Integrated Optical Gas Sensors on Silicon-on-Insulator Platform

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Abstract: We demonstrate highly sensitive micro-optical hydrogen and ethanol gas sensors using SOI microring resonators (MRR) coated with sensitive films. Hydrogen concentrations below the lower explosion limit and ethanol vapor concentration below 100ppm are detected.

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1. Introduction

Applications such as environmental pollution monitoring, industrial process & explosion control, and forensic breath analysis heavily rely on gas sensors.

The Optical gas sensing route is becoming attractive compared to other competitive technologies, such as electrical gas sensors, for various reasons. Robustness, multiplexing of sensor arrays, safety, remote sensing and low power consumption are among the interesting features about the optical sensors [1].

Most of the optical sensors reported to date have been based on optical fibers. These sensors have enabled multiplexed multipoint and remote gas sensing. However, fiber optical sensors are not convenient for integration. On the other hand, inexpensive and compact gas sensors which can elegantly fit to a wide range of applications have been of a significant interest in the gas sensing community. The possibility to miniaturize gas sensors opens a way to a chip level implementation, integration with other vital functionalities, and mass fabrication. This way, fairly cheap, highly compact and multi -purpose gas sensors can be available. However, the implementation of optical gas sensors at integrated level has been challenging mainly due to the technological limitations.

Optical structures fabricated on the silicon on insulator (SOI) platform have recently been proving to be promising for a wide range of integrated optical applications [2]. These structures have been demonstrated with submicron scale features and can be realized on a very small area on a chip owing to the high index contrast between the waveguides and the surrounding claddings. Moreover, the compatibility of the SOI devices to CMOS fabrication tools and the promise of inexpensive mass fabrication makes them highly attractive. Owing to these facts, the research on SOI optical structures is recently extending beyond the telecom to other applications such as optical bio-molecule and gas sensing.

We demonstrate two highly sensitive gas sensors, namely, a hydrogen sensor and an ethanol sensor based on SOI microring resonators.

2. Integrated optical gas sensing with SOI circuits coated with sensitive films

Optical gas sensors can be realized either with direct light – gas interaction or with the aid of transducer chemical coatings on optical circuits [1, 4]. Gas sensitive chemical coatings significantly reduce the very long interaction length that would have been required if a direct spectroscopy of gases were used. Moreover, a proper choice of both the sensitive optical component and the chemical coating can lead to a significant enhancement in the sensor response. Chemical coatings made from metal oxides have been extensively studied for electrical gas sensing applications [5]. However, not much work has been done with regard to their potential for optical gas sensing especially at integrated level. We demonstrate the promise of a reasonably sensitive, compact and inexpensive optical gas sensing route using metal oxide coatings on SOI micro-ring resonators (MRR).

In this work, a hydrogen sensor and an ethanol vapor sensor are implemented using two different sensing principles. A catalytic Pt doped WO_3 film is coated on silica clad micro ring resonator for hydrogen sensing. The heat generated from the combustion of hydrogen in air modifies the effective index of the guided mode in the underlying ring resonator through thermo-optic effect. MRR resonance shifts higher than 1nm are measured for hydrogen concentrations below the lower explosion limit (LEL).

The ethanol sensing relies on rather a different principle. In this case, a Porous ZnO film is coated on SOI ring resonator. The ZnO film refractive index changes on ethanol vapor adsorption at room temperature. The MRR resonance wavelength is as a result shifted to longer wavelengths via evanescent field interaction with the film. Ethanol vapor concentration as low as 150ppm is experimentally detected with this scheme.

3. Sample Fabrication

The 5µm radius microring resonators are fabricated by patterning and etching a 220nm thick Si top layer on an SOI wafer using 193nm deep Ultra-Violet optical lithography in a standard CMOS fabrication process [2]. The waveguide structures are made to have the lateral cross section of 450nm to achieve a Single TE mode operation. The buried SiO_2 layer has a thickness of 2µm. The WO_3 hydrogen sensitive material is prepared using the sol-gel method, and a layer of a few microns is drop coated on the top SiO_2 cladding [4].

