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Extended Abstract

Surface Plasmon Resonance Sensor based on inkjet 3D printing†

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Abstract: A novel surface plasmon (SPR) sensor was designed, manufactured, and experimentally tested. A novel approach was followed to fabricate the sensor. It is based on a combination of both inkjet 3D printing process and the use of optical adhesives, which were used as an alternative solution to the use of plastic optical fibers (POFs). The obtained experimental results showed good performances, at least in terms of figure of merit (FOM) for the 3D printed sensor, which were quite similar to those gained SPR-POF configuration. Next, through a cost analysis the possibility of manufacturing the SPR sensor at low cost was proved, thus being economically advantageous towards conventional sensors.

Keywords: 3d printing; additive manufacturing; photocurable resin; plasmonic sensor.

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1. Introduction

The Surface Plasmon Resonance (SPR) Sensors working principle relies on the refractive index discrepancy at the interface between a dielectric medium and a metallic film. This family of sensors can be used to analyze different substances, such as pollutants, pesticides, toxic metals, viruses and other molecules. As alternative of silicon-based technologies, SPR sensors could be fabricated by mean of a novel technique relying on inkjet 3D printing. Hence, developing an innovative planar approach. In this way, it would be possible to realize more complex geometries, different from basic cylindrical fibres [1-3]. Thus, obtaining a freedom design approach. An additional benefit in developing organic optoelectronic devices is their low-cost if compared to silicon-based ones [4], as clean rooms are not needed, unlike microelectronics industries.

In this work, a novel SPR sensor has been designed and manufactured via inkjet 3D printing process combined with optical adhesive use. This approach was previously adopted as a substitute to plastic optical fibers (POFs) [5], but with no reference to SPR phenomena. The numerical and experimental results have been presented as well. Eventually, through a cost analysis it has been proved that the 3D printed sensor is economically advantageous.

2. 3D printed Surface Plasmon Resonance Sensor

2.1 SPR sensor design and fabrication

The SPR sensor has been designed as a disassembled composed by four different parts by using Autodesk® Fusion 360 (Figure 1), then the STL files were generated. Next, the G-Code instructions for the 3D printer were realized via the software Objet Studio™. Finally, the sensor construction was performed by using the PolyJet 3D printer Stratasys Objet260 Connex 1 (Stratasys, Los Angeles, CA, USA). The used material was a liquid photopolymer ink (VeroClear RGD810). Once the SPR sensor parts construction was completed (Figure 2), the waveguide core of the 3D printed optical device was fabricated. Thus, the UV photopolymer adhesive (NOA88, Edmund Optics, Nether Poppleton York, UK) was microinjected into the sensor channel and cured for 10 min by mean of a lamp bulb with UVA emission at 365 nm, as shown in Figure 3.

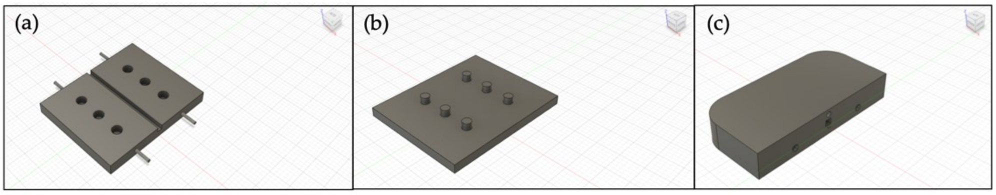

Figure 1. Disassembled parts of the Surface Plasmon Resonance (SPR) sensor designed on Autodesk® Fusion 360. a) Substrate having the functionality of cladding for the waveguide core; b) cover as cladding for the upper part of the waveguide core; c) support for fotting with 1 mm POF waveguides.

