Read-out of a microring resonator based gas sensor with an on-chip spectrometer

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The interest for energy efficient, portable, and low cost sensors has always been increasing in a wide range of industrial, biomedical, environmental and scientific applications. In this respect, CMOS fabricated micro-optical bio-chemical and gas sensors present themselves as highly promising alternative sensor technologies. In this work, we demonstrate an on-chip interrogated microring resonator based optical ethanol vapor sensor. The microring resonance shifts upon interaction with ethanol vapor. We interrogate the resonance shift by monitoring the intensity ratio between adjacent channels of an Arrayed Waveguide Grating which is coupled to the sensor on the same chip. 100 – 1000ppm ethanol vapor concentrations are detected with this scheme.

Introduction

Recent advancements in integrated photonic structures and device fabrication have opened opportunities for new technologies solutions in various industrial, environmental and medical applications. Silicon photonic devices in particular are highly attractive owing to features such as compatibility with CMOS fabrication technology, high compactness, multiplexing capabilities and potential for low power operations. Integrated bio-chemical and gas sensing is one of the areas where photonic sensors fabricated on silicon on insulator platform have recently drawn a considerable interest. Exploiting the benefits of the well-established CMOS fabrication technology, and the high index contrast material system, Silicon-on-Insulator (SOI) micro-optical sensors are highly promising for ultraportable and low cost sensor implementation. SOI microring resonators (MRRs) in particular are very attractive for sensing due to features such as high sensitivity to the surrounding refractive index variations, readiness for wavelength multiplexing, and compactness [1,2]. On the other hand, despite the considerably promising potential, some technological issues are yet to be addressed so as to ensure the feasibility of MRRs for sensing applications. Currently, expensive tunable laser light sources or spectrum analyzers are often used to operate and interrogate MRR based sensors[1,2]. A promising solution to such an issue is the use of on-chip spectrometers along with cheap broadband light sources instead of tunable lasers. Integrated Planar Concave Gratings (PCGs) and Array Waveguide Gratings (AWGs) have been widely studied and used for wavelength division multiplexing applications [3]. In contrast to PCGs, narrow channel spacing AWGs can be realized on much smaller footprints on an SOI platform [3]. Different techniques based on AWGs have been recently reported for wavelength shift interrogation in Fiber Bragg Grating sensors [4,5]. The application AWG interrogation for on-chip sensors such as ring resonators has not been yet demonstrated. In this paper, we demonstrate that a 1.6nm channel spacing AWG with broad spectral response can be used to interrogate very sensitive MRR based gas sensors. The AWG used in this work takes a footprint of

500µm x 200µm and is fabricated on a chip which also contains the MRR sensor. We use this AWG to interrogate our recently reported MRR based ethanol vapor sensor [2]. Ethanol vapor concentrations ranging from 100ppm to 1000ppm are readily monitored with our sensor–interrogator system by measuring the intensity ratios between adjacent AWG channels

Interrogation scheme

In an AWG-interrogated MRR sensor configuration, the drop port of the microring resonator is connected to an AWG input port. The AWG is designed such that its adjacent output channels overlap significantly, so the MRR resonance will consequently be detected at any two of such overlapping channels. Ultimately, the variations in the intensity ratio between the adjacent channels can indicate the MRR resonance shift due to environmental effects.

Design and fabrication

In an AWG-interrogated MRR sensor configuration, the drop port of the microring resonator is connected to an AWG input port. The AWG is designed such that its adjacent output channels overlap significantly, so the MRR resonance will consequently be detected at any two of such overlapping channels. Ultimately, the variations in the intensity ratio between the adjacent channels can indicate the MRR resonance shift due to environmental effects.

For wavelength shift interrogation, fairly sharp response is required while maintaining an adequate channel overlap. In such an application, a simple broad input waveguide can be used to obtain broader channel profiles. In this work, a 16 channel, 200GHz (1.6nm channel spacing), AWG is designed such that the output from a 5µm radius MRR drop port overlaps with any two adjacent channels. For this particular sensor interrogation application, an adiabatically tapered input waveguide with start width of 0.45µm and a broader end width of 4µm is chosen in order to broaden the channel response, and hence, enhance the overlap between adjacent channels.

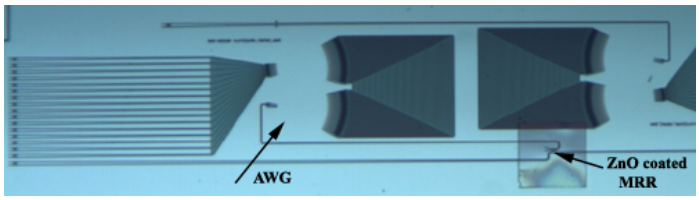

Fig. 2. An optical microscope image of the AWG interrogated ethanol vapor sensor with ZnO porous film on the MRR. The AWG used for the spectral response characterization is partially shown in the image.

The device is fabricated in a CMOS fab using 193nm deep UV lithography as detailed in [3]. To add gas sensitive functionality to the device, about 240nm thick porous ZnO film is locally coated on the MRR. The ZnO film is prepared from colloidal nanoparticles suspended in ethanol. The porous nature of the film offers a large surface area for gas adsorption. The detailed nanoparticle synthesis and sensitive film preparation procedures are presented in [2]. Fig. 2 shows an optical microscope image of the fabricated AWG interrogated ethanol vapor sensor. For the purpose of

preliminary studies on the AWG channel response, an additional AWG is fabricated on the same chip without a ring attached to it.

