Cantilever deflection read-out with a grated waveguide optical cavity

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***Abstract* - We propose a novel and highly sensitive mechano-optical device for gas-sensing through nano-displacements, based on micro-cantilevers, supplied with a selective gas absorbing layer (Pd), suspended above a Si_3N_4 grated waveguide (GWG). We present the simulation and preliminary experimental results, which indicate the sensing of nanodisplacements, an important intermediate step for the gas-sensing purpose.**

Keywords* - *grated waveguide; microcantilever; gas-sensing; mechano-optical sensor

I. INTRODUCTION

Waveguide gratings are often referred to as one-dimensional (1D) photonic crystals, which have a periodic variation of the dielectric constant along the propagation direction. An important property of a grated waveguide (GWG) is the occurrence of fringes in the transmission spectrum near the stop-band edges. It is well known that these oscillations are due to Fabry-Perot resonances of Bloch modes propagating in the cavity defined by the grated section [1]. Based on this property of GWGs, a demonstration of the potential of such structures for sensing of index changes was reported using a cavity with a high quality factor (high Q) [2]. In addition, the potential of micro-cantilevers to convert concentration changes efficiently into displacements was also demonstrated [3-6]. For these reasons, we were motivated to integrate a GWG and a microcantilever into one chip as a novel compact mechano-optical sensor for hydrogen gas. Such a sensor enables the detection of the concentration of hydrogen gas through the change of nanodisplacements of the microcantilever, which is monitored optically by shifts of resonance peaks of the transmission spectrum [7]. In this paper we present the simulation results and preliminary optical characterization results of the fabricated chips, which confirm the possibility of such a GWG-cantilever integration as a platform for gas-sensing.

II. WORKING PRINCIPLE AND SIMULATION

A picture of the envisioned device is given in Fig.1. The device consists of two main components which are integrated: a grated waveguide as an optical read-out, and a micro-cantilever suspended above the GWG. The device is functionalized by depositing a sensitive layer on top of the cantilever; for hydrogen (H_2) sensing, palladium (Pd) can be used. Absorption of H_2 into Pd will cause the cantilever to bend [3-6]. This bending of the cantilever can then be optically detected by exploiting the properties of the GWG. The presence of a dielectric object, in this case a cantilever, in the evanescent-field region of the GWG may lead to the occurrence of propagating modes for wavelengths inside the stop band of the grating, and so to resonances (defect modes) inside the stop band [2,7]. As the cantilever approaches the grating, the first near band edge resonance peak is pulled inside the stop band and its spectral width decreases. This effect can be used for the detection of cantilever displacements and so the detection of gas concentration.

Figure 2 shows the 2D cross-sectional model of the device. A 2D bidirectional eigenmode propagation (BEP) method [6] was applied to this model to analyze the nanodisplacement sensing, through the effect of the suspended microcantilever on the output transmission spectrum. As a result, the spectral shift due to the change of the gap between the GWG and the cantilever was observed. A critical gap width, at which the microcantilever starts influencing the evanescent-field region of the GWG, is calculated to be ~ 400 nm (as shown in Fig.3). On the other hand, if a thin cantilever is coated with a metal layer, the evanescent field of the GWG may reach the metal layer through the thin-film and cause an optical loss. Partial metal coating can be used to avoid such a loss. Simulations using a channel mode solver were carried out to estimate the optical absorption. The result shows that the safety distance between the metal tip and the oxide tip, where the cantilever is not covered in the region that overlaps the modal field, is estimated to be 15 µm.

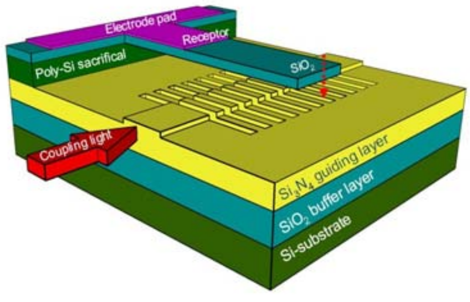

Fig.1 . The grated waveguide-cantilever device

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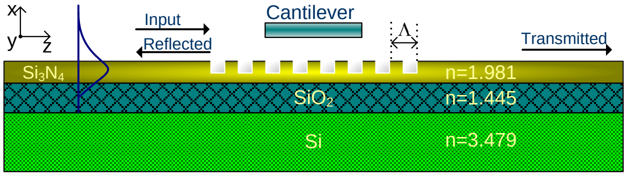

