Lossy mode resonance based sensors in planar configuration: a review

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***Abstract*—Lossy mode resonance based sensors have attracted much interest during the last decade in the domain of optical fiber. Here it is shown the progress made in the transfer of this technology to planar waveguides with different sensing applications such as environmental sensors and biosensors. In Addition, the inherent advantages in terms of robustness, simplicity and easiness to generate novel complex structures are discussed.**

Index Terms— Optical sensors, Lossy mode resonance; Planar waveguide, refractometer, biochemical sensors

I. Introduction

A lossy mode resonance (LMR) is a phenomenon observed in the optical spectrum when a mode guided in a waveguide experiences a transition to guidance in a thin film deposited on the waveguide (the waveguide is sometimes referred as substrate) [1]. LMRs also require that the real part of the thin film permittivity is positive and higher in magnitude than both its own imaginary part and the refractive index of the waveguide and the surrounding medium [1], [2]. This explains that metallic oxides and polymers are the most typical materials used for generation of this type of resonance [3]. Related to this, promising materials such as graphene oxide [4], black phosphorus [5], tungsten oxide [6] and perovskites [7], can be used for the purpose of obtaining LMRs, which increases the potential of these type of sensors compared to other similar ones.

LMRs are excited by light at angles of incidence approaching 90º [8]. This explains the success of deposition of thin films around the optical fiber. In this structure light is transmitted in the longitudinal axis with an incidence angle approaching 90º related to the interface of the fiber and the thin film around the fiber. In addition, this LMR technology that uses optical fiber as a waveguide (LMR-OF), shows a very high refractive index sensitivity of 5,000 – 10,000 nm per refractive index unit in the water region and more than 1,000,000 in the silica region [9-11]. This permits to obtain many applications such as humidity sensors, pH sensors, volatile organic compound sensors, gas sensors, chemical sensors or biosensors [12-19].

Some interesting reviews on LMR based optical fiber sensors can be found in [20-21]. Furthermore, LMR technology has gone beyond the limits of sensors to enter other areas, such as the design and implementation of electro-optically modulated devices [22] and the detection of electroactive species by modulation of the resonant peak when a potential is applied [23].

Another major advantage of LMRs is that, provided the real part of the thin film refractive index shows a low wavelength dispersion, their position in the optical spectrum can be easily controlled by the thin film thickness because there is a close relation between thin film thickness and wavelength [24]. However, the major drawback is that resonances are rather broad [3]. In fact, this affects more to the first LMR, the one that is first observed in the optical spectrum during the progressive deposition of the thin film. The problem of broad resonances is solved in some part by using D-shaped fibers, which permits to separate the TE and TM contribution (also the guidance of a single mode in the core and the separation of the core and the thin-film by a cladding contributes to the reduction of the LMR width). This facilitates to obtain figures of merit of around 1,000, which can compete with the best optical fiber sensors [25].

However, though optical fiber has advantages in terms of small size, multiplexing capability and immunity against electromagnetic interferences, it is important to have an alternative method to generate LMRs for applications where other configurations are more effective than optical fiber sensors. One of these configurations is the lateral incidence on the edge of a planar waveguide (LMR-PW), which guarantees the 90º incidence obtained with optical fiber, with advantages such as robustness, simplicity and cost reduction.

These planar waveguides consist of simple glass slides or coverslips of thickness 1 and 0.15 mm respectively, being it possible to use other dimensions provided the waveguide is not too thick, because, according to the experiments performed in [26], the visibility of the LMRs is reduced when the thickness increases [3]. With these sensor heads it is possible to compete with other types of sensors for applications that until now were vetoed for optical sensors. An example is the Internet of Things, where a large number of sensors need to be deployed to detect multiple parameters at a reduced cost [27]. Another field is wearable sensors, which require low cost easily replaceable and disposable sensors. In this regard, the possibility of using multiple substrates as waveguides of micrometer thicknesses would allow them to be easily conformed and their replacement would be very simple [28-29]. Likewise, this LMR-PW

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technology could be used in the development of flexible sensors, a field with an enormous growth and that until now was almost limited to electronics [30].

In fact, one of the stimulus that has prompted the authors of this work to dedicate their efforts to trying to transfer the existing LMR-OF to a simpler and cheaper way using LMR-PW, has been the Stardust H2020 project, where the objective is to propose different sensory alternatives to be applied to environments related to smart cities [31].

Consequently, this transfer of optical fiber LMR technology to planar waveguides may make it possible the long-awaited and difficult leap in all sensing technologies: its massive use in real applications. The different works published in this domain will be presented and explained in the next sections and they predict a promising future.

The remainder of this manuscript is organized as follows. The characterization of this type of sensors will be addressed in the methodology section. In section III, some design considerations will be given for its adaptation in some of the applications that will be explained in section IV. Finally, some concluding remarks will be made.

II. METODOLOGY

A. Experimental set-up

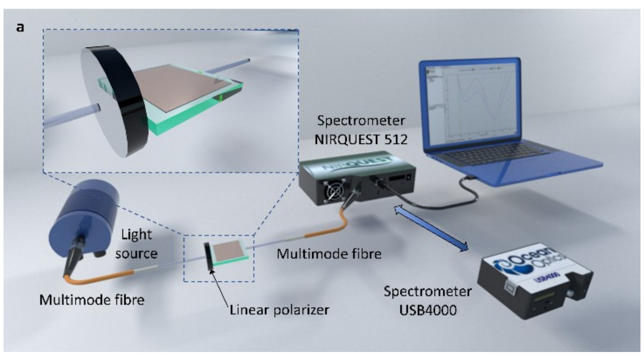

Fig. 1. Experimental setup for generating LMRs in planar configuration. (a) Detail of the sensor together with a linear polarizer. Copyright © Springer Nature. All rights reserved. Reprinted, with permission, from [47].

