Highly Sensitive and Fast Responsive Photonic Integrated Relative Humidity Sensor using Porous SiO_2 Cladding

Student Paper

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ABSTRACT

Silicon dioxide (SiO_2) surface is known to be hydrophilic in nature. By increasing the porosity of SiO_2 thin layers, one can realize a much larger surface area to trap a significantly larger amount of water. Exploiting these effects, a micro-ring resonator (MRR) based photonic integrated relative humidity sensor with a porous SiO_2 cladding is demonstrated. The MRR easily tracks a 30 – 70 % relative humidity change (with a respective 3 nm resonance shift) and a linear operation region is observed between 30 – 55 %. Time-resolved humidity measurements indicated the highly sensitive and fast responsive nature of this sensor compared to a commonly used electronics-based sensor.

Keywords: Humidity, sensor, photonic, integrated optics, micro-ring resonator.

1. INTRODUCTION

Measurement and accurate control of humidity are much needed in agriculture, food storage, medical, drug production and process industries such as semiconductors and automotive [1]. Such a sensor implemented with optical and photonic integrated devices can potentially offer advantages like small form-factor, lightweight, high sensitivity and immunity to electromagnetic interference [2]. Materials such as $CoCl_2$, polyvinyl alcohol, sol-gel silica that naturally adsorbs water from ambient conditions have been used as a cladding material for realizing photonic relative humidity sensors [2]–[4]. In this work, a new technique for realizing a photonic integrated relative humidity sensor is demonstrated using porous silicon oxide (SiO_2) which has been previously studied for its water adsorption property at the surface [5]. The porous cladding layer results in increased surface areas and hence increased trapped water content yielding higher sensitivity [6]. Using these two effects, a novel photonic relative humidity sensor is demonstrated that presents high sensitivity (>75pm/%) and fast response (<2 sec) properties. This demonstrated technique offers a pathway towards highly sensitive photonic integrated relative humidity sensor using low-cost foundry friendly material that is also suitable for flexible substrates due to low-temperature deposition conditions.

2. DEVICE FABRICATION

For probing the changes within the cladding layer due to water absorption, a highly sensitive micro-ring resonator (MRR) was used that was fabricated using hydrogenated amorphous silicon (a-Si:H). The a-Si:H layer of 210 nm thickness was deposited at 80 °C by inductively coupled plasma-enhanced chemical vapor deposition (ICP-PECVD) technique [7]. The MRR radius was 25 μm and consists of *a*-Si:H waveguide that is 480 nm in width by 210 nm in height. The SiO_2 cladding was deposited using an ICP-PECVD system with a deposition temperature of 80 °C. The thickness of the deposited SiO_2 cladding was 300 ± 5 nm. And the refractive index determined using spectroscopic ellipsometry measurement was n=1.388 ± 0.015 at 1550 nm indicating the porous nature of the material.

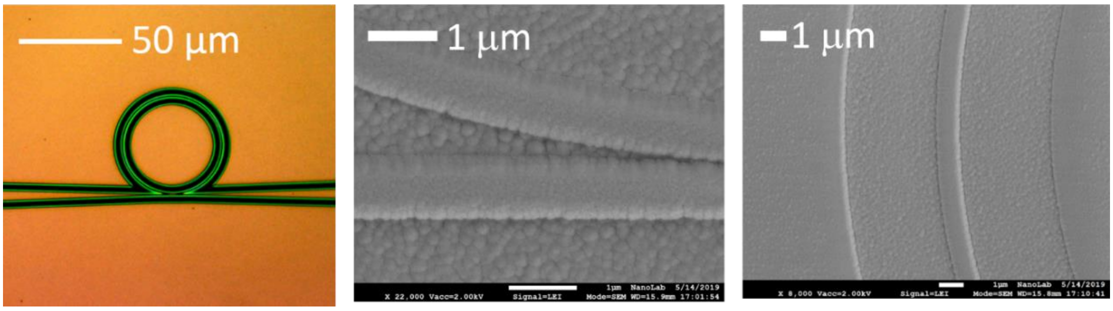

Figure 1. The optical microscope image of the fabricated a-Si:H MRR (left) scanning electron microscope (SEM) image of the MRR waveguide sections with porous SiO_2 cladding (middle and right).

