Refractive Index Sensor Based on Long-Range Surface Plasmon Polariton Waveguide

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Abstract Straight long-range surface plasmon polariton (LRSPP) waveguides are demonstrated as liquid refractive index (RI) sensors (Barnes et al. in Nat Mater 424:824–830, 2003, [1]). The sensors consist of 5 µm-wide, 20 nm-thick straight Au stripes that are embedded in ultraviolet (UV) sensitive polymer SU-8. The double layer liftoff fabrication is adopted to fabricate the embedded rectangular and smooth Au stripes. An etched microfluidic channel allows the contact of analyte to Au surface for RI detection. Within the range from 1.576 to 1.596, a sensitivity of 821 dB/RIU can be obtained. The proposed device has potentials in the portable and compact refractometer application.

Keywords LRSPP · Waveguide · RI sensor · Polymer · Lift-off

1 Introduction

Surface plasmon resonance (SPPs) is propagating modes existed at the interface between a metal and dielectric medium. Due to the characteristic of strong mode confinement, SPPs are very sensitive to the RI (RI) change near metal surface [1]. However, the high light absorption in metal leads to a high propagation loss. Therefore, long-range surface plasmon polaritons (LRSPPs) that are propagating plasmon waves excited on both sides of symmetrically embedded metal stripes are investigated [2]. To enhance the firmness and simplify the fabrication of LRSPP waveguide, we

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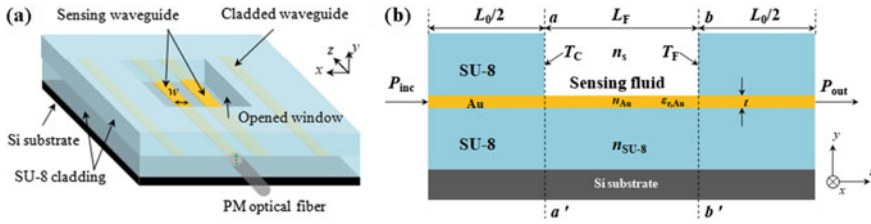Department of Physics, University of Ottawa, Ottawa, Canada

Fig. 1 Configuration of **a** three-dimentional illustration of the straight LRSPP waveguide RI sensor. A polarization-maintaining (PM) optical fiber is butt-coupled to the input of the waveguide to excite the LRSPP mode thereon, **b** longitudinal cross section of the straight LRSPP waveguide sensor

choose the ultraviolet (UV) polymer of SU-8 as the cladding material, which has good adhesion on silicon substrate without using hexamethyldisilazane (HMDS) excess layer. Its high glass temperature and resistance to the erosion of most solvents, such as acetone and isopropyl alcohol (IPA), promise good structural stability [3]. The smooth SU-8 film surface is also favorable to high quality metal layer deposition.

2 Device Design

The proposed straight LRSPP waveguide RI sensor is shown in Fig. 1. Straight Au stripe with the width $w = 5$ µm and thickness $t = 20$ nm is embedded in SU-8 claddings. The whole structure is supported by a silicon substrate. The thicknesses of upper and bottom claddings are both 5 µm. The microfluidic channel with length L_F is formed on the top of Au stripe by wet chemical etching. As measuring, the analyte with a RI of n_s that is around n_{su-8} fills the channel. The RI change above the straight Au waveguide will result in the variation of output optical power.

