Fabrication of microcantilever-based IO grated waveguide sensors for detection of nano-displacements

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We propose a novel and highly sensitive integrated read-out scheme, capable of detecting sub-nanometre deflections of a cantilever in close proximity to a grated waveguide structure. A very compact and stable sensor element can be realized by monolithically integrating a microcantilever structure with the grated waveguide (GWG), using conventional layer deposition and sacrificial layer etching techniques. The platform integrating a high quality GWG and a low initial bending cantilever has been fabricated and characterized.

Introduction

Microcantilever-based sensors can be used to detect molecular adsorption, which causes changes in the surface stress [1], leading to deflection of the cantilever. Often, an optical beam deflection method is used to measure the cantilever deflection [2]. Although the method is simple and accurate, it is bulky, and therefore dense and compact integration of cantilever sensors is not possible with this method. Different designs for integrated optical read-out of microcantilever deflection have been proposed and demonstrated e.g. [3]. Based on our simulations we propose a compact integrated chemo-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. In this paper, we present the fabrication process and preliminary characterizations of the fabricated device.

Device structure and its working principle

We consider a grating defined in a shallow ridge silicon nitride (Si_3N_4) waveguide (WG). The grating is defined using laser interference lithography. A very compact and stable sensor element is realized by monolithically integrating a microcantilever structure with the GWG, using conventional layer deposition and sacrificial layer etching techniques. The cantilever core material is chosen to be silicon dioxide (SiO_2). 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 [4]. 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 [5]. 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.

Fabrication procedure

The process flow chart of the fabrication of an integrated device is shown in Fig. 1. An 8-µm thick SiO_2 buffer layer was grown on a (100) Si wafer, using thermal oxidation. Next, a 275-nm thick Si_3N_4 core layer was deposited using the stoichiometric LPCVD technique. The refractive indices of Si_3N_4 and SiO_2 are 1.981 and 1.445, respectively. A 5-µm wide ridge waveguide, with 5 nm ridge height, was defined using photolithography and accurately etched into the Si_3N_4 layer using the BHF wet-etching process. The 490-nm period gratings were defined with laser interference lithography (LIL), using a Lloyd's-mirror-setup, producing a pattern size 2.7×10 cm^2. For our application, smaller patterns needed to be added at certain positions in order to be able to align gratings and cantilevers perpendicular to each other. Therefore, another mask was used to define the size (number of periods) and position of the gratings. The grating patterns were transferred into the Si_3N_4 layer using reactive ion etching (RIE).

In the next step, a 400 nm sacrificial poly-Si layer and an 800 nm TEOS SiO_2 layer were deposited using LPCVD techniques. Microcantilever patterns were defined on a TEOS SiO_2 layer by conventional photolithography and by removing unnecessary SiO_2 areas using RIE. Then, metallic layers, viz. a 10 nm Cr adhesion layer and a 50 nm Pd receptor layer, were sputter-deposited at room temperature, and patterned using a lift-off process. Finally, microcantilevers were released using a 5% TMAH wet-etching solution at 70°C.