Fig. 1 shows the typical experimental setup used for generating LMRs in planar configuration. A broadband source launches light into a multimode fiber whose end is cleaved and placed in front of the edge of a planar waveguide that is deposited in one or both faces by an LMR generating nanofilm (different techniques have been used for deposition of LMR generating materials, such as layer by layer self-assembly, sputtering or atomic layer deposition [32-34]). After passing through the waveguide (the waveguide can be supported by a lower refractive index material to reduce leakage), the light is received by another optical fiber connected to a spectrometer, which in turn is connected to a computer that allows the central LMR wavelength to be monitored and tracked. Optionally, one can visualize both the visible and the near infrared regions with two spectrometers, as described in Fig. 1 in order to observe the resonances in the visible or near infrared regions.

B. Characterization of the LMR

Fig. 2a-b shows the transmission spectra as a function of the deposition time when a nanofilm, an indium oxide nanocoating in this case, is deposited with DC sputtering onto both a microscope glass slide (thickness 1 mm) and a coverslip for a microscope glass slide (thickness 0.15 mm) [26].

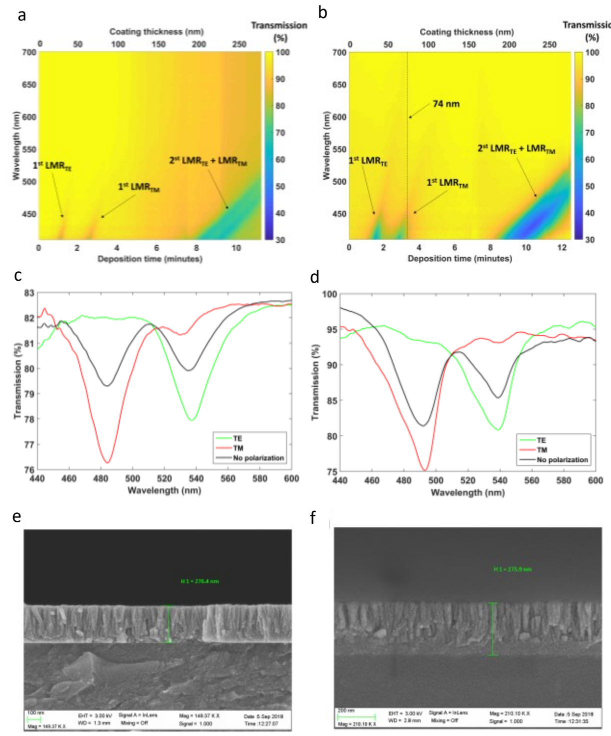

Fig. 2. Transmission spectra as function of the deposition time: (a) glass slide, (b) coverslip. TE and TM componentes for (c) glass slide, (d) coverslip. FESEM image of the nanocoating deposited on (e) glass slide, (f) coverslip. Copyright © Springer Nature. All rights reserved. Reprinted, with permission, from [26]

It is clear that the visibility of the LMRs is increased with the coverslip, Fig. 2b, compared to the glass slide in Fig. 2a. This occurs because the coverslip is thinner than the glass slide and, consequently, a higher evanescent field is created [35] (also the diameter of the multimode optical fiber, similar to the thickness of the coverslip, plays a role in the increase of the LMR depth). In addition, Fig. 2c-d shows the effect of using a polarizer in the transmission spectrum after finishing the deposition, both for the glass slide and the coverslip. It is evident that the linear polarizer in Fig. 1 permits to separate the TE and TM components and to increase the visibility of the LMR. This can be done by orienting the polarizer in such a way that electric field axis after the polarizer is parallel or perpendicular to the surface of the thin. Polarizers present a mark indicating this, and, if there is no mark, another method is to rotate the polarizer until a maximum depth in the TE or TM LMR is achieved. Finally, Fig. 2e-f shows the microscope images obtained with a FESEM device, indicating that the nanocoating thickness is quite similar for both depositions performed on the glass slide and the coverslip.

III. SOME DESIGN CONSIDERATIONS

There are different parameters that must be taken into account when designing devices based on LMR in planar configuration. First of all, it should be noted that while a material is being deposited on a planar waveguide, the first resonance corresponding to the TE mode appears first (LMR_{TE}) and then the one corresponding to the TM mode (LMR_{TM}). As the thickness or the index of refraction of the nanofilm increases, more resonances start to be visible in the spectrum following this same order (first TE, then TM), while the rest of resonances are progressively red shifted. This occurs also when the surrounding medium refractive index (SMRI) is gradually close to the substrate refractive index [3]. In addition, as commented in the introduction, the first resonances show a higher sensitivity, whereas the second, third and higher order LMR are typically narrower but less sensitive [32]. This idea is shown in Fig. 2a-b, where the slope of the TE and TM first LMRs is higher than the slope of the second LMR (the wavelength shift of the first LMRs as a function of thickness is higher than in the second LMR). Consequently, focus must be centered in the first LMR, the most sensitive one. As a counterpart, this first resonance is the widest one, so its tracking is more complicated.

