Sol-Gel Imprint Lithography for Guided Mode Resonance Structures

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Abstract: A sol-gel based imprint lithography process has been developed to fabricate guided-mode resonance (GMR) structures. The inexpensive process offers a rapid means to create sub-micron grating waveguide structures over large surface areas. Both one-dimensional and two-dimensional GMR devices have been successfully fabricated and characterized.

1. Introduction

Guided mode resonance (GMR) structures consisting of sub-wavelength gratings exhibit narrowband optical resonances in a broad range of optical spectrum [1]. Undergone rapid technical developments, GMR-based devices have been found useful for widespread applications [2, 3]. The existing methods to fabricate a sub-micron GMR structure include e-beam lithography, interference lithography, and nanoreplica molding. These methods require additional processes following the lithography, such as a dry etching or a thin film coating. The sol-gel method is known for producing solid metal oxides from liquid precursors and it has been used to fabricate nanoscale features [4]. This paper demonstrates a sol-gel imprint lithography method for the fabrication of 1D and 2D GMR structures. Here, the sol-gel TiO_2 material was chosen due to its relatively high refractive index. The sol-gel based approach offers several advantages, including: simplicity, low cost, tuning of resonance, and the potential to incorporate optically active dopants in the GMR waveguide.

2. Sol-gel based fabrication process

The sol-gel imprint process starts with preparing the TiO_2 sol-gel solution following the procedure shown in [5]. Tetrabutylorthotitanate (TBT) and ethanolamine (ETA) were dissolved in ethanol (EtOH) and stirred for two hours. Deionized water (H_2O) and ethanol were subsequently added into the mixture and the alkoxide solution was hydrolyzed at room temperature. The amount of each chemical in the solution was TBT:ETA:EtOH:H_2O = 1.2:2:32:1.3 in molar ratio. As shown in Fig. 1(a) - (c), the sol-gel solution was spun onto the polydimethylsiloxane (PDMS) mold, which was replicated from the silicon template with the desired grating structure. Next, the sol-gel coated PDMS mold was pressed against a glass coverslip and baked at 200 °C under a pressure of 50 kPa. After baking, the PDMS mold was peeled away and the sol-gel GMR structure preferentially remained on the coverslip.

The scanning electron microscope (SEM) images in Fig. 2 (a) - (c) show the fabricated 1D and 2D GMR structures. The grating period (Λ), depth (d_w), and waveguide layer thickness (h_w) of the 1D GMR structure are 400 nm, 80 nm, and 130 nm, respectively. The 2D GMR structure has a period of 500 nm and a depth of 150 nm. Fig. 2 (d) is a photograph of the 1D GMR.

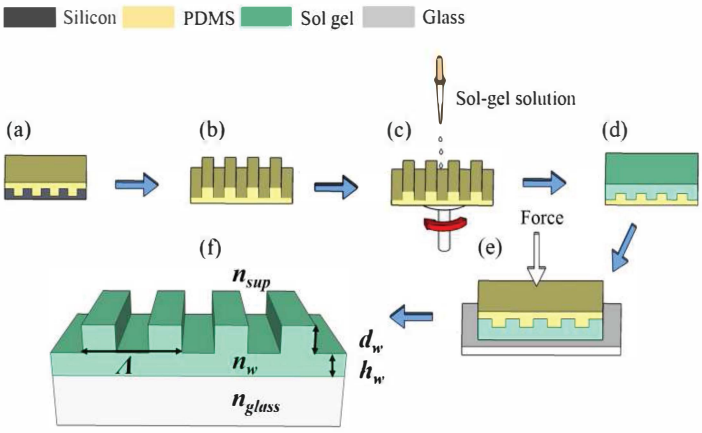

Figure 1. Process flow diagram for the sol-gel GMR structure. Schematic diagram of the 1D GMR shown in (f), where h_w and d_w represent the thickness and depth of the grating waveguide. The n_w, n_{sup}, and n_{glass} are the refractive indexes of sol-gel material, superstrate, and substrate, respectively.

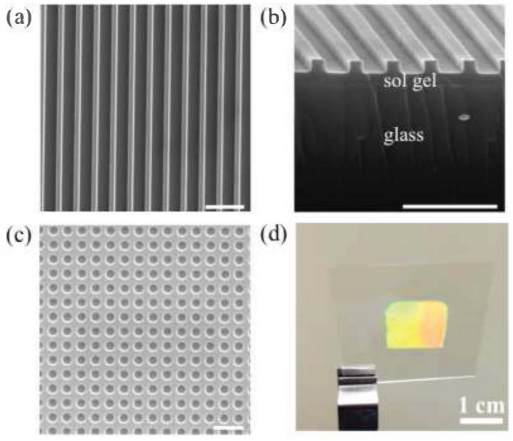

Figure 2. SEM images of the 1D GMR (a) top view and (b) cross sectional view. (c) SEM of the 2D GMR structure. (d) Photograph of the 1D GMR. (Scale bar: 1 μm).

3. Results and discussion

The fabricated GMR devices were characterized by measuring their far-field reflection spectra. The reflection spectra were obtained from the devices under the normal incidence of white light. For the 1D GMR device, both TE-polarized (electric field is parallel to the grating) and TM-polarized (electric field is perpendicular to the grating) modes were measured. The measured reflection spectra for the 1D and 2D GMR devices are shown and compared with simulation results obtained using rigorous coupled wave analysis in Fig. 3.

