Fabrication of Grating Couplers and Optical Waveguide Sensors

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Introduction:

Interest in chemical sensors has been rapidly increasing due to the need for a low cost, high sensitivity, and portable sensor that could provide a rapid response for detecting different chemicals and biological agents. In the past, different techniques and methods have been investigated in order to create real time sensors, such as acoustic wave-based devices, magnetoelastic sensors, electrochemical sensors based on conductometric or impedance methods, and optical sensors [1].

Optical systems are one of the most accepted techniques in order to perform detection of chemicals. The main reasons behind their popularity are the simplicity of the fabrication methods and the many different environments in which they can be used [2]. Several optical sensors are based on measuring changes in the index of refraction of a sensing material as analytes are adsorbed. Different methods using optical sensors have been reported. Ymeti *et al*. proposed a technique using interferometry in order to detect herpes simplex virus type 1. This method offers a rapid approach that increases the sensitivity and selectivity previously reported by other groups.

In this work we describe a novel method for fabricating grating couplers and optical waveguides that can be used as the base for an optical interferometric chemical sensor. This method is based on a technique developed previously [3], in which electron beam lithography (EBL) is used to create grating structures on a silicon substrate, which is then utilized as a template in order to transfer the pattern to a quartz substrate via imprinting and plasma etching. New findings suggest that the UV curable polymer that acted as an etch mask can be used directly as the substrate for the grating couplers, reducing the amount of steps in the fabrication process.

mr-UVCr06	Before	After
Index of Refraction	1.5355	1.5427
Film Thickness	216.26 nm	193.83 nm

Table 1: Measurements of mr-UVCur 06 before and after baking.

Materials And Methods:

In order to create the grating couplers and optical waveguides the fabrication process was divided into three main steps. The first step was to create the grating template on a silicon substrate using EBL, the second step was to imprint the grating structures into the UV curable polymer by using nanoimprint lithography (NIL). The last step was to deposit the silicon nitride waveguide by plasma enhanced chemical vapor deposition (PECVD). The deposition of silicon nitride is done at 300°C, and for this reason, a number of tests had to be performed prior to the fabrication of the device in order to determine if the transition temperature of the UV curable polymer was greater than the fabrication temperature.

UV Curable Polymer Evaluation:

An UV curable resist was purchased from Micro Resist Technology (mr-UVCur06). The UV curable resist was spun into a silicon wafer at 3000 rpm for 60 seconds. Next, the UV curable polymer was exposed to 365 nm light at room temperature for 75 seconds. The power density of the UV lamp used was 13 mW/cm^2. Subsequently, the substrate was baked in vacuum for 2 hours at 350°C. The thickness and index of refraction of the UV curable resist was measured before and after baking (Table 1).

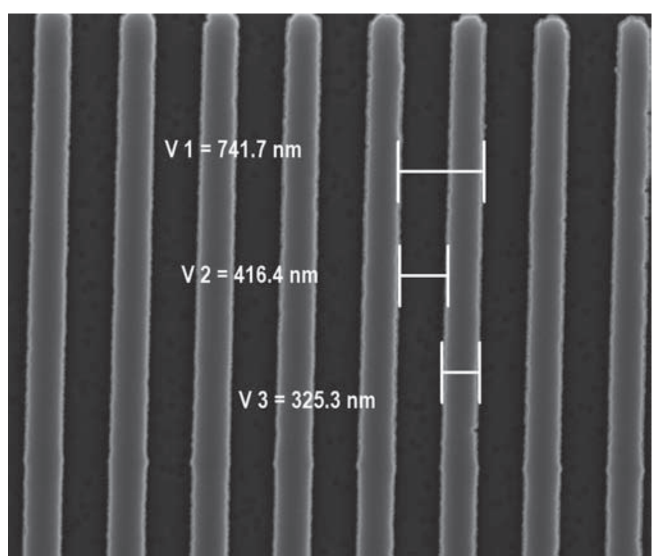

Figure 1: SEM image of the silicon template.

