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Fabrication of long-range surface plasmon-polariton Bragg gratings with microfluidic channels in Cytop claddings

Sa'ad Hassan [a], Maryam Khodami [b], R. Niall Tait [c], Pierre Berini [b,d,e,*]

[a] Department of Chemical & Biological Engineering, University of Ottawa, 161 Louis Pasteur St., Ottawa, ON K1N 6N5, Canada
[b] School of Electrical Engineering and Computer Science, University of Ottawa, 800 King Edward Ave., Ottawa, ON K1N 6N5, Canada
[c] Department of Electronics, Carleton University, 1125 Colonel By Drive, Ottawa, ON K1S 5B6, Canada
[d] Department of Physics, University of Ottawa, 150 Louis Pasteur, Ottawa, ON K1N 6N5, Canada
[e] Centre for Research in Photonics at the University of Ottawa, 800 King Edward Ave., Ottawa, ON K1N 6N5, Canada

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ABSTRACT

The fabrication of a novel plasmonic Bragg grating, consisting of a gold stripe lithographically stepped in width to form a waveguide Bragg grating, embedded in Cytop claddings, with an etched fluidic channel is described. The structure is designed and fabricated to be used as a compact biosensor excited via butt-coupling to an optical fibre carrying TM-polarized light. Fabrication includes Cytop bottom and top claddings, a stepped-in-width gold stripe defined by optical contact lithography, metal evaporation and lift-off, and fluidic channels etched into the top cladding via an anisotropic radical ion beam. Completed devices are presented along with preliminary optical measurements.

1. Introduction

A biosensor is a device which contains a receptor that binds a biological element, such as an antigen, antibody, whole cell or virus. The biosensor transduces the binding event into a measurable electrical or optical signal [1]. Biosensors have been produced which detect, *e.g.*, glucose in blood, drugs in serum, and neurodegenerative causative proteins [2]. The need for sensitive, compact and low-cost biosensors motivates research on high-sensitivity planar optical biosensors that can be fabricated using wafer-scale processes and standard tools. Surface plasmon-polaritons (SPPs) are transverse electromagnetic (EM) waves coupled to charge density oscillations which propagate at the interface between a metal and a dielectric at optical wavelengths [3]. SPPs are commonly excited and used as transducer waves in optical biosensors because of their high surface sensitivity. Once appropriately functionalised, the metal surface supporting SPPs becomes selective to a target analyte, and as analyte binds, the properties of the SPPs are altered, producing a change in the measured output in an appropriately designed structure [3].

If a thin metal film is used and cladded by dielectrics that are symmetric, *i.e.* that have a similar refractive index on both surfaces of the metal film, then SPPs that propagate as far as several centimetres can be excited. Such SPPs are known as long-range surface plasmon-polaritons (LRSPPs) [4]. LRSPPs on thin gold planes [5–10] and stripes [11–14] have been used for biosensing, as they hold the promise of better sensing performance compared to single-interface SPPs due to their longer optical interaction length with the sensing surface [15]. Stripes are advantageous compared to planes because they enable compact integrated geometries [4].

An integrated optic geometry operating with LRSPPs, of strong interest for biosensing, consists of a waveguide grating implemented as a gold stripe periodically stepped-in-width over a length – a plasmon-polariton Bragg grating (PPBG). Such structures have been demonstrated previously as narrowband passive filtering elements [16] (as have step-in-thickness structures [17]). A PPBG reflects a portion of the input wave at the Bragg wavelength due to additive reflections at each unit cell along the structure. As the reflection is phase-sensitive, a biosensor can be implemented by exposing the PPBG in a microfluidic channel and allowing biomaterial to bind to its surface thereby modifying the phase of the LRSPPs, which results in shifting the Bragg wavelength of the structure. Such a biosensor is therefore phase sensitive, as opposed to biosensors based on a uniform metal stripe which is loss sensitive [12–14]. Recent modelling validates the concept of a PPBG biosensor operating with LRSPPs and provides good designs for the structure [18]; high surface sensitivity is expected combined with a narrowband spectral response enabling accurate tracking

* Corresponding author at: School of Electrical Engineering and Computer Science, University of Ottawa, 800 King Edward Ave., Ottawa, ON K1N 6N5, Canada.
E-mail address: berini@eecs.uottawa.ca (P. Berini).

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of the reflection peak (or transmission dip). In this paper, the fabrication of PPBG structures in Cytop claddings with an etched microfluidic channel is presented and initial optical measurements demonstrating Bragg operation with LRSPPs are reported.

2. Device structure and fabrication process flow

The biosensor consists of a structured thin Au film cladded in Cytop, a fluoropolymer [19]. Cytop is of interest as a cladding material because it has a refractive index close to that of water which constitutes many of the sensing media of interest – this property is advantageous because it enables the propagation of LRSPPs which require that the refractive index of the media bounding the Au film be similar (*i.e.*, the structure must be optically symmetric), and it enables optically non-invasive microfluidic channels once filled. Cytop has low optical absorption and it has been used to create dielectric optical waveguides [20–22] and LRSPP waveguides [12–14].