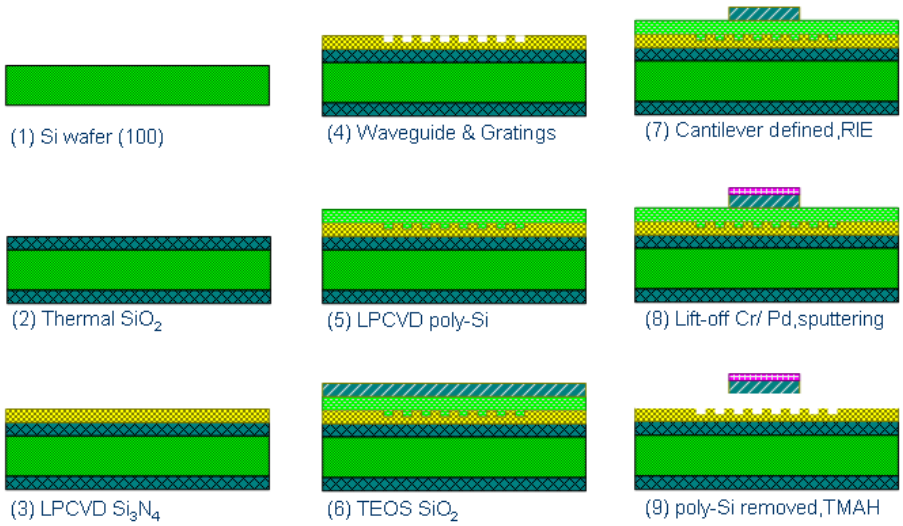

Fig.1. Process flow chart of fabrication of an integrated device

Results and discussions

Several processing steps needed to be investigated and optimized in order to obtain good-quality devices.

The TMAH wet-etching solution, which was used to selectively remove the sacrificial poly-Si layer in order to release the microcantilevers, might affect other materials of the device as well. This possible effect was investigated using AFM topographic surface measurements of the Si_3N_4 and metallic layers. Figure 2 shows the surface roughness of the Si_3N_4 films before and after the wet-etching process. The RMS roughness values (R_q) in both cases are 1.41 nm and 0.46 nm, respectively. This result means that the TMAH wet-etching solution did not damage the Si_3N_4 surface, but, on the contrary, reduced the surface roughness, which is known to reduce the optical losses of the waveguide. Fig. 3 shows the surface roughness of the sputtered Pd layers before and after wet-etching process. The sputtered Pd film has roughness (R_q) of 0.56 nm (see Fig. 3(a)). The Pd surface becomes rougher after dipping into TMAH solution, i.e., 5.8 nm (see Fig. 3(b)). This roughness of the Pd film is expected to increase the contact area which effectively absorbs the detected gas (H_2).

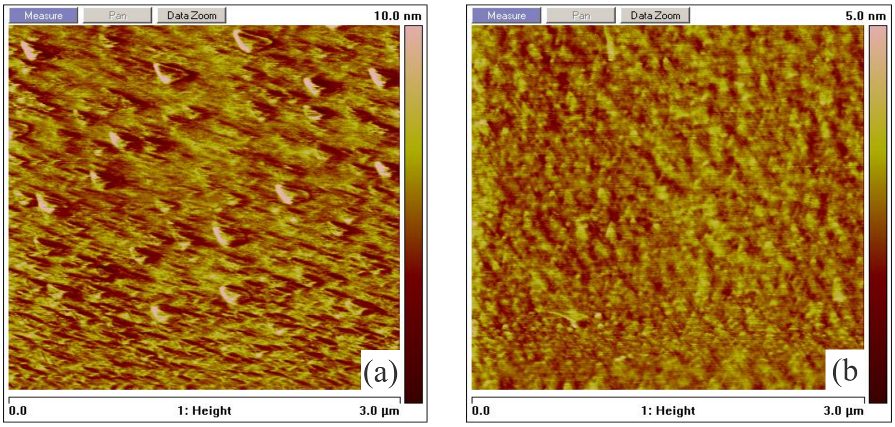

Fig. 2. AFM topographic images of (a) as-deposited LPCVD Si_3N_4 surface roughness, R_q=1.41 nm, and (b) Si_3N_4 after TMAH etching, R_q=0.46 nm