3. RESULTS AND DISCUSSION

The fabricated device was tested in a humidity-controlled chamber with relative humidity conditions varying between approximately 30 - 70 %. In the following figure, the MRR response shift with respect to relative humidity conditions is reported. It is clearly shown that the MRR without cladding was minimally responding to the changes in the relative humidity. While the device with approximately 300 nm thick SiO_2 cladding was responding very well to changes in relative humidity. Between 30 – 55 % the changes are seen to be linear, while the resonance shift tends to be saturated until the increase of the relative humidity up to 70%. It is important to note that, the redshift of the resonance was observed, which indicates an increase of the effective refractive index as a result of water loading within the porous network. During this experiment, the temperature changed between 24.9 to 25.6 °C, which is not expected to affect the resonance much since the device sensitivity to temperature was determined to be 79.5 pm/°C.

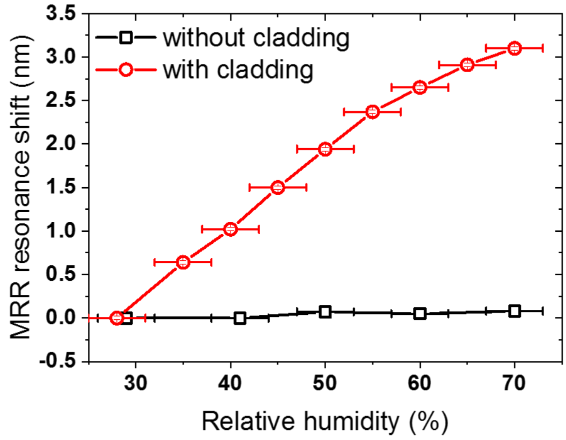

Figure 2. MRR resonance shift with respect relative humidity for MRR with and without porous SiO_2 cladding.

The sensitivity of the device was examined with a commercially available electronics-based relative humidity sensor, DHT22 as the humidifier was abruptly turned ‘ON’ and ‘OFF’ (Figure 3). The DHT22 sensor was interfaced with an Arduino Uno to act as a real-time relative humidity and temperature logger. Data were collected every 2 seconds.

