (b) cross-section of the GWG-cantilever device, and (c) calculated transmission spectra for various gap sizes, illustrating the sensing principle [2].

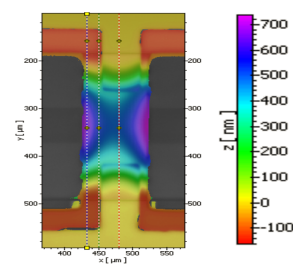


Fig. 2. Top view image of the device attained using a white-light interferometer, showing an initial up-bending of ~ 500 nm at the center of the micro-bridge.

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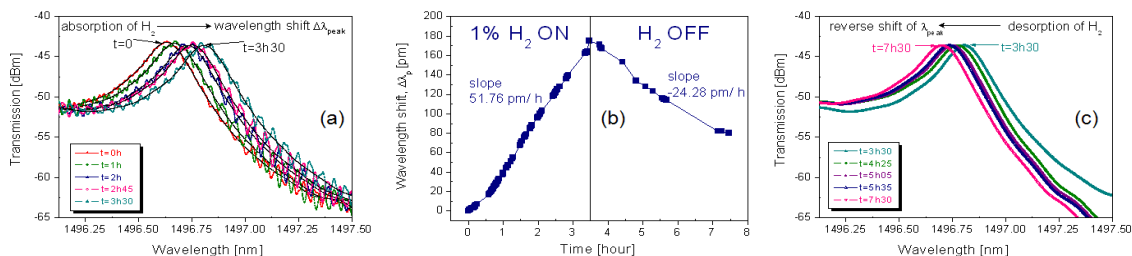


Fig. 3. Transmission curves of the device in response to the absorption (a) and desorption (c) of H_2 , and the amount of wavelength shift $\Delta\lambda_p$ versus the reaction time (c).

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 ($\Delta\lambda_p(t) = \lambda_p(t) - \lambda_p(t_0)$).

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 ($\sim 50\%$) 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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