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Employment the Laser to Fabricate the Surface Plasmon Resonance Sensor

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Abstract

The Optical Fiber sensor based on the Surface Plasmon Resonance (SPR) technology has been a successful performance sensing and presents high sensitivity. This thesis investigates the performance of several structure of SPR sensor in field of refractive index and chemical applications. A structure of Multi-Mode Fiber- Single Mode Fiber- Multi Mode Fiber (MMF-SMF-MMF) had been designed and manufactured. The outer diameter of the SMF sensing region) had been reduced to (65, 45, and 25) µm. This is achieved using the chemical etching method. Then this sensitive area coated with gold layer using Magnetron Sputtering plasma System. The thickness of the gold layer is (40 nm).In most of the previous research in this field of the line of research: the surface Plasmon resonance sensor experiment is conducted using light sources with a wide range of wavelengths. To improve the accuracy of analysis (resolution), helium-neon laser was used as a light source when determining the Plasmon resonance wavelength as a function of the index of refraction of chemical solutions. The sensitivity for samples of salt solutions was 140 and 142 (nm/RIU) for the two dips of the spectrum and the sensitivity for samples of glucose solutions was 38 and 42 (nm/RIU) for the two dips of the spectrum.

Keywords: Chemical optical fiber sensor, Chemical etching, single mode optical fiber, Laser, Surface Plasmon Resonance.

1. Introduction

The first studies in optical fiber sensors that adopted surface Plasmon resonance were conducted in 1993 by Jorgenson and Yee[1].Fiber-optic sensors have many applications in environmental, communication technology, biological, chemical, and medical fields. This is due to the fact that these sensors are small in size and have high sensitivity for minimal changes in parameters of the samples to be sensed [1,2].The surface Plasmon resonance (SPR) sensor relies on the fact that the surface of Plasmon is stimulated by electromagnetic waves and influenced by changes in the refractive index of material around the surface of the metal, which is deposited very thin on the optical fiber core, as an alternative to the lower refractive index of the optical fiber core material [3,4,5].This method of optical detection relies on the principle of the interaction between the free electron waves present in metals and the electromagnetic waves falling on them. Resonance occurs when the wavelength of the incident light is equal to the wavelength of the oscillation of free electrons. As a result of this reaction, the intensity of the wave reflected off the medium is due to a large portion of its energy being transferred to the deposition layer of the metal [6,7].The most important optical elements that can be used to study these processes are high refractive indices prism, optical gratings, and optical fibers that have become widely used recently. These sensors were widely used in science, education, and industry due to the importance of non-destructive samples, its high sensitivity, and acceptable selectivity. When light is absorbed, the surface Plasmon resonance sensor detects resonant electron oscillations across both the metal surface and a dielectric substrate. The advantages of optical fiber sensors are that they are highly sensitive, light in weight, and in small diameter, its exposure to electromagnetic waves is minim [8].

This sensor is usually made of silica fiber and its mode (SMF) and multimode (MMF) types, and because of its cost, it has been replaced by a plastic fiber, which is highly flexible and easy to design. In order to create a strong optical fiber surface Plasmon resonance, it is crucial to improve its efficiency factors including such sensitivity, signal to noise ratio, etc. (SPR). These output properties are mostly influenced by the sensor's geometric layout and a few physical factors, such as the existence of surface treatments and the materials' dielectric continuity. It is claimed that the ideal geometry and the key variables that govern how the sensor interacts are the source of the issue [3].

2. Theoretical concepts

There are a number of parameters commonly studied to measure the performance of such sensors, which use optical fibers as a key component in their construction, by comparing the properties of the input light to those of the output light. The first of these variables is sensitivity, which is defined as the ratio between the change in resonance wavelength values and the corresponding change in the index of refraction of ambient matter and contact with metal, according to the following equation [9].

$$S_n = \frac{\delta\lambda_{res}}{\delta n_s} \quad \text{------ (1)}$$

Where (S_n) is the sensitivity and (λ_{res}) is the resonance wavelength and (n_s) is the equivalent change in the index of refraction.