In order to obtain a higher wavelength shift of the optical resonance of the device as a function of a parameter to detect (better sensitivity), it was empirically demonstrated that one must increase the thin-film refractive index, its thickness and/or the SMRI [32]. This idea agrees well with the analytical equation for the sensitivity obtained in [24], which considering an incidence angle approaching 90º can be simplified to:

$$S = \frac{2\pi n_2^2 d_2 \left(\frac{1}{n_3\sqrt{n_1^2 - n_3^2}} + \frac{2\sqrt{n_1^2 - n_3^2}}{n_3^2} \right)}{\left[arctan\left(\frac{n_2^2\sqrt{n_1^2 - n_3^2}}{n_3^2\sqrt{n_2^2 - n_1^2}} \right) \right]^2 \left[1 + \frac{n_2^4(n_1^2 - n_3^2)}{n_3^4(n_2^2 - n_1^2)} \right]} \quad (1)$$

where n_1, n_2 and n_3 are the refractive indices of the waveguide, the thin film and the SMRI, whereas d_2 is the thin film thickness.

Expression (1) confirms the empirical results. When the refractive index of the substrate (n_1) and the surrounding medium refractive index (n_3) approach each other, the sensitivity increases up to theoretically infinite when both indices are equal. That is why an exponential growth of the sensitivity was empirically observed in [32] when the SMRI increased and approached the substrate refractive index. Regarding the thickness (d_2), the sensitivity is proportional to this parameter. Finally, the effect of increasing the thin film refractive index is more difficult to analyze because it is present in several parts of the equations. This explains why in (1) an increase in the sensitivity was observed as a function of the thin film refractive index but a stabilization was observed for higher values of n_2. Related to this, it is also important to discuss the comparison in terms of sensitivity of LMRs generated with materials of different refractive index. Due to this higher sensitivity of the LMR generated with a higher refractive index material, the thickness required to obtain the LMR is lower than the thickness required to generate an LMR with the lower refractive index material. This explains that, when comparing materials, materials that lead to a higher sensitivity require a lower thickness than materials with a higher refractive index. This is not a contradiction with the previous conclusion, that the sensitivity increases with thickness, because this increase is true when comparing sensors obtained with the same material.

Finally, it is important to mention that the sensitivity can be expressed as a function of the wavelength *(λ)* [1]:

$$S = \frac{\lambda^2}{2\pi d_2} \frac{\left(\frac{n_2^2}{n_3\sqrt{n_1^2 - n_3^2}} + \frac{2n_2^2\sqrt{n_1^2 - n_3^2}}{n_3^2} \right) n_3^4}{n_2^4(n_2^2 - n_1^2) + n_3^4(n_2^2 - n_1^2)} \quad (2)$$

Expression (2) explains why in some works it is stated that a higher sensitivity can be attained at longer wavelengths provided the LMR is located in the wavelength range that can be monitored by the spectrometer or optical spectrum analyzer [18, 36]. Consequently, by combining this peculiarity with the previous strategy of using a substrate whose refractive index is very close to that of the SMRI, and considering that the absorption lines of most gases are in the medium or long wave infrared, it could be concluded that using a type of aerogel as a planar waveguide, volatile compounds could be detected with great sensitivity in the infrared region using this technology, although a further analysis should be carried out to confirm this idea. This would make possible to use this technology to, for example, detect biomarkers in the breathing or explosive detection, where sensitivities of the order of parts per billion (ppb) or per trillion (ppt) are usually required [37,38].

Another interesting consideration is to reduce the spectral width of the resonances, which according to the analytical equations of [24] is inversely proportional to the sensitivity. This means that the figure of merit, expressed as the ratio between the sensitivity and LMR width (typically expressed in terms of full width at half maximum (FWHM) or full width at half minimum (FWHm) cannot be improved without exploring other parameters not considered in these equations. The first one is the imaginary part of the thin-film refractive index. LMRs are based on materials with a small imaginary part of the refractive index. In [39], by controlling the ambient for the deposition of metallic indium-rich indium tin oxide as the coating material, it is possible to regulate the extinction coefficient (imaginary part of the refractive index) of the thin film. As a result, the depth of the LMR was increased for the case with a higher imaginary part. However, one must keep in mind that according to numerical results, if the imaginary part is further increased, the LMRs are shallower because absorption affects in the whole wavelength range that is being monitored [1]. This idea is confirmed in [40], where CuO leads to the generation of broader LMRs than those obtained with SnO_2 and ITO, with a lower imaginary part than CuO.

Another way to improve the figure of merit of LMR-PW based devices is to separate conveniently the contribution of both, TE and TM resonances, in order to avoid its superposition that leads to a spectral width increase. In the case of a planar configuration, TE and TM are generated by 90º rotation of a simple linear polarizer. In optical fibers, it is necessary to use a fiber with a non-cylindrically symmetric transversal section and an in-line polarizer and a polarization controller that permits to control the polarization in a standard single-mode fiber, or to employ a side-polished polarization maintaining fiber [41]. Finally, it exists another possibility to enhance the figure of merit in LMR based devices. It consists of the deposition of a low refractive index intermediate layer. Fig. 3a, shows an example of this structure, where an intermediate layer of SiO_2 is placed between the waveguide and a TiO_2 thin film, both of them of higher refractive index than SiO_2 (Fig. 3b). Fig. 3c shows the sensitivity (red on the right) and the FWHm (blue on the left) as a function of the intermediate layer thickness. Depending on the thickness of the lower index intermediate layer, the FWHm can be reduced, thus enhancing the FoM. In this case, the optimum occurs at about 350 nm, although this improvement is accompanied by a reduction in sensitivity, in agreement with the analytical equations obtained in [24].