3 Experimental

The double layer liftoff fabrication flow is depicted in Fig. 2. Firstly, the 4 inches silicon wafer was cleaned. SU-8 2005 (MicroChem Corp., US) was spin-coated onto the silicon substrate as the bottom cladding. Then, SU-8 was prebaked at 65 and 95 °C for 5 and 10 min, respectively. After flush exposure at a UV dose of 100 mW, post-exposure bake was done at 65 and 95 °C for 10 and 20 min, respectively. Photoresist LOR-1A (MicroChem Corp., US) and MICROPOSIT S1805 (Shipley Corp.,) were directly spin-coated on the SU-8 bottom cladding and cured at 180 °C for 3 min, respectively. Waveguide patterns were transferred from the photomask to S1805 by UV photolithography. After development in MICROPOSIT MF-321 (Shipley Corp.,), a 20 nm-thick Au film was deposited by electron beam evaporation (Angstrom Co., CA). Thereafter, the liftoff process was done with two baths
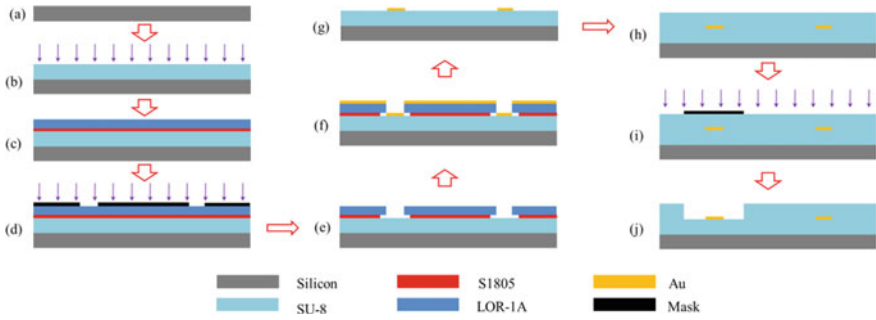
Fig. 2 **a** Preparation for silicon wafer, **b** spin-coating and prebake of SU-8 bottom cladding, **c** UV cure of SU-8 bottom cladding, **d** spin-coating and baking of bi-layer photoresist LOR/S1805 stack, **e** UV exposure and development, **f** Au film deposition by E-beam evaporation, **g** liftoff of LOR-1A and S1805, **h** spin-coating and solidification of SU-8 upper cladding, **i** UV photolithography and fluidic channel etch, **j** spin-coating of SPR 220 resist

of Remover PG (MicroChem Corp., USA) at room temperature. Finally, the SU-8 microfluidic channel was formed by UV photolithography and wet chemical etching.

The fabricated Au stripe was characterized by atomic force microscope (AFM) NX10 (Park Corp., ROK), as shown in Fig. 3. It can be seen that root mean square roughness of Au stripe is 1.470 nm and the roughness of SU-8 is 0.772 nm. The remains left on Au stripe surface can be removed by further oxygen plasma cleaning.
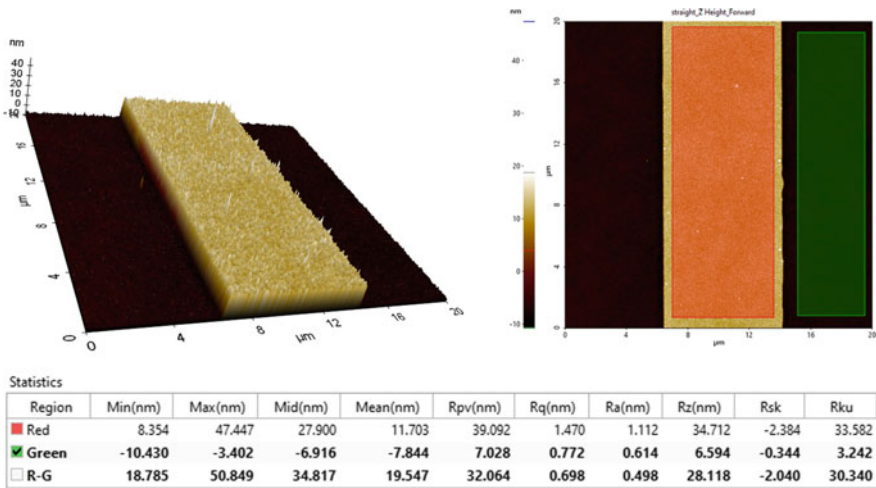

Statistics

Region	Min(nm)	Max(nm)	Mid(nm)	Mean(nm)	Rpv(nm)	Rq(nm)	Ra(nm)	Rz(nm)	Rsk	Rku
■ Red	8.354	47.447	27.900	11.703	39.092	1.470	1.112	34.712	-2.384	33.582
☑ Green	-10.430	-3.402	-6.916	-7.844	7.028	0.772	0.614	6.594	-0.344	3.242
☐ R-G	18.785	50.849	34.817	19.547	32.064	0.698	0.498	28.118	-2.040	30.340

Fig. 3 AFM image of fabricated Au stripe on SU-8 surface

4 Results

The RI sensing performance was characterized by the setup shown in Fig. 4. RI matching liquids (Series A, Cargille) with an increment of 2×10^{-3} RIU were sequentially injected into the fluidic channel. The optical power change captured as a function of RI of liquid is illustrated in Fig. 5.

