Figure of Merit Comparison Between Surface Plasmon Resonance and Bloch Surface Waves

Bernardo Dias[1,2*], *José* M. M. de Almeida[1,3], and *Luís* C. C. Coelho[1,2]

[1]INESC TEC–Institute for Systems and Computer Engineering, Technology and Science, Faculty of Sciences, University of Porto, 4169-007 Porto, Portugal
[2]Department of Physics and Astronomy, Faculty of Sciences, University of Porto, 4169-007 Porto, Portugal
[3]Department of Physics, School of Science and Technology, University of Trás-os-Montes e Alto Douro, 5001-801 Vila Real, Portugal

Abstract. The sensing performance of two types of electromagnetic surface waves are compared, a Surface Plasmon Polariton, where a gold thin film is used, being a standard material in biosensing applications; and a Bloch Surface Wave, using a photonic crystal made of a stack of silica and titanium dioxide layers. It is verified that the sensing performance (as measured by the Figure of Merit) of the gold film is higher, even though the Bloch Surface Waves can serve specific applications due to its narrow bandwidth. At the same time, it is concluded that further research must be made in order to choose the right set of parameters that maximize the Bloch Surface Wave performance.

1 Introduction

Of the multiple types of electromagnetic surface waves (ESW) reported so far, the Surface Plasmon Polariton (SPP) [1] has dominated the optical sensing research field, and only recently have other types of ESW's been considered for sensing purposes, such as Bloch Surface Waves (BSW's) [2] and Tamm Plasmon Polaritons [3]. In this work, the performance of SPP's and BWS's are analyzed, thus establishing a comparison between the two types of waves.

Created at the interface between a metal and a dielectric (or, more generally, between two media with different permittivity signs), the SPP consists on coupling of light to the free electrons of a metal when the resonance conditions (dictated by the material's properties and thicknesses) are met. In the optical spectrum, this resonance is seen as the absorption of light in a specific wavelength range, creating an absorbance band which can be highly sensitive to refractive index (RI) changes on the surface. This kind of ESW has been used in optical sensing applications for several decades [4] and has developed into an important research field.

On the other hand, BSW's are generated at the interface between a photonic crystal (PhC) and a dielectric (or between two PhCs) [2], producing sharp resonances in the optical spectrum due to the symmetry breaking caused by the PhC – dielectric interface. While the experimental observation of BSW's was made almost five decades ago [5], it is now emerging as a new field for sensing purposes, and a few experimental realizations have already been reported [6].

In this work, a comparison between these two ESW's is made, focusing on the external RI sensitivity and resolution, which are key parameters for optical sensor application in real world scenarios.

2 Experimental Setup

In both SPP's and BSW's, direct excitation of the surface wave is not possible due to a mismatch between the coupling conditions of the wave and the directly incident light. To obtain the wavevector matching for both ESW's, a prism technique is used based on the Kretschmann's configuration [7]. A silica prism was used along with silica substrates, over which the thin films were deposited using an RF Magnetron Sputtering system. Figure 1 illustrates the experimental setup used for the observation of both waves.

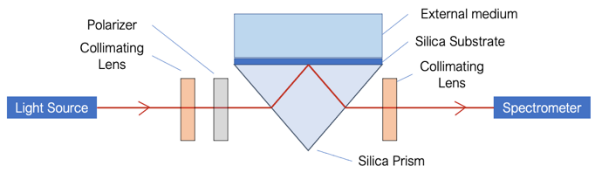

Fig. 1. Experimental setup based on the Kretschmann configuration for ESW excitation.

Using water solutions of sucrose at different ratios, the RI (measured using an Abbe Refractometer – model Atago DR A1 Plus) on the top layer was changed, causing variations in the transmitted spectra which was acquired by a high resolution spectrometer (model AvaSpec-ULS2048CL-EVO). By tracking the band's position and full width at half maximum (FWHM), the performance of each wave as a refractometric sensor can be analyzed, using the Figure of Merit (FOM), defined as [8]

* Corresponding author: bernardo.s.dias@inesctec.pt

$$FOM = \frac{d\lambda/dn}{FWHM} \quad (1)$$

in which $d\lambda/dn$ represents the shift in the wavelength peak due to the change of external RI (commonly referred to as the sensitivity).

For the case of the SPP, a structure composed of Cr (5nm) and Au (50nm) was used. The Cr layer promoted a better adhesion of the Au to the silica substrate, while the Au layer is the active plasmonic component. For the case of the BSW, a photonic crystal made of three bilayers of TiO_2 (135nm) and SiO_2 (180nm) and a final TiO_2 layer (100nm) was fabricated. Both structures were previously simulated using a transfer matrix approach [2], which showed the appearance of ESW's in *p* polarized light for both cases.