Fabrication Process:

A 4″ silicon wafer was patterned using a standard EBL process with hydrogen silsesquioxane (HSQ) as the resist. The etching was performed using the Plasmatherm ICP. Before use, the silicon template was dipped in hydrofluoric acid (HF) for 10 seconds in order to remove the native oxide layer. Subsequently, a fluorine based polymer was deposited by exposing the silicon template to C_4F_8 plasma for 30 seconds in the ICP (Plasmatherm). The fluorine based polymer acted as a release layer for the nanoimprint process. Figure 1 shows the final silicon template with the grating structures having a period of 740 nm. The depth of the gratings was measured to be 50 nm using an atomic force microscope.

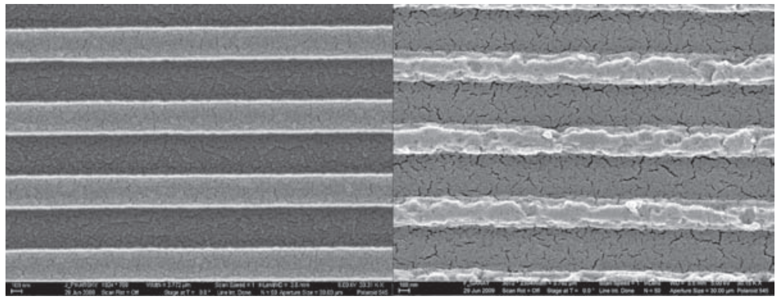

Figure 3: Pattern transfer improvement.

Fused quartz was used as the substrate for the nanoimprint step. The quartz substrate was cleaned by dipping it in sulfuric acid at 80°C for 1 hour. After rinsing the quartz with deionized water, it was baked at 200°C for 1 hour. Next, the UV curable resist was spun into the quartz substrate at 3000 rpm for 60 seconds. After this, the silicon template was placed on top of the quartz substrate and pressure was applied by hand in order to prevent them from separating. Next, they were placed on a hot plate at 85°C for 1 minute.

UV based nanoimprint lithography was performed using a commercial nanoimprinter (Obducat). The UV curable resist was imprinted by applying a pressure of 15 bars for 180 seconds at room temperature, followed by UV light exposure; the UV dose was 1000 mJ/cm^2. After release of the imprinted gratings, a 1500 Å layer of silicon nitride (Si_3N_4) was deposited by PECVD at 300°C.

Results and Discussions:

An improved fabrication process was developed in order to create grating couplers and optical waveguide using an UV curable polymer as the substrate. By using the new material as the substrate for the gratings, one third of the steps in the fabrication process (plasma etching and resist stripping) were eliminated, reducing time and cost of the fabrication.

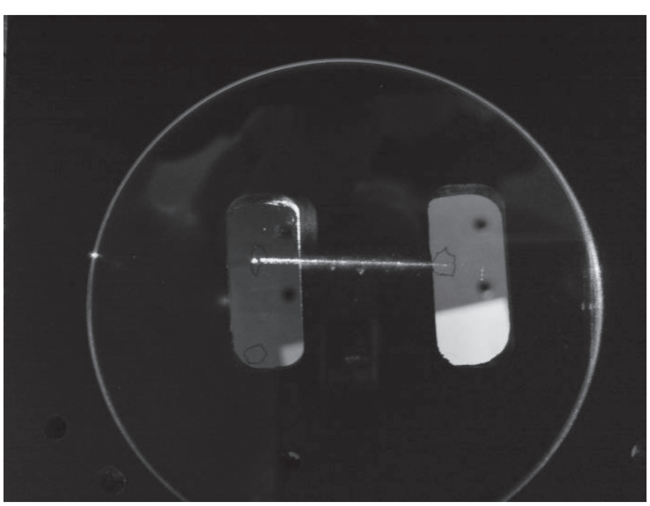

Figure 2: Optical image of final device.

Figure 2 shows an optical image of the grating couplers and waveguide guiding 633 nm light from a HeNe laser. Furthermore, transfer of the pattern into the UV curable polymer was improved by applying a thicker layer of a fluorine based polymer to the surface of the silicon template (Figure 3).

Additional testing is needed in order to obtain the coupling efficiency of the gratings and the optical intensity loss of the waveguide, but qualitative evidence so far indicates that devices made using this process will provide a viable alternative to the standard fabrication methods.

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References:

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