The output optical mode from straight LRSPP waveguide is bright and clear with seldom surrounding radiation within the RI range from 1.576 to 1.596. Moreover, the brightness of output mode pattern grows steadily with the increment of RI of liquid, which corresponds to the linear decrement of insertion loss. As shown in Fig. 5, the largest output signal corresponds to the analyte with a RI of 1.596. This value is supposed to be very close to n_{su-8} (cured SU-8). The most significant signal variation of $\Delta S = 34.087\ \mu W$ is obtained when the RI shifts from 1.576 to 1.596, which corresponds to a sensitivity of 821 dB/RIU. For our setup, the standard deviation of
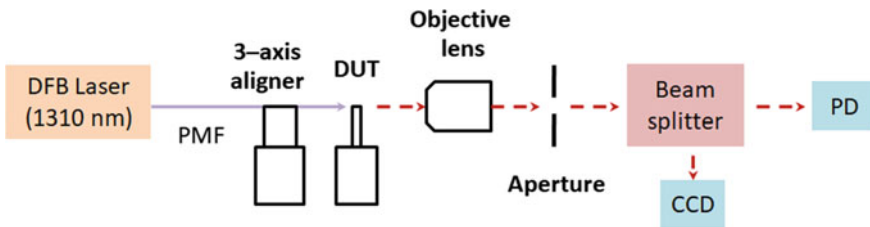

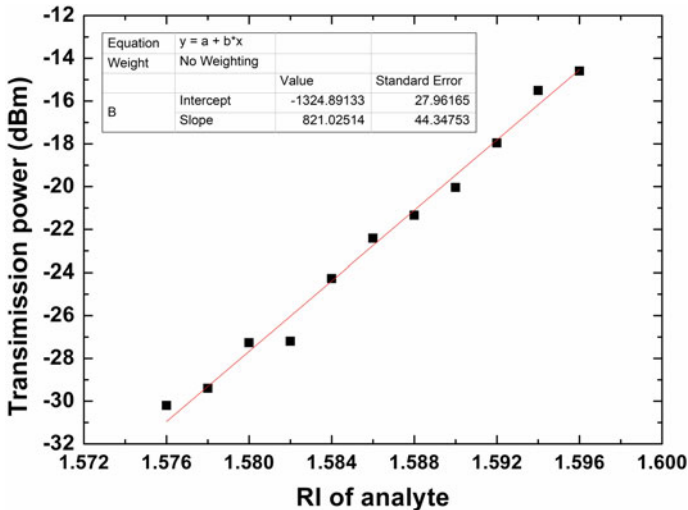**Fig. 4** Measurement setup for straight LRSPP waveguide RI sensor at $\lambda = 1310$ nm

Fig. 5 Transmission power of 5 μm-wide straight LRSPP waveguide versus RI in fluidic channel ($\lambda = 1310$ nm)

output power can be lowered to $\delta = 5$ nW with our measurement setup [4]. For signal-to-noise ratio $\Delta S/\delta = 1$, the detection limit is 2.934×10^{-6} RIU at the wavelength 1310 nm within the detection range.

References

1. Barnes WL, Dereux A, Ebbesen TW (2003) Surface plasmon subwavelength optics. Nat Mater 424, 824–830
2. Charbonneau R, Berini P, Berolo E, Lisicka-Shrzek E (2000) Experimental observation of plasmon-polariton waves supported by a thin metal film of finite width. Opt Lett 25:844–846
3. Ji L, Sun X et al (2017) Surface plasmon resonance refractive index sensor based on ultraviolet bleached polymer waveguide. Sens Actuat B-Chem 244:373–379
4. Krupin O, Asiri H, Wang C, Tait RN, Berini P (2013) Biosensing using straight long-range surface plasmon waveguides. Opt Express 21:698–708