The structure of interest is depicted in Fig. 1, and consists of a 35 nm thick Au stripe bounded by bottom and top Cytop claddings of equal thickness of approximately 8 μm each. A PPBG of length L_g is concatenated to uniform input and output waveguides, each of length 0.5 L_s, to excite the structure and extract light emerging from its output. Target dimensions for the PPBGs were determined through modelling [18] such that the Bragg wavelength would fall near $\lambda_0 = 1550$ nm. A range of periods and steps-in-width are thus of interest: $\Lambda = 1690–1800$ nm ($d_1 = d_2$), and $w_1 = 8$ μm with w_2 ranging from 2 to 5 μm. Operating at shorter wavelengths (say near $\lambda_0 = 850$ nm) would enable a more sensitive and compact device [18], but the grating period would decrease, challenging photolithography. A fluidic channel is etched into the top cladding exposing the PPBG, readying the device for biosensing. The structure propagates LRSPPs which are excited by butt-coupling to an optical fibre. Sensing could then be achieved by measuring changes in, *e.g.*, the transmittance spectrum of the structure near the Bragg wavelength as analyte binds to the surface of the PPBG [18].

An overview of the fabrication flow is depicted in Fig. 2. Fabrication of the device proceeds in several steps: wafer selection and cleaning, bottom cladding deposition, lithography and metallization of the PPBG and waveguides, top cladding deposition, fluidic channel etching, and top cladding long-bake. The PPBG biosensor poses several fabrication challenges, primarily, stringent lithographic resolution and the need to form the top Cytop cladding without destroying the embedded metallisation while ensuring that the cladding does not crack or remain tacky. The fabrication flow and process steps build on previous work with these materials [23,24].

3. Fabrication details

3.1. Wafer selection and bottom cladding

Fabrication begins with a 4 inch p-type (100) silicon wafer, which is dipped in a 10% HF solution to etch away any native oxide. The wafer is then placed in an oxygen reactive ion etch (RIE) in a Plasmatic plasma-preen II 862 to clear any remaining organic molecules on the surface of the wafer and dehydrate it. The power, pressure, and oxygen flowrate of the RIE are 100 W, 350 Torr and 44 sccm, respectively.

Once the wafer preparation steps have been completed, the Cytop bottom cladding can be deposited. To ensure adequate smoothness, it is necessary to produce the Cytop bottom cladding via multiple coats that are spun at high spin speeds. The bottom cladding fabrication procedure is detailed in Table 1. The first layer of the bottom cladding is CTL-809M "M-grade" Cytop which has superior adhesion to silicon and metals due to its amino-silane functional groups [19]. This layer contributes 0.4 μm to the bottom cladding thickness. The following three layers constitute the optically infinite Cytop stack and are comprised of CTX-809SP2, i.e. optical quality "S-grade" Cytop. Each of these layers is 2.35 μm thick. Finally, the bottom cladding is topped with a diluted s-grade smoothing layer. A final 5% s-grade layer is sun on top of the stack to improve the smoothness of the surface. This final layer contributes 1.4 μm to the bottom cladding thickness. The bottom cladding therefore has a total thickness of 8.8 μm.

3.2. Plasmon-polariton Bragg gratings

Once the bottom cladding is fully deposited, fabrication of the waveguide layer can begin. Cytop presents a highly hydrophobic surface which is inimical to many lift-off resists (LOR) and so requires two priming steps to ensure proper adhesion of the LOR.

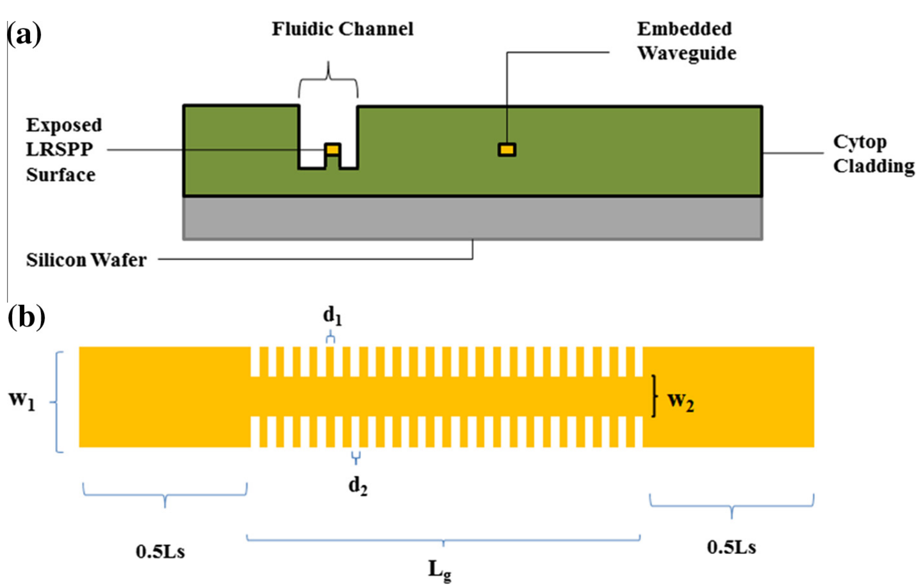

Fig. 1. (a) Front cross-section of the Cytop-cladded LRSPP biosensor. (b) Top view of a Au waveguide PPBG consisting of steps in width (w_1, w_2) of period Λ defined as $\Lambda = d_1 + d_2$. The PPBG of length L_g, is flanked by two access waveguides, each of length 0.5 L_s.