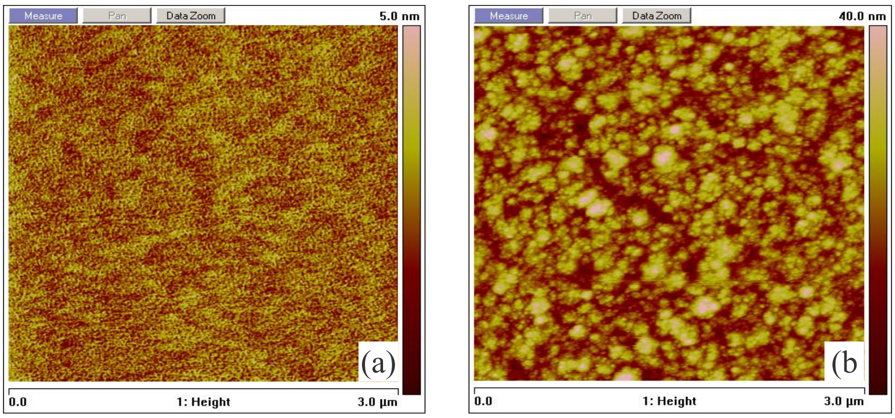

Fig. 3. AFM topographic images of (a) Bare Pd (by sputtering 50 nm) roughness R_q=0.56 nm, and (b) Pd (after TMAH) roughness R_q=5.8 nm

The LIL nanolithographic process used for creating the resist pattern for the gratings should preferably produce gratings with 50% duty-cycle. The duty cycle of the resist pattern increases with the exposure dose. The 50% target duty cycle was attained with a 3.3-mJ/cm^2 dose using a 20-s exposure time.

The RIE process for transferring the grating pattern into the Si_3N_4 layer was optimized for uniformity and aspect ratio. As a result, the Si_3N_4 gratings were etched in an O_2(10 sccm):CHF_3(100 sccm) plasma at 40 mTorr, 250 W, for 2 min. Fig. 4(a) shows an SEM image of a grating.

Microcantilevers with various dimensions were released by etching the sacrificial poly-Si underneath. Fig. 4(b) shows an SEM image of a 50 µm long cantilever. Due to residual stress between SiO_2 and metallic layers, the microcantilevers showed an initial bending after release (1 µm at the tip in this case). The initial bending could be compensated by applying a DC voltage to the metal pad.

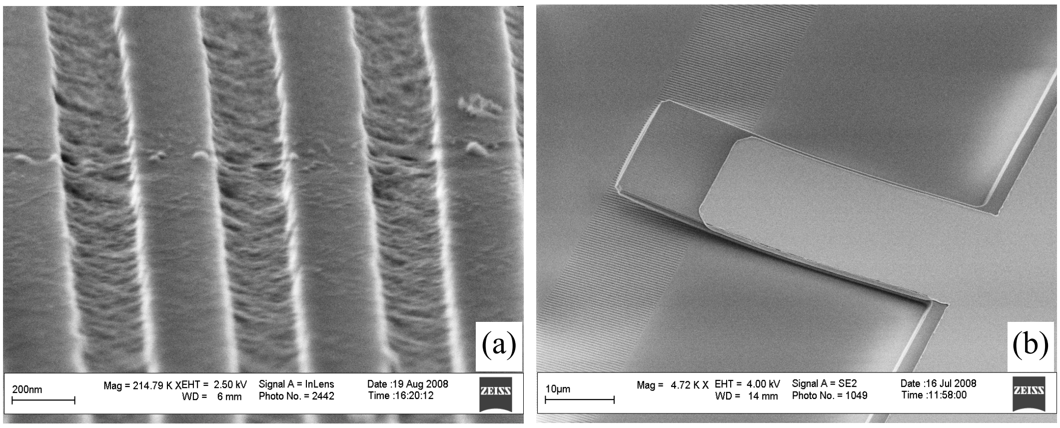

Fig. 4. Fabricated devices (a) gratings (period Λ=490 nm) fabricated by Laser Interference Lithography (LIL), and (b) a low initial bending cantilever (ca. 1µm) of the integrated device

Conclusion

We presented the fabrication of a chemo-mechano-optical sensor for hydrogen gas, based on microcantilevers suspended above a grated waveguide. Integrated devices with good-quality gratings and low initial bending cantilevers were realized. Optical characterization and sensing measurements are ongoing.

Acknowledgements

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