3 Results and discussion

For the case of the Au film, the results are shown in Figure 2.

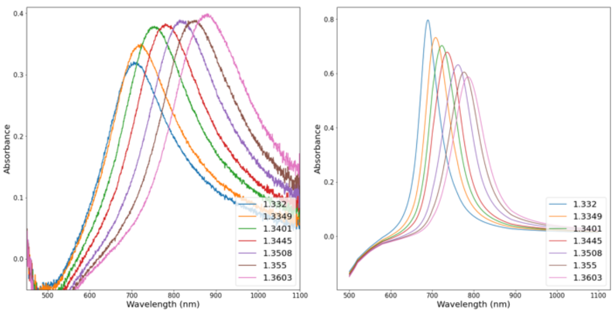

Fig. 2. Absorbance spectra of SPR wave supported on Au thin film: a) Experimental results, b) transfer matrix simulations.

In Figure 2, it is possible to see that the FWHM of the experimental results are considerably larger than the simulations. This is because the simulations employ the permittivity data from bulk Au, which can deviate from thin films. An experimental sensitivity of 6111 nm/RIU was verified, but the FOM was considerably affected by the large FWHM, which was measured to be 203 nm for the pure water RI. Figure 3 illustrates the results of the BSW configuration.

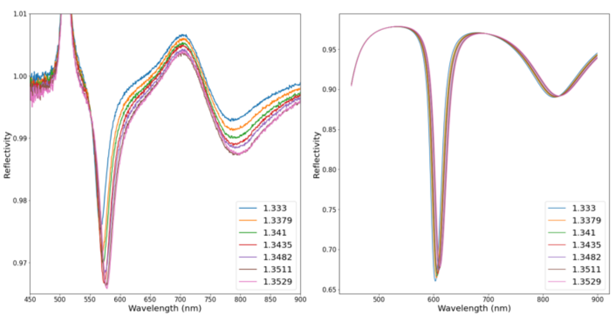

Fig. 3. Reflectivity spectra of BSW wave supported on a photonic crystal: a) Experimental results, b) transfer matrix simulations.

As expected, the BSW produces a much sharper resonance (24.5 nm in pure water), but also a much lower sensitivity, which was measured to be 501 nm/RIU. In this case, the FOM is significantly affected by the low sensitivity inherent to the BSW. The simulations and experimental results seem to agree fairly well.

From the experimental results for both ESW's, the FOM can be calculated, which can establish a comparison between the two structures, as shown in Figure 4.

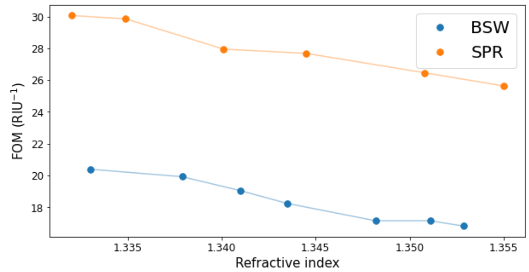

Fig. 4. Experimental values for the Figure of Merit for SPR and BSW.

In Figure 4 it is possible to observe that even with a larger FWHM, the SPR sensor still outperforms the BSW in this particular metric. This is due to the high sensitivity displayed by the surface plasmon, which is one order of magnitude above that of the BSW. Nevertheless, it should be noted that while for the Au SPR there is not much room for improvement (other than improving the optical quality of the gold layer), for the BSW several parameters should be tuned to maximize the FOM, such as the number of bilayers, layer thicknesses and RI ratio (by changing materials). Further research is needed to optimize the performance of BSW's and establish this kind of ESW as a viable alternative to SPR.

References

1. A., Otto, Eur. Phys. J. A **216**, 398-410 (1968)
2. P. Yeh, A. Yariv, and C. Hong, J. Opt. Soc. Am. **67**, 423-438 (1977)
3. M. Kaliteevski, I. Iorsh, S. Brand, R. A. Abram, J. M. Chamberlain, A. V. Kavokin, and I. A. Shelykh, Phys. Rev. B **76**, 165415 (2007)
4. V. Yesudasu, H. S. Pradhan, R. J., Heliyon, 7, 3, 2021
5. P. Yeh, A. Yariv, and A. Y. Cho, Appl. Phys. Lett. 32, 104 (1978)
6. E. Gonzalez-Valencia, I.D. Villar, P. Torres, Sci Rep 11, 11266 (2021)
7. E., Kretschmann, Sens. Actuators B Chem. **35**, 212 (1996)
8. J. Homola, *Surface Plasmon Resonance Based Sensors* (Springer Berlin, Heidelberg 2006)