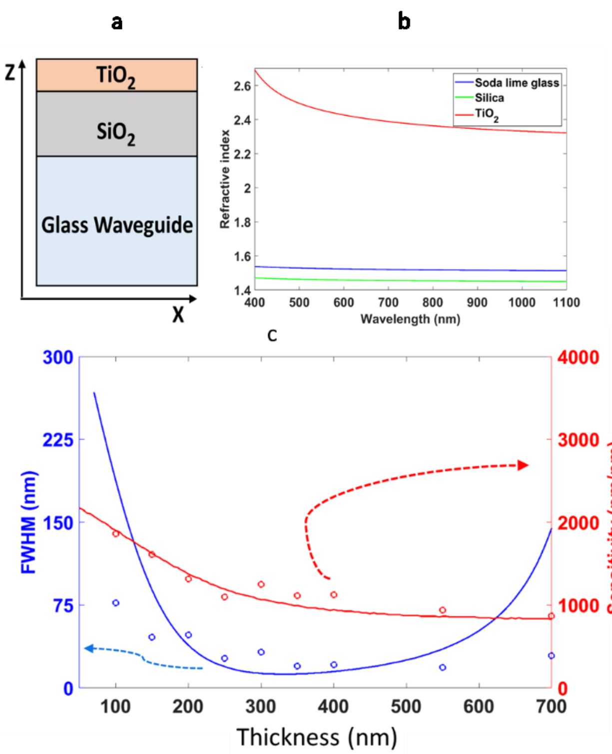

Fig. 3. Full width at half maximum enhancement in lossy mode resonance based sensors by deposition of a low refractive index intermediate layer: (a) structure of the multilayer waveguide where SiO_2 is the intermediate layer between the waveguide and the thin film, (b) Refractive index of the substrate, soda lime glass, and of the two layers: SiO_2 and TiO_2, (c) Sensitivity, in red on the right, and full width at half minimum (FWHm), in blue on the left, as a function of the SiO_2 layer.

Another important strategy to consider in order to improve the sensitivity of these type of refractometers based on LMR is to use an adequate substrate as planar wave guide whose refractive index is as close as possible to the one of the SMRI.

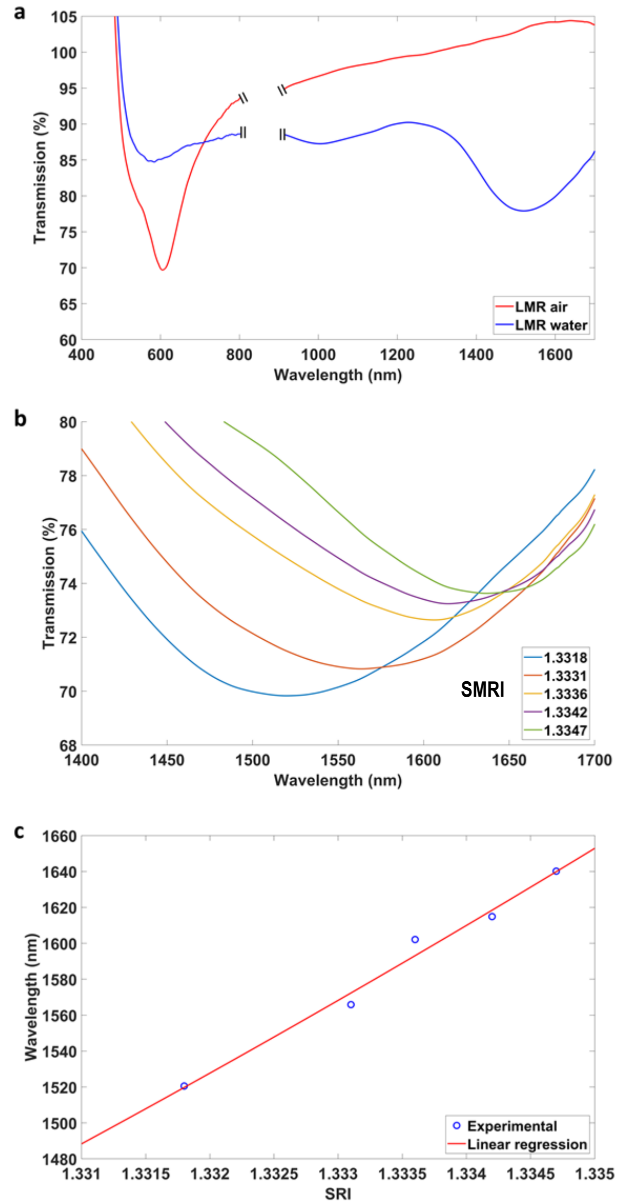

Fig. 4. LMR obtained after deposition of a 33 nm thick ITO nanofilm on a PFA substrate: (a) First LMR when the sensor is in air (visible) and submerged into water (infrared), (b) Transmission spectra for different SMRI values around the one of the water, (c) Sensitivity of the sensor (wavelength shift as a function of SMRI). Reprinted, with permission, from [41].

Dominguez *et al.*, in [42], make use of the proximity of the refractive index of a PFA (tetrafluoroethylene-perfluoro polymer) substrate to that of water in order obtain sensitivities as high as 41,034 nm per refractive index unit (nm/RIU), as deducted from Fig. 4. This record is for refractive indices close to that of water, i.e., ranging from 1.3318 to 1.3347. This enormous sensitivity can be used for the development of biochemical sensors where the required limit of detection (LoD) is very low. In optical fiber-based configurations it would be comparatively very costly to apply this strategy [43], but not so in a simple disposable planar configuration.