Experimental results

In an AWG-interrogated MRR sensor configuration, the drop port of the microring resonator is connected to an AWG input port. The AWG is designed such that its adjacent output channels overlap significantly, so the MRR resonance will consequently be detected at any two of such overlapping channels. Ultimately, the variations in the intensity ratio between the adjacent channels can indicate the MRR resonance shift due to environmental effects.

The spectral response from an AWG with a 4µm input waveguide measured with an SLED and a spectrum analyzer is shown in fig. 3. The transmission is normalized to that of a 450nm wide photonic waveguide on the same chip. The insertion loss for the central channels is about -3dB, and the nearest neighbor cross talk is around -17dB, which is of a typical order for such compact SOI AWGs. Notably, a strong overlap between neighboring channels is achieved. The 3dB bandwidth of a channel response is approximately 2.3nm with over 0.9nm overlap with channels at either side.

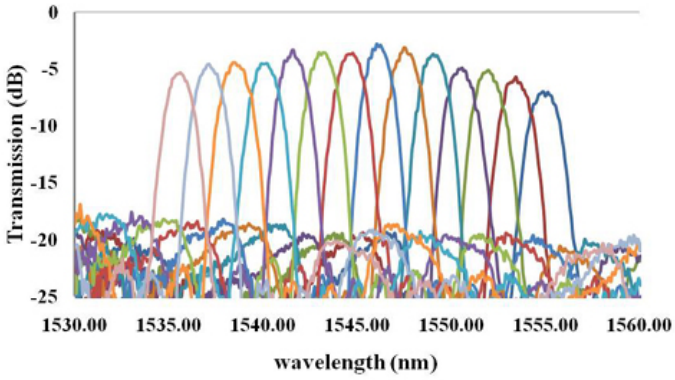

Fig. 3. Normalized transmission spectrum of an AWG with 4µm wide input waveguide

In the eventual sensing system, the broadband source and the detectors will be co-integrated with the sensing chip. However, for the present experiment the sensing chip is placed in a small gas chamber and the light source and the detector were kept outside. Vertical coupling through gratings is used to couple light in and out of the sensor. The top side of the gas chamber is covered with a glass window to facilitate the coupling. While a single mode fiber is used for in-coupling, the output light is collected by an Infrared Camera. Further details on the setup are presented in [3]. The measurement accuracy of this setup is highly influenced by the noise due to the light which is scattered from the sample surface and reaches the camera. Due to the typically low power spectral density of a broadband source, we have chosen to use a tunable laser source of about 3mW to couple sufficient light through the glass cover. Operating at such low powers reduces the noise on the camera measurement and allowed us to characterize the device in a gas environment.

The output intensities from three consecutive AWG channels are simultaneously monitored before and after exposure to 120ppm, 240ppm, 480ppm and 960ppm ethanol vapor concentrations. The average intensity measured from each channel is then used to calculate the fractional intensity between adjacent channels at a given gas concentration. To better visualize the relation between the resonance wavelength and

the intensity ratios, the resonance shifts at these vapor concentrations are recorded from the MRR through-port. Fig. 4(a) depicts the average channel intensities as a function of vapor concentration, and figure 4(b) shows the intensity ratios calculated at the corresponding measured resonance shifts. The solid curve in figure 4(b) is an exponential fit to the ratios between channels 2 and 3.

As observed in fig. 4, fairly smooth transition from a pair of adjacent channels to the next pair is readily achieved signifying a good overlap between neighboring channels. More interestingly, the third channel emerges to take part in the play as the intensity ratio between the first two channels begins to fall below 0.2, which is comparable with the simplified theoretical estimate for a 2nm FWHM AWG as shown in fig. 1. The FWHM of the resonance measured at the MRR through port is less than 50pm. While our on-chip sensor-interrogator system is very suitable for highly sensitive gas sensors as demonstrated in this work, it can also be used to detect small resonance shifts. From the trend shown in fig. 4(b), resonance shifts ranging from 50pm to 800pm should be readily interrogated with the ratio between just two channels.

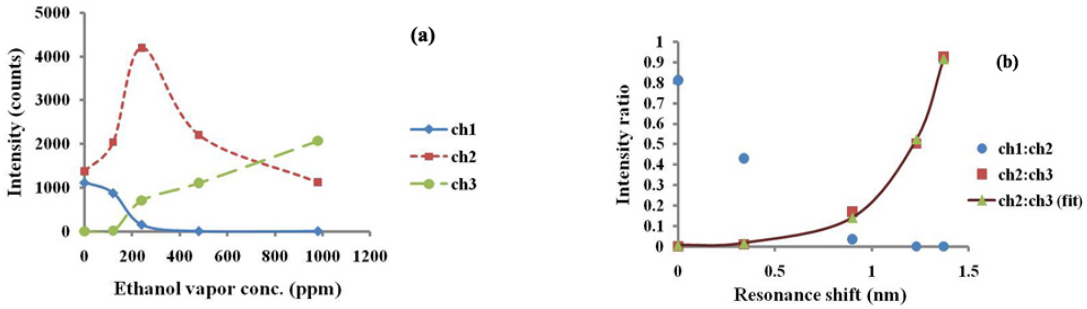

Fig. 4. (a) average intensities measured from three channels at different ethanol vapor concentrations, (b) calculated intensity ratios as a function of resonance shifts corresponding to vapor concentrations shown in fig (a) with an exponential fit to ch2:ch3 (solid line)

Conclusions

We demonstrate that a compact on-chip AWG spectrometer can be used to interrogate resonance shifts from MRR sensors. An SOI MRR ethanol vapor sensor is interrogated by a 200GHz AWG designed to have strongly overlapping output channels. Such an on-chip interrogation system presents itself as an attractive solution to the current interrogation challenges, and opens opportunities for low cost and compact implementation of MRR based sensors

References

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