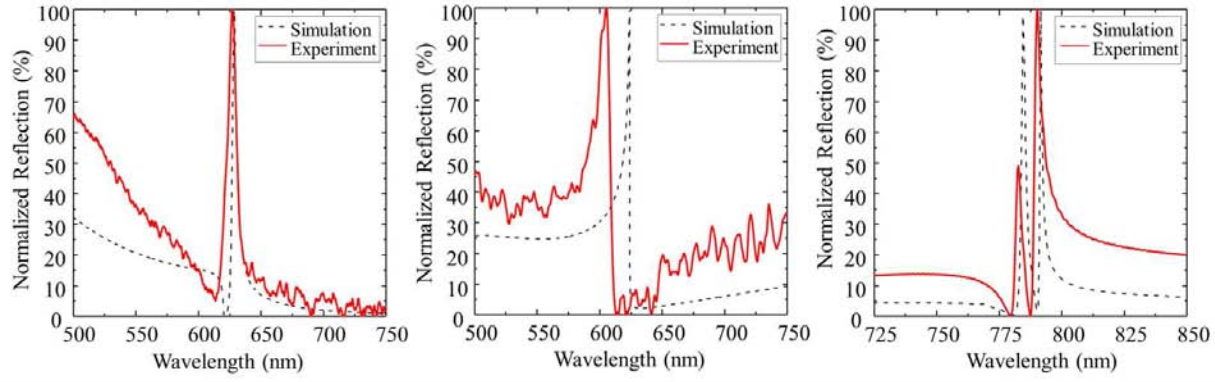

Figure 3. Simulated and measured reflection spectra from the 1D GMR device for a TE-polarized (a) and a TM-polarized (b) white light. (c) Simulated and measured reflection spectra from the 2D GMR device.

An interesting feature of the sol-gel GMR device is its tunability. During the fabrication, varying the spin speed resulted in different waveguide layer thicknesses. Fig. 4 (a) shows the change of resonant wavelength in a range of 30 nm by increasing the h_w. The resonant wavelength of a sol-gel 1D GMR device can also be tuned by changing the superstrate material (n_{sup}) as shown in Fig. 4 (b). As a refractometric sensor, the fabricated GMR device exhibits a bulk index sensitivity of $S_b = \Delta\lambda/\Delta n \sim 50$ nm/RIU. We also used the 1D GMR device to monitor the deposition of a monolayer of polypeptide (poly (Lys, Phe)) in real time. Fig. 4 (c) shows the time evolution of the resonant wavelength during the polypeptide deposition.

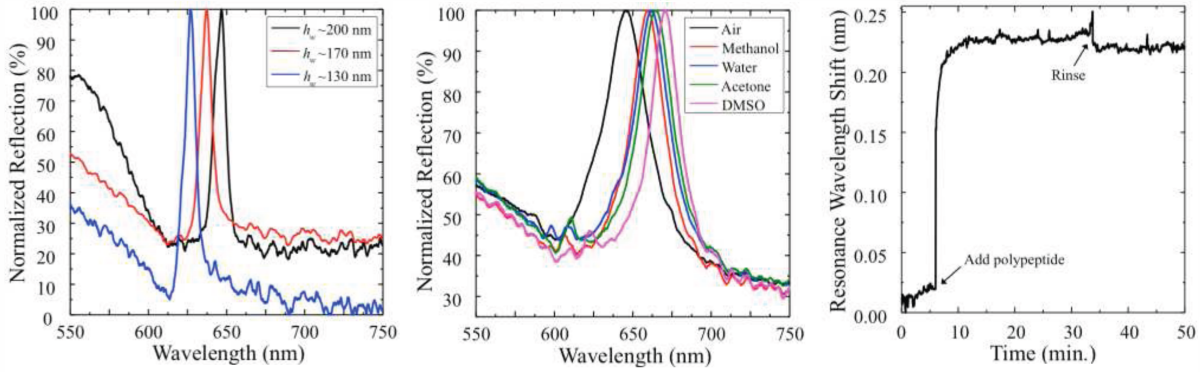

Figure 4. (a) Reflection spectra of 1D GMR devices with the waveguide layer thicknesses of 130, 170, and 200 nm, respectively. (b) Reflection spectra of a 1D GMR device immersed in different superstrate materials (air, methanol, water, acetone, and DMSO with refractive index of 1.0, 1.327, 1.333, 1.359, and 1.359, respectively. (c) The temporal shift of the resonant wavelength during the deposition of poly (Lys, Phe).

Reference:

[1] S. S. Wang, R. Magnusson, J. S. Bagby, and M. G. Moharam, "Guided-mode resonances in planar dielectric-layer diffraction gratings," *JOSA A.,* vol. 7, pp. 1470-1474, 1990.

[2] T. Sorin, R. Magnusson, T. A. Maldonado, P. P. Young, and T. R. Holzheimer. "Dielectric frequency-selective structures incorporating waveguide gratings." *IEEE. Trans. Microw. Theory. Tech.,* vol. 48, pp. 553-561, 2000.

[3] C. Brian, J. Qiu, P. Li, and B. Lin, "Enhancing the surface sensitivity of colorimetric resonant optical biosensors," *Sens. Acurator B Chem.,* vol. 87, pp. 365-370, 2002.

[4] P. Christophe, V. Chauveau, E. Barthel, and E. Søndergård, "Nanoimprint lithography on silica sol-gels: a simple route to sequential patterning." *Adv. Mater.,* vol. 21, pp. 555-558, 2009.

[5] R. Kyung-min, K. Yang, H. Lee, and H. Kim. "Formation of TiO_2 nanopattern using reverse imprinting and sol-gel method." *J. Vac. Sci. Tecnol., B,* vol.27, pp. 2810-2813, 2009.