The most important variable that we've been looking at is how important it is to use a laser instead of a light. This variable is the resolution of the sensor and can be mathematically defined as the least change in the index of refraction of a material that can be detected by the sensor used. It is given the following relationship [9].

$$R = \frac{\delta n_s}{\delta\lambda_{res}}\, \delta\lambda_{DR} \quad \text{--------- (2)}$$

Where (R) is the resolution $(\delta\lambda_{DR})$ is the spectral resolution of the spectrometer

3. Preparing sensor and setup:

The main structure of this sensor consists of three types of optical fiber: the central fiber, which is the sensing region of the single mode (SMF) type, is associated at the end with another optical fiber, which is multimode (MMF), to control the entry and exit of the light signal. SMF fiber with a standard core/cladding diameter (10/125) μm and a suitable length of 3cm.The fiber was stripped and thoroughly cleaned. Then the stripped area was immersed in dilute hydrofluoric acid at 40% concentration for 180 seconds to obtain a diameter of 65μm. The fiber is then cleaned again to deactivate the acid and completely stop the chemical reaction by placing the fiber in distilled water for several minutes. The diameter of the outer fiber has been measured using a (Nikon Eclipse ME600) type of optical microscope with a magnification to (100X). To obtain a layer of surface Plasmon metal, a previous stripped fiber coating with gold Nano particles is done. The most common method used is sputtering to produce a thin film of this material. This method is known as physical vapor deposition (PVD) and occurs in a vacuum of air, where the Nano materials are deposited on the surface of the samples by extracting atoms from the material to be deposited and concentrating them on the samples. As for the gold-layer thickness obtained by this method, it was 40 nm by controlling the process of spraying the thickness of the gold layer could be controlled in this work 15 min was the required time to get this thickness. After this stage was completed, this part of the sensor at both ends was linked to an optical fiber of a (MMFs) type by using an optical fiber splicer machine Fujikura (FSM-60S Japan).

With regard to the preparation of the test samples, which are represented by solutions of different concentrations and correspond to different refractive indices. They were made of both salt and sugar. Concentrations ranged from (0.05 - 0.45) moll/L and these refractive indices were measured using a device Refractometer ((BOECO Digital ABBE Refractometer). For the setup of the experiment, one end of the sensor was delivered to a 632.8 nm Helium-Neon laser source, and the other end was delivered to an optical spectrum analyzer (OSA) (Ocean Optics USB- 2000) with range (200-1100) nm. The reaction area of the sensor, SMF, is submerged in saline and sugar solutions, alternately to show the effect of changing concentrations on the output signal. The reflection spectrum is directly measured and analyzed for each reflection state of the transmitted signal. Figures (1, 2) shows the photographic image at the set up.

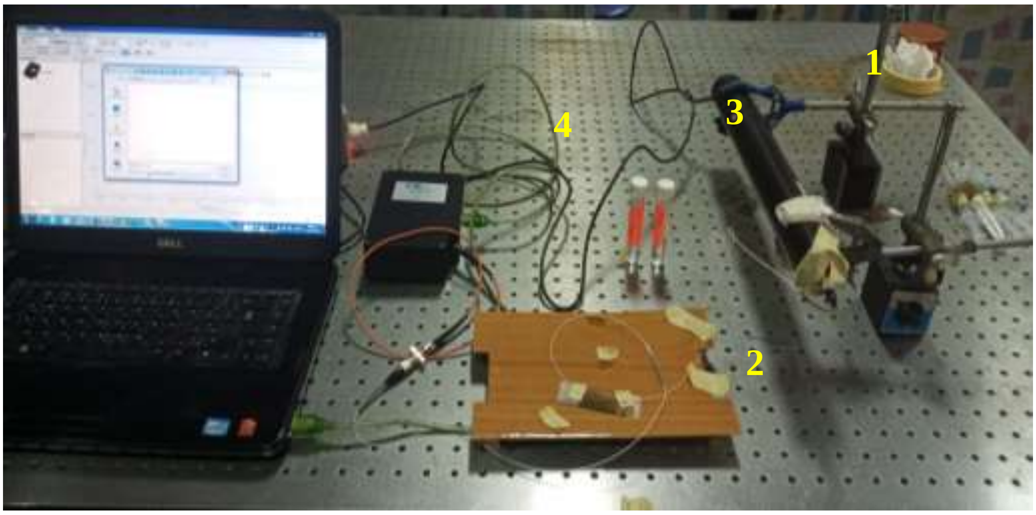

Fig [1] the photographic image of SPR sensor based on macro bending optical fibers where [1] He: Ne laser Source, [2] SPR macro bending Sensor, [3] different solutions, [4] OSA with Pc.