IV. Some Applications

A. Single nanocoationg deposition

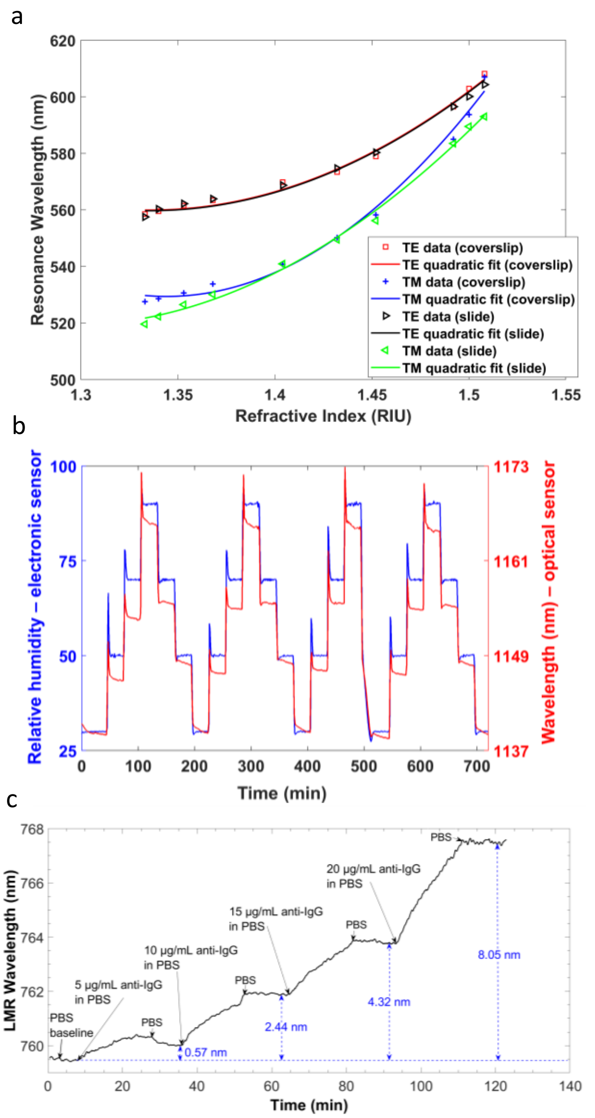

Fig. 5. Examples of LMR-PW based sensors. (a) Refractometer, copyright © Springer Nature, all rights reserved, reprinted with permission from [26]; (b) humidity sensor, copyright © Elsevier, all rights reserved, reprinted with permission from [40]; (c) Immunoglobulin biosensor, copyright © MDPI, all rights reserved, reprinted with permission from [44].

With the simple setup presented in Fig. 1, the LMR-PW configuration, it is possible to obtain many sensing applications. The most obvious is refractometry. Fig. 5a shows the wavelength shift at TM and TE polarization as a function of the SMRI for both the glass slide and the coverslip-based waveguides of section II. It is interesting to observe that the type of waveguide plays no role on the sensitivity, though it must be highlighted that the noise of the signal was not considered for the analysis of Fig. 5a. When a complete sensorgram is shown, as for the relative humidity (RH) sensor of [44], the dynamic range of the signal is again the same for both types of waveguides but the coverslip waveguide is better in terms of accuracy, because the signal is less noisy. That is why most of the applications in planar configuration have been developed with coverslips. In Fig. 5b, an RH sensor based on coverslip was implemented by using CuO as the LMR generating layer, a 10 nm SnO_2 layer to protect the CuO layer and to make the device sensitivity to RH, and a final layer of agarose to multiply the sensitivity of the device by more than a factor of 10, up to 0.636 nm/%RH [43]. In addition, Fig. 5c shows the sensorgram corresponding to a biosensor for detection of anti-IgGs with a limit of detection of 2.2 µg/mL and a range of concentrations analyzed from 5 µg/mL and 20 µg/mL [45].

Other sensors applications using this simple LMR-PW configuration have been implemented, such as volatile organic compound, breathing, or temperature sensors, for example [6,46-47].

B. More complex configurations

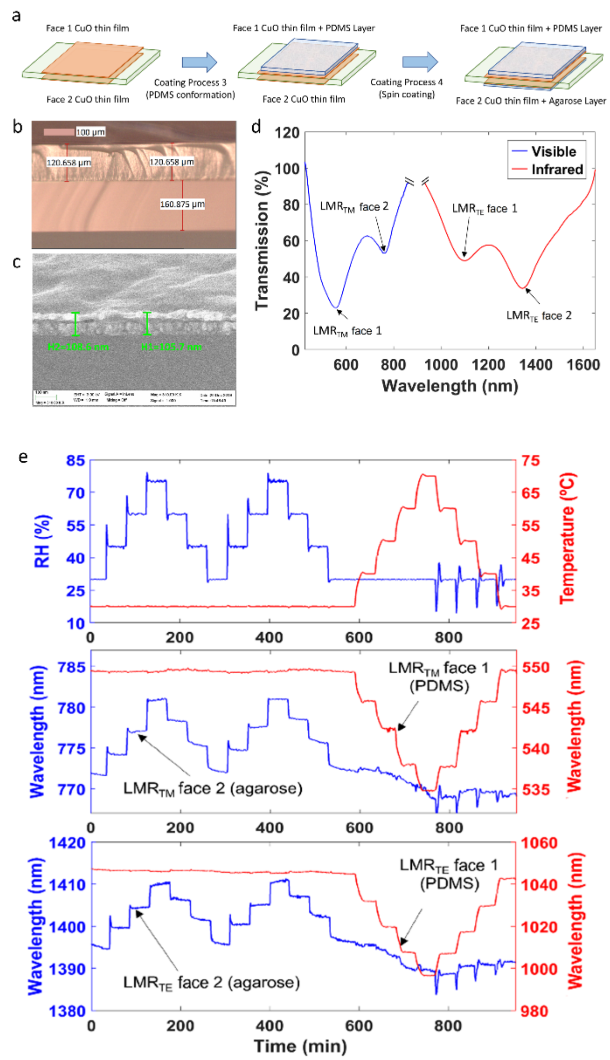

Fig. 6. (a) Process of deposition of a coverslip with CuO on both faces, a further PDMS layer in one face and an agarose layer in the other. The PDMS permits to detect temperature and the agarose to detect relative humidity. (b-c) Microscope images of the cross section on both faces of the coverslip. (d) Transmission spectrum with two TM LMRs in the visible wavelength region and two TE LMRs in the infrared wavelength region. (e) Sensorgram. Copyright © Springer Nature. All rights reserved. Reprinted, with permission, from [47].