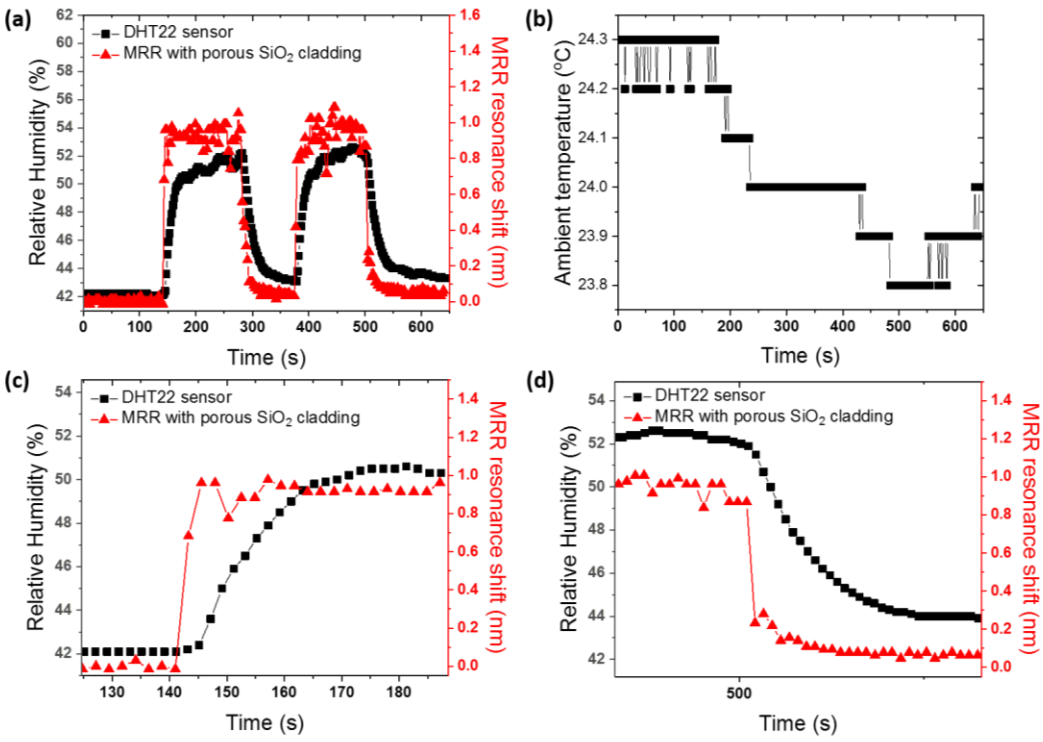

Figure 3. (a) Dynamic response comparison between the MRR with porous SiO_2 cladding and DHT22. (b) Recorded ambient temperature during the experiment. (c) The rise time and (d) the fall time comparison between the MRR with porous SiO_2 cladding and DHT22.

The MRR cladded device showed a stable response initially just as the DHT22. Turning 'ON' and 'OFF' the humidifier triggered both devices. As the relative humidity was changed by 10%, the MRR response red-shifted by approximately 1 nm as shown in Figure 2. During the experiment, the ambient temperature was quite stable as shown in Figure 3 (b). It is worth noting that the MRR device holder temperature was TEC controlled. Therefore, temperature affecting the photonic device response can be considered negligible. Careful inspection of the rise time and fall time for both devices clearly indicate that the MRR is very fast in responding to the changes in the relative humidity compared to DHT22. Also, MRR with porous SiO_2 cladding tends to saturate faster compared to DHT22. In addition, it was also found that the sensor can be used to probe alcohol based substances in the ambient. In Figure 4(left), the test setup is shown with the photonic chip and DHT22 sensor. Few drops of 2-propanol are left to evaporate nearby as shown in the figure. While the DHT22 response remained fairly constant, the response of the porous SiO_2 cladded MRR shifted every time 2-proponol drop was placed until it completely evaporated. This was reproduced several times as shown in Figure 4(right).

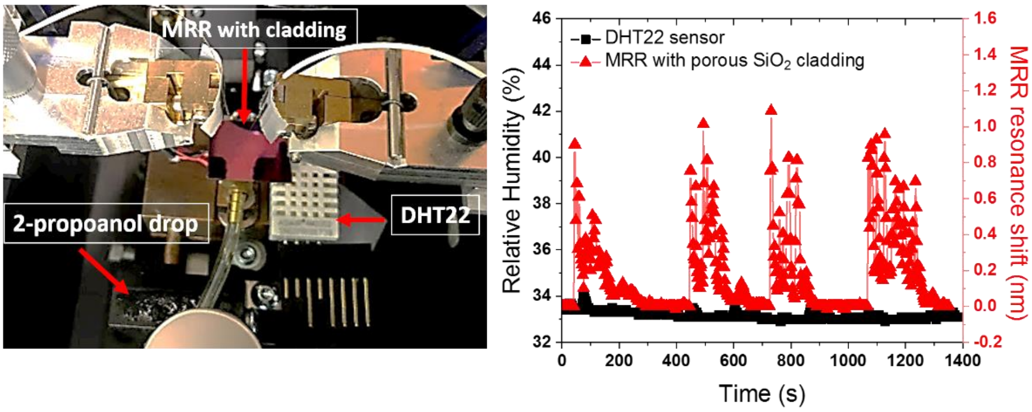

Figure 4. Sensitivity to 2-propanol presence, the verticle coupling setup with 2-propanol drop (left) and the measured response (right).

4. Conclusions

Porous SiO_2 attracts water from ambient humid conditions [5], [6]. By cladding a micro-ring resonator with this material, it is possible to sense the changes in the ambient relative humidity. It was found that the response change of the device to the relative humidity device is linear between 30 - 55 % according to the measurements. However, the most important attribute is perhaps the highly sensitive and fast-responding nature of this device, compared to a commonly used electronics-based sensor. Therefore, this technique can be suitable for application areas where small changes in humidity conditions are needed to be identified in a fast manner. Finally, the technique can be suitable for sensing other substances in the ambient as well. However, this needs further elaborate research work to understand the complete scope of this sensing material.

ACKNOWLEDGEMENTS

We thank Dr. Aaron Albores Mejia for arranging the access to the humidity control chamber and facilitating the measurements at Effect Photonics B.V.

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