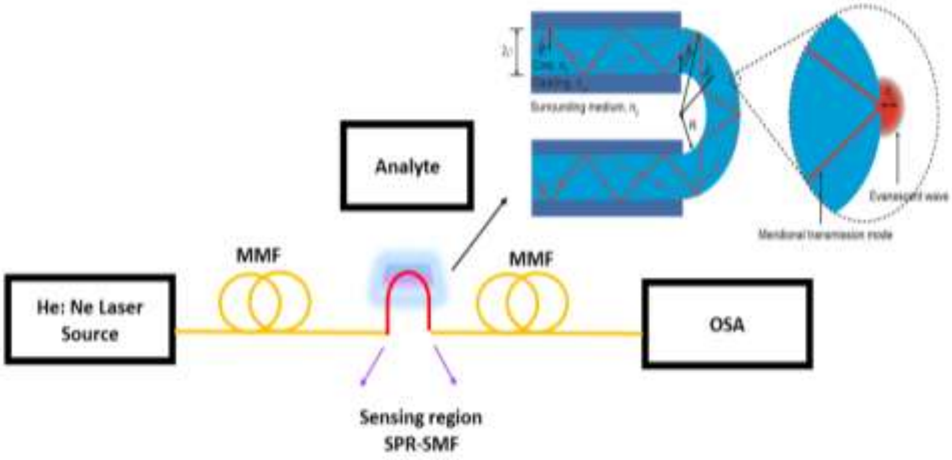

Fig [2] a schematic diagram of the main experimental components and how they are arranged.

4. Results and discussion:

At this stage, some changes have been made to experiments that are typically conducted in this field, using a laser source instead of a conventional light source and increasing the intensity losses of the light entering the sensor by bending the optical fiber at the sensing zone to improve its performance.

4.1 influence of the fiber bending:

To increase the intensity of the light that's involved in the interaction with the surface wave of the metal, the bending of the optical fiber increases the intensity losses of the light that's passing through the optical fiber. When we draw the relationship between intensity and wavelength, for both cases, with and without bending in straight optical fiber and the micro bending fiber, we see that there are multiple dips that represent the intentional losses in intensity that will improve the performance of the sensor. Figure (3) shows that.

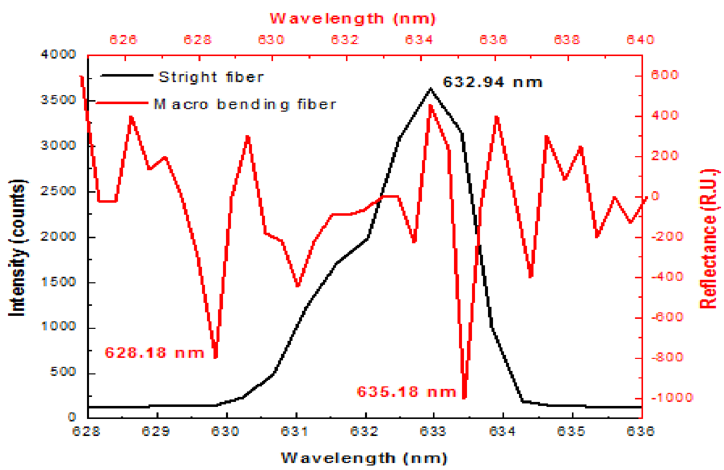

Fig [3] the influence of micro bending in transmitting light

4.2 Measure the resonance wavelength

For NaCl solutions: To test the performance of the sensor, saline solutions of different concentrations (corresponding to different refractive indices) were used. When observing the optical spectrum analyzer, the relationship between laser wavelength and the reflectivity of the metal surface was drawn. In the presence of the solutions, the wavelengths of the plasma resonance and for two dips were determined. The sensitivity of the sensor was calculated by using the equation (1) also the resolution of the sensor was calculated using equation (2) for two dips. From Tables (1, 2) and Figure (4) we can see that there is an improvement in this parameters.