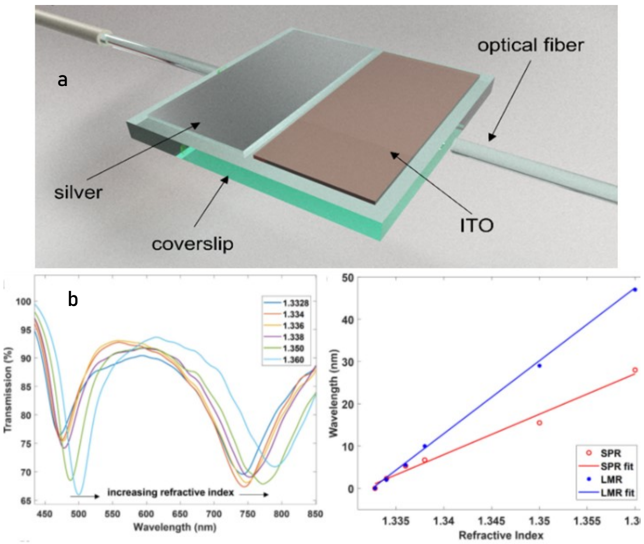

Fig. 7. (a) Coverslip nanocoated with silver and ITO nanofilms. (b) Transmission spectra (TM polarization) for different surrounding medium refractive indices. (c) Relative wavelength shift as a function of refractive index for both the LMR and SPR. Copyright © MDPI, all rights reserved, reprinted with permission from [48].

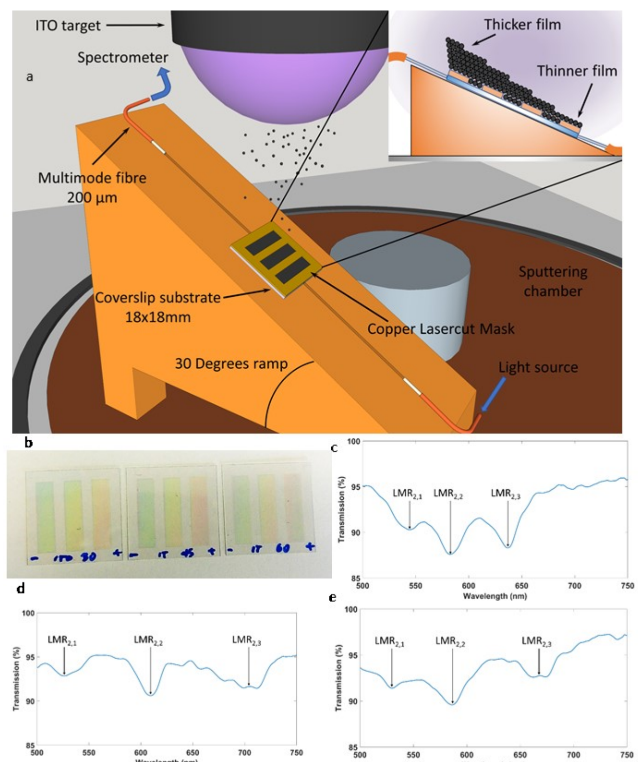

Fig. 8. (a) Sputtering deposition of coverslip with an angle. (b) Picture of coverslips deposited with 30, 45 and 60º. (c) Transmission spectrum for 30º, 45º and 60º in (c) (d) (e), respectively. Copyright © Springer Nature. All rights reserved. Reprinted, with permission, from [49].

The planar configuration permits to operate at both faces of the waveguide at the same time. This concept is demonstrated in Fig. 6, where both faces of a coverslip are deposited initially with CuO layers of different thickness (36 and 66 nm, respectively) in order to generate two TE LMRs in the infrared and two TM LMRs in the visible wavelength range [48]. To this purpose, both in the visible (TM LMRs) and in the infrared (TE LMRs), the LMR at shorter wavelength is generated by the 36 nm coating and the LMR at longer wavelengths is generated by the 66 nm thin film, because, as stated in previous sections, there is a direct relation between thickness and wavelength (as the thickness is increased, the LMR is shifted to longer wavelengths).