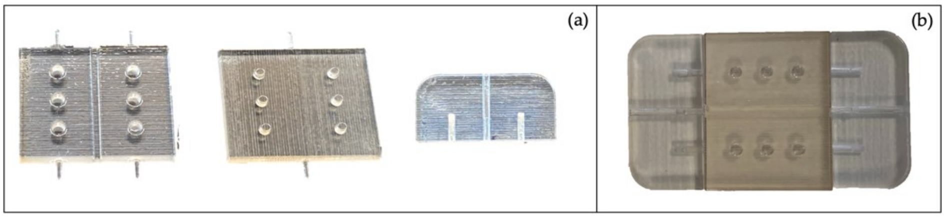

Figure 2. a) SPR sensor's 3D printed disassembled parts. b) Assembled SPR sensor.

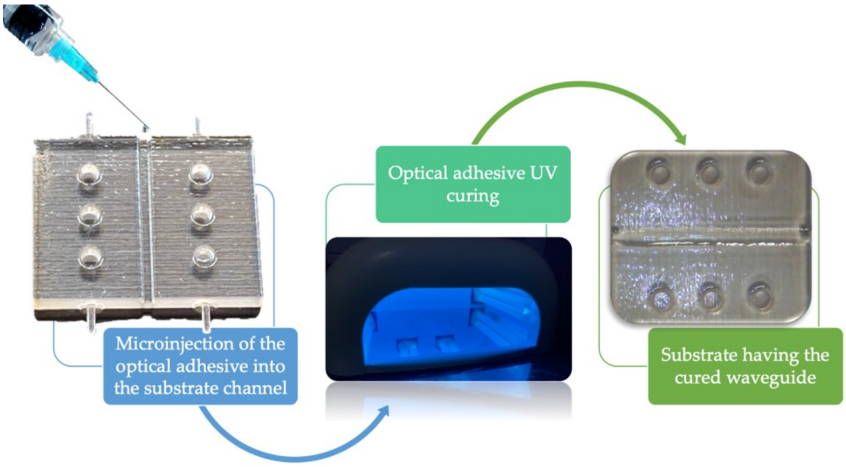

Figure 3. Waveguide core made of cured optical adhesive (NOA88) fabrication.

Next, to generate the SPR phenomenon, the cured core was gold sputtered with a coater (Bal-Tec SCD 500, Schalksmühle, Germany), in such a way as to present a noble metal nanofilm. The thickness of the sputtered gold was about 60 nm.

2.2 *Experimental setup*

To monitor the developed plasmonic sensor a simple experimental setup has been used, as shown in Figure 4, to carry out a low-cost sensor system. In particular, it comprises a halogen lamp, as a white light source (HL-2000LL, Ocean Optics, Dunedin, FL, USA), two POF patches (1 mm total diameter) used to couple and to collect the light into the 3D printed plasmonic sensor, and a spectrometer (FLAME-S-VIS-NIR-ES, Ocean Optics, Dunedin, FL, USA) having a detection range from 350 nm to 1023 nm.

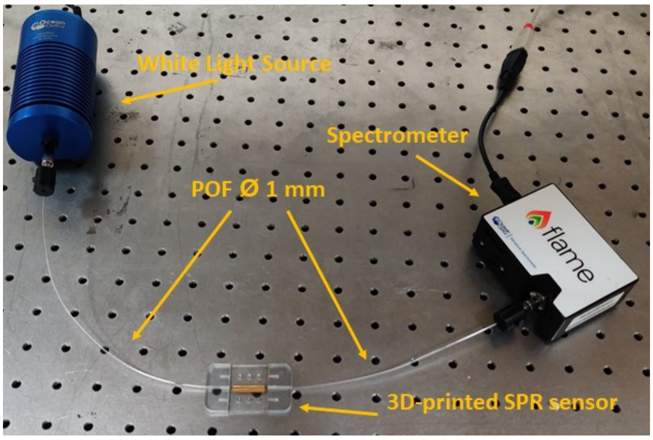

Figure 4. Experimental setup used to test the developed 3D printed SPR sensor.