Table (1) illustrate the values of resonance wavelengths and calculated sensor parameters

RI of NaCl solution (RIU)	Resonance Wavelength (nm) for dip 1	Resonance Wavelength (nm) for dip2
1.3436	628.467	635.467
1.344	628.485	635.495
1.3445	628.565	635.572
1.3451	628.602	635.612
1.3456	628.681	635.68
1.3461	628.758	635.768
1.3468	628.823	635.833
1.347	628.903	635.901
1.3476	628.983	635.993
1.3481	629.095	636.095

Table (2) the sensitivities and spectral resolution of macro bending SPR- optical fiber immersed into salt solution

Resonance dip	Sensitivity (nm/RIU)	Spectral Resolution (RIU)
Dip 1	140	7.14×10^{-4}
Dip 2	142	7×10^{-4}

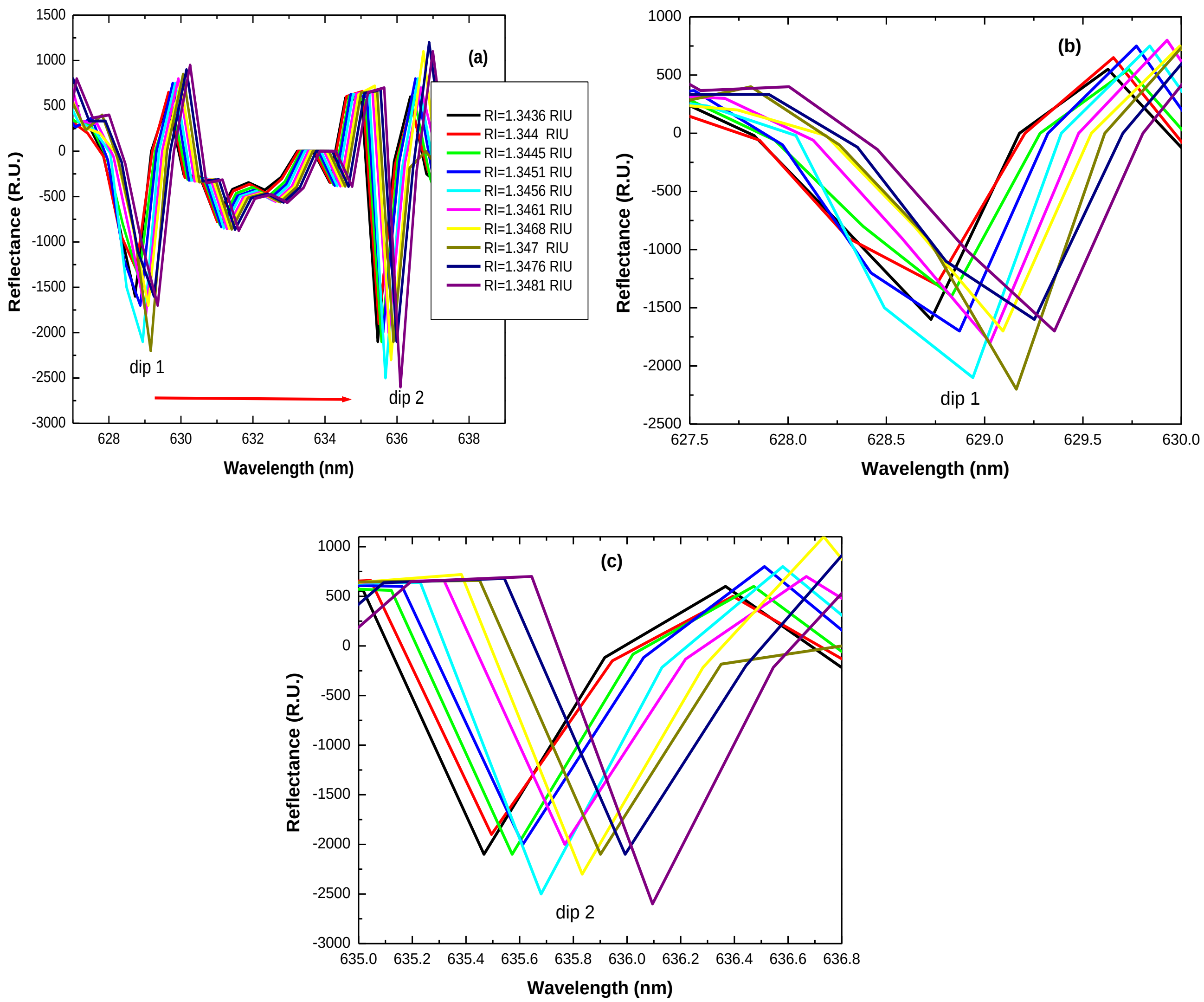

Fig [4] the relationships between wave length and reflectance recorded by OSA in RPS for NaCl at two dips (a) the all spectrum, (b) zoom spectrum of dip1, and (c) zoom

4.2.1 Resonance wavelength as a function of RI

Based on the previously calculated values listed in two Tables (1, 2), the relationship between resonance wavelengths are drawn as a function of the different refractive coefficients of saline for both dips. When looking at these relationships, a direct relationship between the two variables was found, meaning that increasing the refractive index of the saline shifted the resonant wavelength towards the long values (red shift). Figures (5) show these relations.