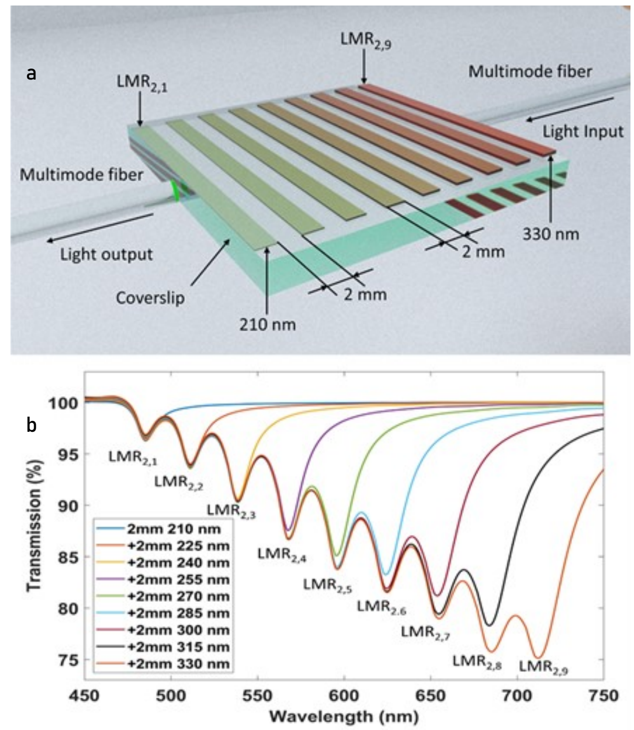

Fig. 9. Array of 9 LMRs. (a) Simulation of the progressive addition of 2 mm strips, each one nanocoated to a different thickness, which permits generation of multiple LMRs in the transmission spectrum. The structure was surrounded by air (RI = 1). (b) Schematic representation of the array of 9 strips generating the corresponding 9 LMR-based sensors, where each one is identified with the resonance peaks of the above transmission spectrum. Copyright © Springer Nature. All rights reserved. Reprinted, with permission, from [49].

After that, similar to the strategy followed for the humidity sensor in Fig. 5b, one of the CuO coatings was covered with agarose to make the LMR sensitive to humidity, whereas the other CuO coating was covered with PDMS, very sensitive to temperature (Fig. 6b and 6c). These permits to obtain the final spectrum in Fig. 6d with the four LMRs, which are wavelength shifted in Fig. 6e independently as a function of temperature and humidity. The results were contrasted with the electronic humidity and temperature sensor of the climatic chamber used to develop the experiment and, except for some drifts in the signal of the LMR corresponding to the face covered with agarose, due to abrupt changes in temperature that affect his material, the LMRs follow adequately the performance of the electronic sensors [48].

Another remarkable configuration is the one used to simultaneously generate surface plasmon resonances (SPR) and LMR in the same planar platform [49], as can be seen in Fig. 7. A coverslip was deposited in one of its two faces with two separate materials: silver and indium tin oxide (ITO). The incidence of light by the edge of the coverslip permitted the generation of both SPRs and LMRs in the same transmission spectrum with a single optical source and detector.

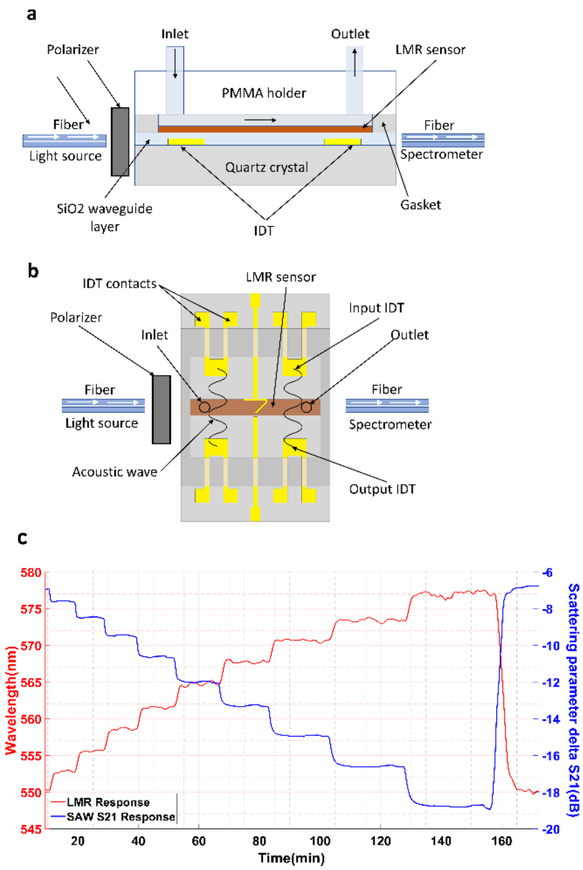

Fig. 10. LMR-SAW platform: (a) Lateral view with optical propagation path along the LMR sensor. (b) Top view with dual acoustic propagation path. (c) LMR wavelength and SAW S21 parameter shift sensorgram. Copyright © The Royal Society of Chemistry. All rights reserved. Reprinted, with permission, from [52].

In addition, multiple resonance can be created in the same planar waveguide using a deposition method like that presented in Fig. 8a, where the substrate is covered with a mask and DC sputtering deposited with inclination. This permits to generate regions of different thickness and hence multiple LMRs in the same transmission spectrum. Fig. 8b shows coverslips deposited with angles 30º, 45º and 60º. The different thickness of each of the three regions deposited by applying a mask is evident in view of the different color. In addition, Fig. 8c-e shows the spectra, where the three LMRs generated by each of the three different regions are more separated when the angle of deposition is higher and, hence, the difference in thickness of the three regions is more acute.

This concept can be expanded towards what it was called the interdigital concept in photonic sensing [50]. This has been one of the results of the aforementioned stardust project, with the aim of passing optical technology to the IoT field for smart cities, where low cost and multi-parameter sensing are key [31], and precisely those are the strengths and most relevant advantages of LMR-PW compared to LMR-OF. Figure 9a is a representation of an array of 9 LMR based sensors obtained with a coverslip coated by 2 mm ITO strips of different thickness ranging from 210 to 330 nm in steps of 15 nm. In Fig. 9b the transmission spectra of the nine sensors are shown.