Fig.2. 2D cross-sectional model of the device

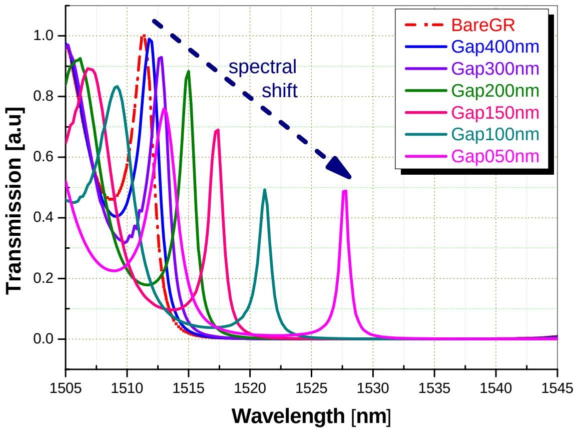

Fig.3. Simulated transmission spectra of a 125-period grating, with a 800 nm thick cantilever suspended above it. A spectral shift due to the change of the gap between the GWG and the cantilever was observed

III. Fabrication and Characterization

A fabrication process was designed and optimized in order to obtain good devices with a uniform grating and a low initial bending of the cantilever. A grating was defined in a shallow ridge silicon nitride (Si_3N_4) waveguide (WG), using laser interference lithography (LIL). The cantilever was released using sacrificial layer etching techniques. The cantilever core material was chosen to be silicon dioxide (SiO_2). Further details of the fabrication process will be described and published elsewhere. For preliminary optical characterization, a series of cantilevers with various lengths of the metal-pads was fabricated. The purpose of changing lengths of metal-pads is to cause a difference in the surface stress, and so in initial bending of the cantilevers. This resulted in different gaps between the GWG and the cantilever (as illustrated in Figs. 4a and 4b). A small metal area (Fig.4a) produces a very flat cantilever and the gap is the same as the thickness of the sacrificial layer of ~250 nm, while a large metal area (Fig.4b) causes an initial bending of ~130 nm, corresponding to a gap of ~380 nm. The difference in gaps leads to different spectral shifts of the transmission spectra as shown in Fig.4c. The first resonant peak next to the band edge of the bare grating (without a suspended cantilever) is at a wavelength of 1488.8 nm. This peak is shifted to wavelengths of 1489.2 nm and 1490.2 nm for gaps of ~380 nm and ~250 nm, respectively. These experimental results are in agreement with simulation results and give good confidence in the gas sensing capability of the device.

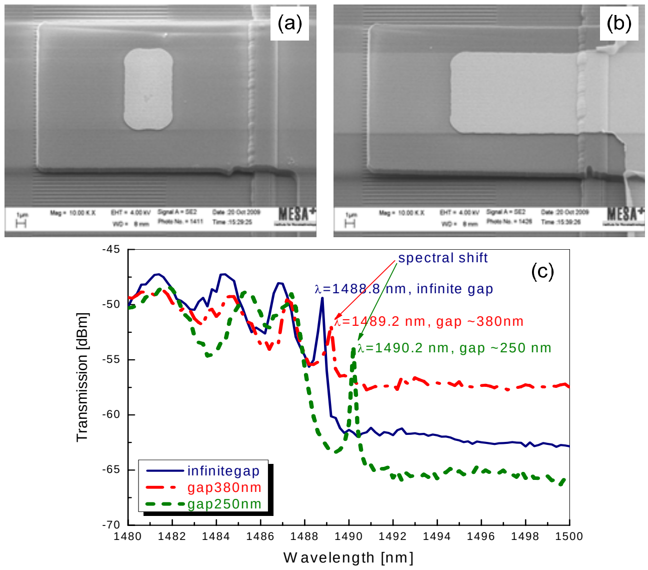

Fig.4. Fabricated chips (a) & (b) and their measured transmission spectra (c) of a 250-period grating, with a 800 nm thick cantilever suspended above it. Gaps between the GWG and the cantilever in (a) and (b) are different, owing to different metal pad lengths leading to differences in stress and so initial bending

IV. Conclusions

We have presented simulations and preliminary experimental results of a novel and compact mechano-optical sensor for nanodisplacements aimed for gas-sensing. The experimental results prove the potential of the considered integrated GWG-cantilever set-up as a platform for gas sensors.

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