Compact On-chip Multiplexed Photonic Gas Sensors

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Abstract: A compact resonator-based integrated photonic sensor for the detection of multiple gas analytes with high resolution is demonstrated. On-chip referencing is employed to compensate for environmental effects and laser instabilities to achieve high accuracy. OCIS codes: (280.4788) Optical sensing and sensors; (140.4780) Optical resonator

Integrated photonic microresonator gas sensors have attracted a lot of attention for their high sensitivity, fast response, and ease of implementation [1-3]. The incoming gas analyte is detected via the refractive index change induced by the diffusion and adsorption of the gas molecules. Unlike their counterpart in biosensing applications, typical polymer-coated gas sensors suffer from a lack of selectivity and specificity. To resolve this issue, an array of different polymers must be used to form a response matrix, as is widely done in the electronic nose technology [4] and recently demonstrated in micro-gas chromatography [5]. By carefully selecting a set of polymers with diverse properties, a response matrix with each row representing a unique signature for a certain gas analyte can be obtained. After obtaining this response matrix during data calibration, not only can the gas sensor identify a single unknown incoming analyte, it can also potentially quantify a mixture of gas analytes. To simultaneously read the response from various polymers, an array of microring resonators is needed, where each of them is functionalized with a different polymer. Moreover, the radius of each microring resonator has to be small to increase the total number of resonators involved [6,7], leading to a large rank of the response matrix and hence better selectivity of the photonic gas sensor.

In the integrated photonic gas sensor demonstrated in this paper, a total number of six resonators with slightly different resonance wavelengths are used. Four of these resonators are used as sensing elements and thus are covered by functional polymers. The polymers are applied with a commercial inkjet printer using a 50 um diameter nozzle (Microfab Jetlab II). Since the microring resonators on a silicon-on-insulator (SOI) substrate are very sensitive to temperature [8] and other environmental variations, the other two resonators are used as on-chip reference to calibrate the measurement data. The on-chip reference resonators are covered with SU-8 that is inert and impermeable to compensate for the effects of temperature variation and other environmental influences as well as any drift in the wavelength of the interrogating laser source [9].

To achieve high sensitivity, the microring resonator is designed to support a high quality factor (high-Q) TM-polarized mode. The device layer is a 250 nm-thick silicon (Si) film, with a 1 µm thick buried oxide layer underneath. The SEM image of an individual sensing resonator is shown in Fig. 1(a), where the outer radius of the microring resonator is ~ 4.3 µm to achieve a large free spectral range (FSR) while still maintaining a high loaded Q of ~ 40,000. The inner radius of the microring is ~ 3.6 µm to ensure single-mode operation.

The fabricated device is treated with a fluorosilane layer to increase its hydrophobicity before the polymer drop coating step. As is shown in Figs. 1(b) and (c), the fluorosilane treatment helps to remove the unwanted coffee ring effect and reduce the size of the polymer after evaporation of the solvent. This step significantly improves the repeatability and quality of the polymer coating. Fig. 2(a) is a micrograph of the multiplexed gas sensor. In this study, resonators #1, #3, #4, and #6 are the four sensing resonators, which are coated with Poly(4-vinyl phenol) or PVP, Poly(vinylidene fluoride) or PVF, Poly(Vinyl acetate) or PVA, and a triptycene polyimide (polymer TPI in [10]), respectively. The solvent used in this study is dimethyl sulfoxide (DMSO). Resonators #2 and #5 are used as on-chip reference resonators to neutralize the temperature and other environmental effects, which help to achieve a wavelength measurement accuracy of ±1 pm [7].

Figure 1 (a) SEM of a single microring resonator; (b) pattern of dried PVP on substrate without fluorosilane treatment, where a coffee ring effect is clearly observed; (c) pattern of the dried PVP on substrate treated with fluorosilane.
The transmission spectrum of the gas sensor is shown in Fig. 2(b). Each resonance is labeled with its corresponding resonator number. The spacing between two neighboring resonances of resonator #5 is ~23 nm, which agrees well with the theoretical calculations of the FSR. The sensor is then integrated with a customized glass chamber and tested with gas analytes. Four volatile organic compounds, isopropanol (IPA), methanol, benzene and acetone, were tested with the four selected polymers. The response pattern of the four analytes with respect to the four specified polymers is shown in Fig. 3, showing the normalized resonance wavelength drifts when each of the saturated gas analytes is injected. This data clearly shows the diversity in the response of the different polymer coatings to the different gas analytes. Further tests with additional polymers and target gas analytes are ongoing and a detailed discussion will be covered in the conference.

Figure 3 Normalized response patterns of the four test gas analytes with respect to the four polymers.

References