The ethanolic ZnO nanoparticle suspension used for making the sensitive film is prepared through a low temperature synthesis technique [6]. An nLof AZ 2070 negative photoresist patterns on microring resonators are prepared using 365nm optical lithography. 100- 200ul of the ZnO solution is drop coated on the patterned sample and left in air for about 20 minutes to dry. The photoresist is finally removed by using standard lift –off in an NMP solution.

4. Results

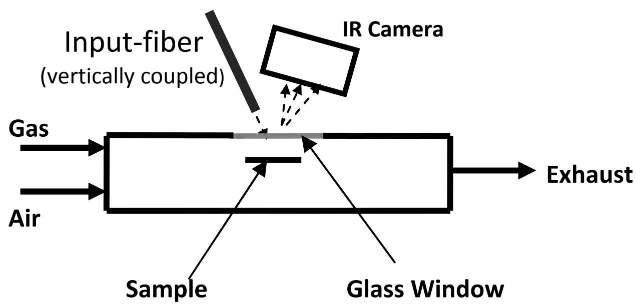

Fig 1 measurement setup

Figure 1 shows the measurement setup used for characterizing our sensors. The sensing samples are kept in a gas chamber sealed by a transparent glass window. An infrared light from a tunable laser is coupled to the sensor through the glass window by aligning an optical fiber vertically to a grating coupler on the chip. The light from the output grating couplers is collected by an infrared camera focused through the glass window.

A slight heating above the room temperature is required for the hydrogen sensor to facilitate the exothermic reaction between the hydrogen and oxygen in the air. Heating to 40˚C is achieved by shining a light from an ordinary halogen lamp. The ethanol sensor is operated at room temperature.

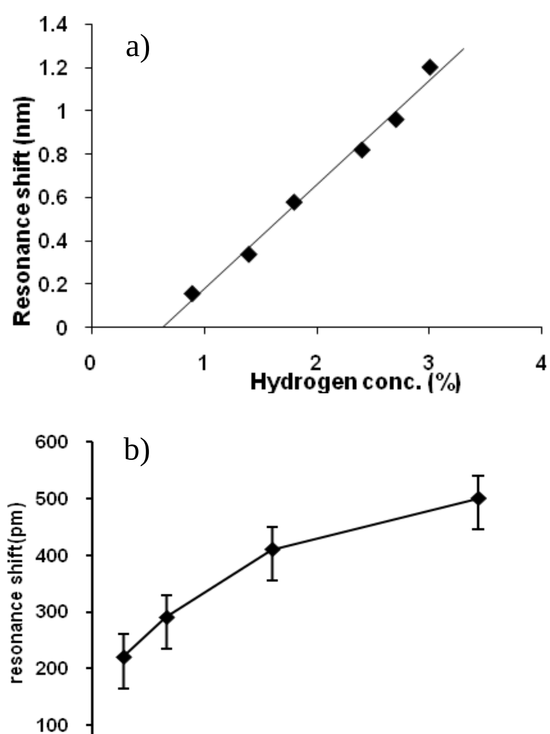

Fig 2a) measured response from the hydrogen sensor, b) measured response from the ethanol sensor

Figures 2(a) and (b) show the experimental results obtained from the hydrogen and ethanol sensors, respectively. Resonance wavelength shifts higher than one nanometer are achieved for hydrogen concentrations below the LEL. A fairly linear resonance shift of around 480pm per %H2 within an accuracy of +/-60pm is achieved. More noticeably, a 1.2nm resonance shift is measured for 3% hydrogen in air.

High sensitivity to ethanol vapors has been achieved with the porous ZnO coated ring resonator. Ethanol concentrations below 150ppm have been detected.

5. Conclusions

Optical structures fabricated on a CMOS compatible SOI technology provide promising platform for integrated gas sensor implementation. With the aid of gas selective chemical coatings on the SOI circuits, compact and very sensitive gas sensors can be realized on an optical chip. Using this technique, highly sensitive integrated optical hydrogen gas, and ethanol vapor sensors are demonstrated on SOI microring resonators.

6. References:

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