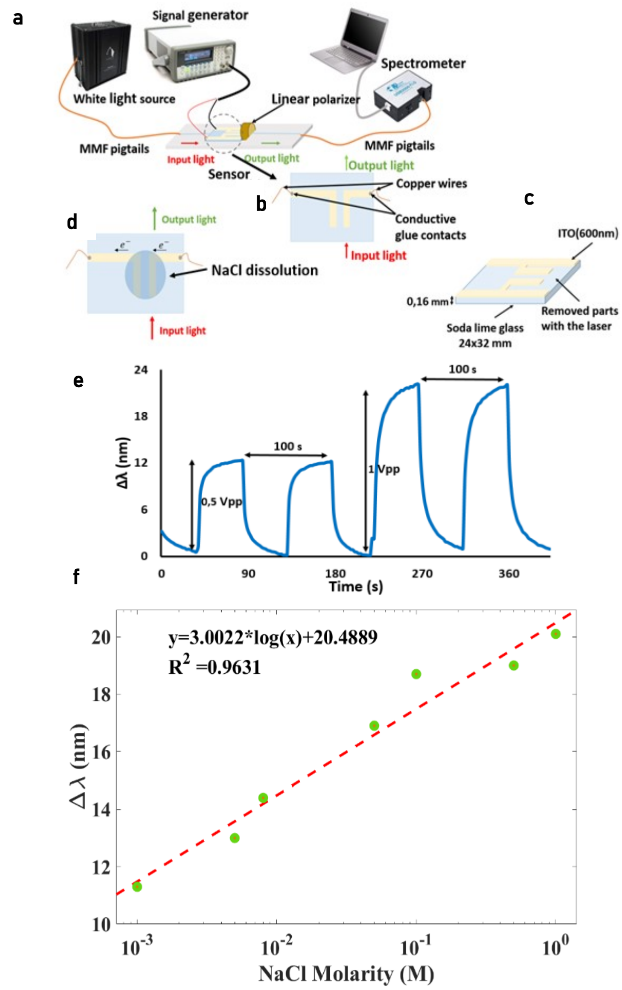

Fig. 11. Experimental set-up to carry out the light modulation by means of electrochemical process generated by ITO coated in planar waveguides: a) Optical configuration. b) Sensor schematic. c) Lateral view of the sensor. d) Detail of the sensor schematic with the NaCl dissolution between the ITO electrodes. e) Monitoring of the LMR stationary regime when subjected to a square signal (f = 0.01 Hz) with peak-to-peak amplitudes of 500 mV and 1 V, respectively. f) Optical detection of NaCl concentrations between 0 and 1 M using a square-wave signal of 0.1 Hz frequency and a peak-to-peak amplitude of 1 V.

Continuing with the previous simile of smart cities, each of these strips could detect, for example, a gas that affects cities (CO, O_3, NO_2, SO_2, etc.) by depositing a specific LMR generating material that is, at the same time, sensitive to these gases in each strip, since metal oxides that generate LMRs are also used to detect gases [51]. Another possibility is the distinct functionalization of the surface of each one of the strips to be able to detect several analytes in the same sample towards development of chemical sensors or biosensors [52].

Finally, a proof of concept for the versatility and potential of these planar waveguides structures is the possibility of hybridizing the optical measurement with other non-optical techniques on the same platform. For example, the combination of LMR and surface acoustic wave (SAW) technologies has been used simultaneously to measure, in real time, viscosity and

c

refractive index of the same analyte, respectively (see Fig. 10) [53]. The proposed LMR-SAW sensor platform was calibrated experimentally for a refractive index range between 1.33 and 1.41, reaching a sensitivity of 332 nm/RIU, which corresponds with the second order LMR. At the same time, viscosity was successfully tested in ranges from 1.005 mPa·s to 9 mPa·s with a sensitivity of -1.5 dB/(mPa·s) [52].

In addition, other devices like optical filters, electro-optical transducers, optical modulators, optical monitoring of electrochemical processes, etc. could be also implemented using LMR technology [22, 54-57]. For example, using the experimental set-up of Fig. 11a, it was possible to implement an electro-optical transducer to measure the conductivity of an electrolyte solution. In this case, two electrodes of indium tin oxide (ITO) were deposited on a planar waveguide (see Fig. 11b and 11c), and the voltage applied to both electrodes permitted to modulate the wavelength of the generated LMR by the electrodes of ITO, as can be seen in Fig. 11e. If a drop of a solution containing NaCl (Sodium Chloride) is deposited on these electrodes (see Fig. 11d), it is possible to detect the wavelength shift of the LMR for different NaCl concentrations in water, as shown in Fig. 11f.

Moreover, other more complex patterns than the one presented in the LMR-PW device of figure 11c can be printed in a much easier way than on optical fibers.

V. Conclusion

The transfer of lossy mode resonance phenomenon to a planar waveguide configuration has opened a new set of possibilities that are difficult to obtain in optical fiber. Here some of them were presented: controlling the sensitivities by using any of the strategies above commented, increasing the figure of merit of the sensors, the use of low cost disposable sensor heads based on two different coatings that permit to generate LMRs that operate independently, or the deposition of multiple strips, each of different thickness, which opens the path to multiparameter sensors. Furthermore, the simplicity and flexibility in the fabrication of these sensors permits its hybridization with other optical technologies, like SPR or acoustic-wave technologies as well as the application of nanopatterns to the thin film in a much simpler way and using flexible substrates as waveguides. In the next few years, it is expected that more applications in the domain of biochemical sensors, gas sensing and optical devices will appear. This new low-cost, high-performance, and highly flexible technology enables the next step to follow: actual transfer to market in consumer applications where optical sensors have not previously entered.

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