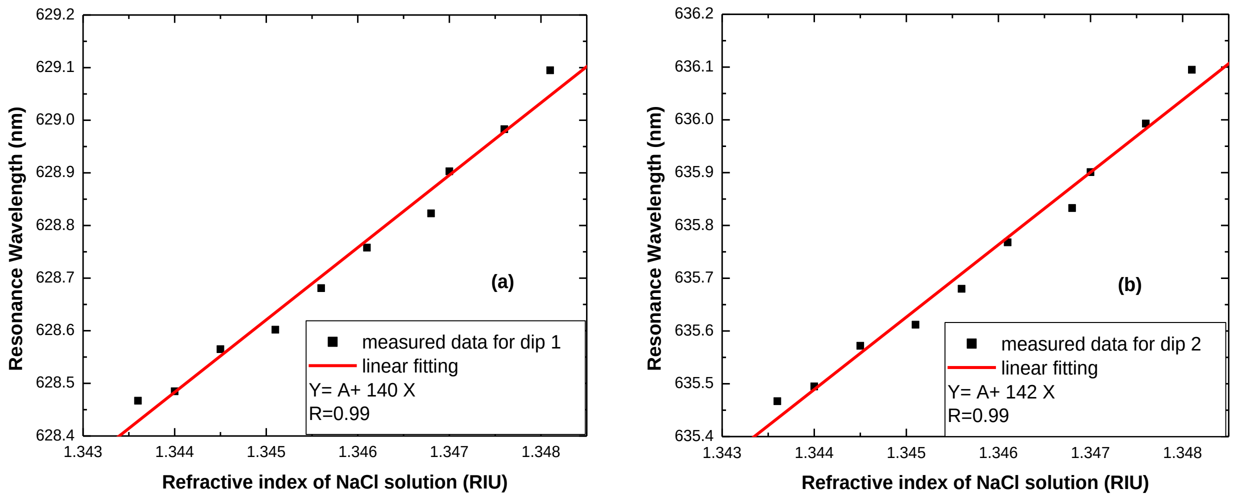

Fig [5] the relationships of RI VS resonance wavelength for NaCl at two dips (a) for dip 1, (b) for dip 2

4.3 Measure the resonance wavelength

For $C_{12}H_{22}O_{11}$ solutions: In this section of research, the sensor was tested using another chemical compound, and all previous brine steps were repeated. As a first step, the compound was prepared in close concentrations, corresponding to different refractive indices with very little change in values, distinguishing this sensor from the others that detect the smallest changes in the samples being tested. This gives different values for the resonance wavelengths for each corresponding index of refraction. After drawing the relationships between the wavelength of light incident at the reaction area of the sensor and its reflectance from the contact layer between the metal and the chemical solution, the Figure (6) were obtained. Using the equations (1, 2) and with the help of the figures drawn, the sensitivity and resolution of the sensor can be calculated, as shown in the Tables (3, 4).