3. Results

3.1. *Experimental Results*

The experimental measurements have been obtained exploiting the experimental setup reported in Figure 4. In particular, several water-glycerin solutions, whose refractive index ranges from 1.332 to 1.382, have been used to test the sensor performances. Figure 5 reports the normalized SPR transmitted spectra obtained using these water-glycerin solutions in contact with the gold sensing surface.

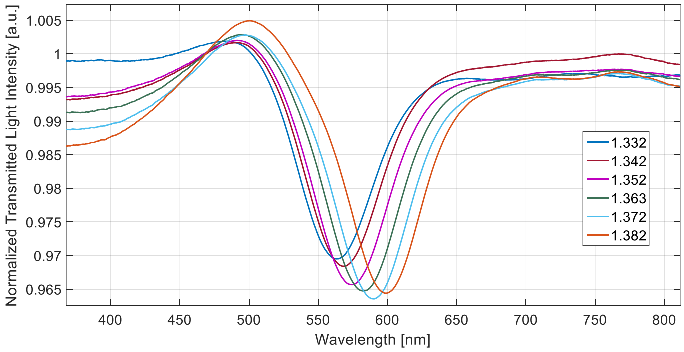

Figure 5. SPR spectra obtained at different refractive indices (from 1.332 to 1.382).

For the proposed 3D printed SPR sensor, the obtained results have shown a good sensitivity equal to about 710 nm/RIU (in the considered refractive index range). This value has been calculated by considering a linear sensor response [6]. Moreover, the 3D-printed SPR sensor has also denoted a Figure of Merit (FOM) equal to 13.6 RIU^{-1} [6], and this value is very similar to the one obtained with another low-cost SPR sensor based on D-shaped POFs [7]. The best improvement with respect [7] is related to an about 40 % improvement of the signal to noise ratio (SNR) [6,7].

3.2. Cost Analysis

By categorizing the costs parameters as process, material and machine, it was modeled the cost needed to fabricate the SPR sensor. The resulting cost allocation is shown in Figure 6. The raw materials cost (model material VeroClear RGD810 393.11 €/kg, support material FullCure705 126.74 €/kg, optical adhesive NOA88 2.50 €/ml) had the greatest impact (equal to 66%), since the 3D printer employed only uses proprietary materials. As result, the determined price for one sensor was ~15 €, which resulted to be very cheaper than traditional sensor anyway. Costs can be further reduced in the next future by using new vat-photopolymerization printers that are being developed and that use more low-price materials (i.e. 50 €/kg).

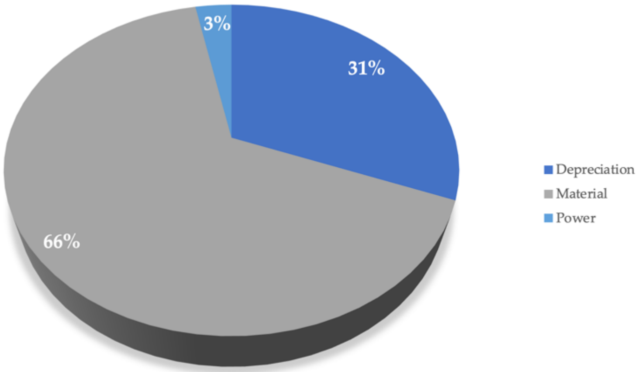

Figure 6. Cost allocation pie chart.

4. Conclusions

Once a CAD modeling was accomplished, by using the inkjet 3D printing technology a cheap SPR sensor was manufactured. It is an innovative approach to obtain sensors in a fast way for mass production. The manufacturing cost resulted to be a very low-price (~15 €), making the proposed approach very cost-effective. Moreover, the total cost for this device could be further decreased by using cheaper resins through the LCD printing.

The experimental analysis performed showed good performances for the SPR sensor fabricated. Indeed, the test run showed a Figure of Merit quite similar to POF based SPR sensor, while the sensitivity resulted to be somewhat minor.

For all these reasons, the fabricated sensor could represent the starting point for developing a new class of plasmonic biochemical sensors for several application, such as "Smart Cities" utilizations, water quality monitoring, and so on.

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