Table (3) the values of resonance wavelengths and calculated sensor parameters

RI of $C_{12}H_{22}O_{11}$ solution (RIU)	**Resonance Wavelength (nm) for dip 1**	**Resonance Wavelength (nm) for dip2**
1.3454	628.479	635.487
1.3481	628.532	635.535
1.3503	628.591	635.585
1.353	628.695	635.78
1.3553	628.774	635.877
1.358	628.872	635.933
1.3604	628.929	636.001
1.3631	628.992	636.096
1.3654	629.085	636.181
1.3682	629.102	636.232

Table (4) the sensitivities and spectral resolution of macro bending SPR- optical fiber immersed into glucose solution

Resonance dip	Sensitivity (nm/RIU)	Spectral Resolution (RIU)
Dip 1	38	$2.6x10^{-4}$
Dip 2	42	$2.3x10^{-4}$

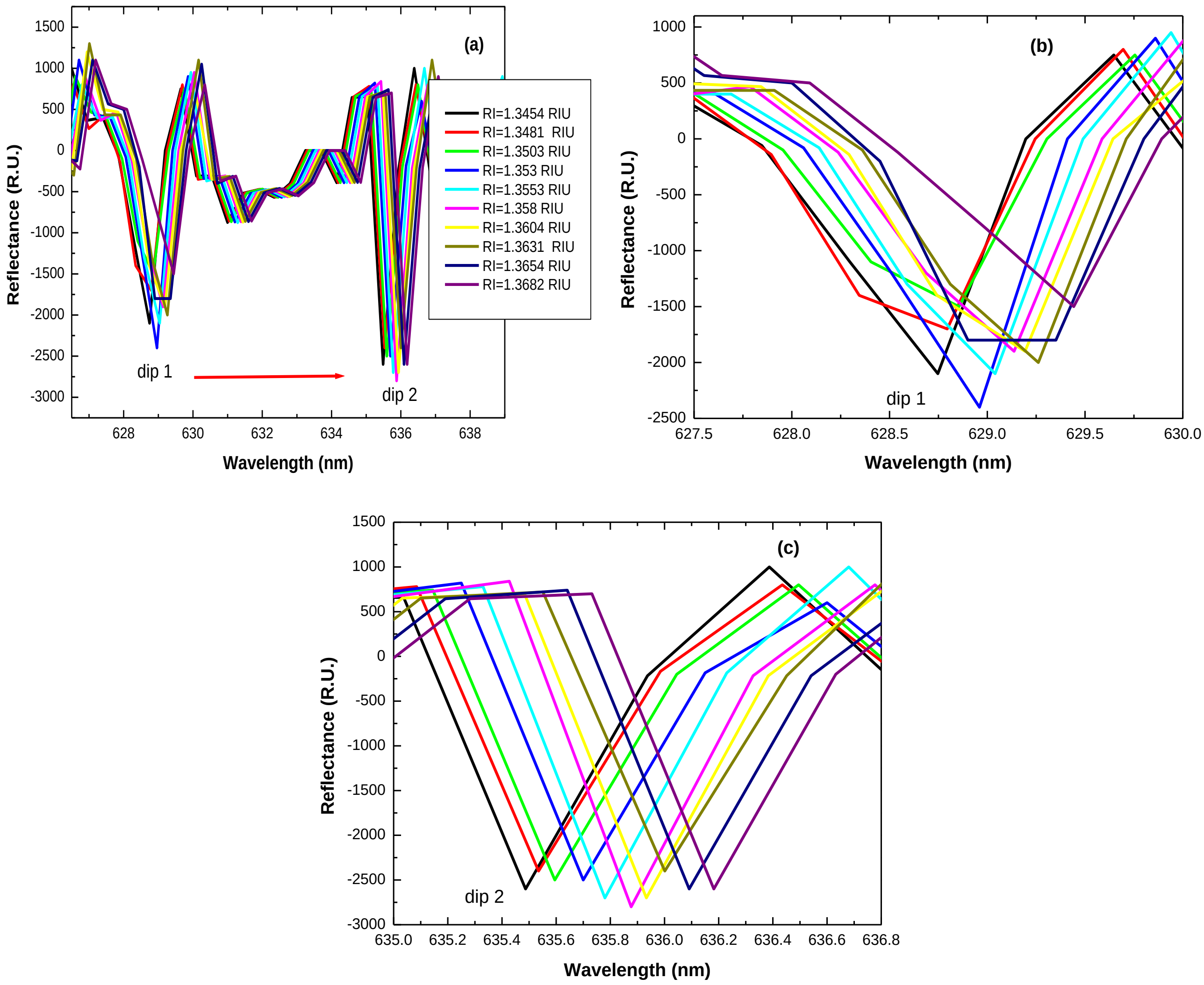

Fig [6] the relationships between wave length and reflectance recorded by OSA in RPS for $C_{12}H_{22}O_{11}$ at two dips (a) the all spectrum, (b) zoom spectrum of dip 1, and (c) zoom spectrum of dip2.

4.3.1 Resonance wavelength as a function of RI

A final step in this research is to draw the relationships between the values of resonance wavelengths obtained from the above figures in the tables for both dips Here we can also see that there is a direct correlation between the indices of refraction and the wavelength of resonance, which is shown by the linear relationship between the two variables. By looking at the Figure (7) below, we can see that there is a clear sense of the least change in refractive index that is reflected in the corresponding values of change in resonance wavelengths.

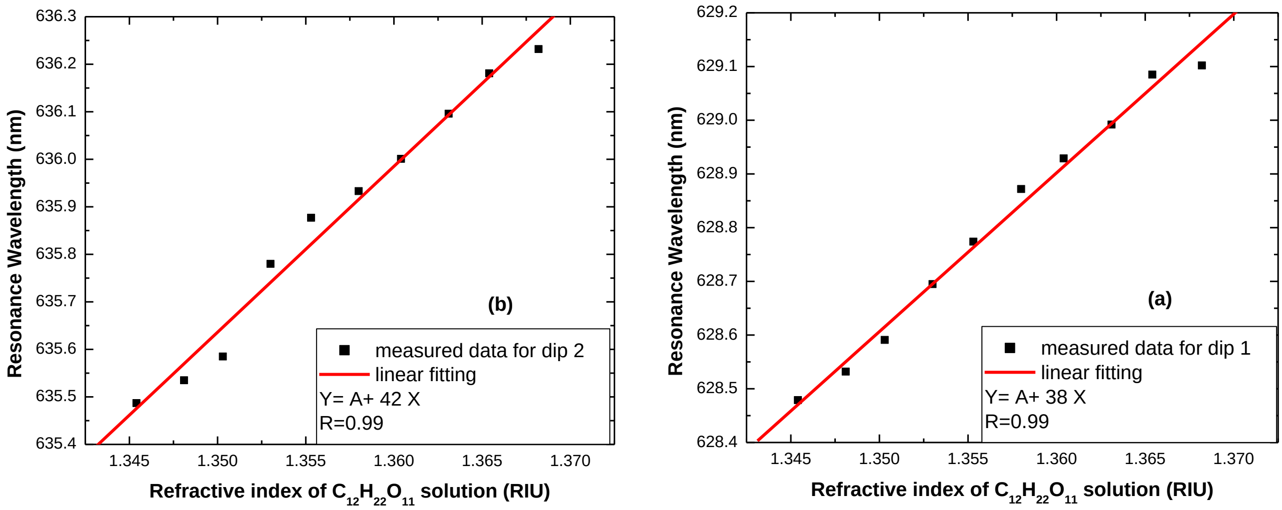

Fig [7] the relationships of RI VS resonance wavelength for $C_{12}H_{22}O_{11}$ at two dips (a) for dip1, (b) for dip2

5. Conclusions

In examining the results of this research, we can conclude that:

- Surface Plasmon is very efficient in sensitizing different chemicals with very different refractive indices, even very small differences.
- When Laser was used as a light source instead of the traditional light sources produces good results in resolution and sensitivity, as evidenced by the appearance of two distinct dips of Plasmon resonance wavelengths.
- Adding micro bending to the optical fiber leads to a deliberate increase in the loss of light in the reaction area, thereby improving the performance of the sensor.

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