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# Optical Fiber Sensors Based on Surface Plasmon Resonance: A Comprehensive Review

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## Abstract

Surface Plasmon sensor is commonly used in chemistry, biologic, and environments nursing. This type of sensor display strange sympathy depends on surfaces Plasmon resonance (SPRs) or localize surfaces Plasmon resonance (LSPRs) effect, which have a commercial application. In this review, we present current progressing in the fields of surfaces plasmatic sensor, principally in the configuration of planar Meta structure and optical-fiber waveguide. In the Meta structures platforms, the optical sensor depend on LSPRs, hyperbolic dispersions, Fanon resonance, and two-dimension (2Ds) material integrations are presented. The optical-fiber sensor integration with LSPRs/SPRs structure and 2D material are summarizing. In addition, we introduced the current advance in quantum plasmatic sensors beyond the classic shot noisy limitation. The challenge and opportunity in this arena is deliberated. The LSPRs biosensor, enabling Nano scale limitation and manipulations of lights, compromise the enhance sensitivity and electromagnetics energies localizations. The combination of LSPRs and fibers-optics techniques is managed to progress the sensors compacts to reduction and remotes recognizing. These comprehensive reviews explore numerous sensors configuration, fibers categories, and geometric outlines, highlight their benefit in term of sensitivities, integrations, and performances improvements. The fabrication technique effort on non-chemical bond strategy and self-assemble of nanoparticle discusses and provide controlling over nanostructures morphologies and enhanced the sensors performances. Bio-application of fiber-optics LSPRs (FOLSPRs) sensor is comprehensive, definitely in bio-molecular interaction and analyze of protein, pathogen and cell, nucleic acid (DNAs and RNAs). Surfaces modifications and recognition structures are emphasizing for their probable in label-free and real-times bio senses. The challenge and prospect of FOLSPRs sensor is addresses, with the development in sensitivities, fabrications technology, and measurements reliabilities. Integrations with developing technology like Nano-material is highlight as a capable directions for upcoming researches. These reviews provide insight into the advancement and possible application of FOLSPRs sensor, pavement the technique for sensitive and adaptable optical bio-sense platform in several arenas.

**Keywords:** Optical Fiber Sensors, LSPR, SPRS, Refractive index sensor, Mach–Zehnder Interferometer, Offset Sensor, Concentration.

## 1. Introduction

Surface Plasmon is combined electrons oscillation that happens at the interfaces among metals with dielectrics, resultant in generate surfaces Plasmon polarities on excitations through lights [1]. This sensation is influence via property of material and incidents lights, permitting to imprisonment with manipulations of lights at Nano-scale [2]. In connection of the oscillate electric fields of the incidents lights with the cooperative motions of electron on the metals surfaces, surface Plasmon could propagated along the metal-dielectrics interfaces, lead to important fields enhancement and the localizations of the electromagnetic energies. If the incidents lights match the wave vectors of the surfaces Plasmon, a depression in the concentration of replicated or transmit lights, identified as the surfaces Plasmon resonances (SPRs) depression, could be observe [3]. This depression is extremely sensitive to change in the refractive indexing (RIs) of the nearby mediums. Therefore, surfaces Plasmon have originate broad applications in label-free and real-times detections of bio-molecular collaboration [4], like DNAs hybridizations and antibody-antigen recognitions, enabled Nano-scales analyzing of biological and chemical interaction over the single property of plasmodia material [5]. The LSPRs is a deviation of the SPRs that occur in nanostructure, such as nanoparticle or periodical array, which have individual plasmodia property [6]. In difference to the SPRs, which relay on macroscopic surface, the LSPRs could be customize by control the sizes, shapes, and compositions of the nanostructure, permitting for tenability of the resonances wavelength and enhance sensitivities [7]. Subsequently, LSPRs sensor is high striking for many requests, include bio-sensing, environment monitor, and Nano-photonic [8]. The combination of the fiber-optic knowledge with the LSPRs has resulting in the advance of compacts and adaptable sensor, simplifying miniaturizations, and remotes recognizing. This advancement is open up novel possibility for high sensitive and compacts optical sensing in several field. Fiber-optic base sensor is gain attentions for their smaller sizes, highly sensitivities, compatibilities with remotes and real-times monitor, and the potentials for multiplex measurement [9]. These reviews aim to offer complete overviews of fiber-optic LSPRs (FOLSPRs) sensor, with a effort on their configuration, type, geometry, fabrications technology, and bio-application. FOLSPRs sensor could be classify into two primary classes: flat headed reflective and straight Transmissive configuration. These conformations offer separate advantage and could be personalized to definite sense requirement, depend on factor like the desire sensitivities, measurements system, and experiment condition [10]. Many fiber type, like single-mode fiber (SMF), multimode fiber (MMF), photonic crystal fiber (PCF), and specialty fiber could be uses in this configuration offering exclusive advantage in term of sensitivities, flexibilities, and integrations with other system. The symmetrical shape employ in FOLSPRs sensor play a important roles in enhance their performances. The LSPRs biosensor with different geometry, include taper, U-types, Ω-types, and D-types shape, efficiently enhanced the sensitivities of the sensor and encounter definite assemblage requirement of succeeding sense structure. Besides, these reviews investigate diverse fabrications technology utilizes in the developments of FOLSPRs sensor. This technique contain top-down fabrications of periodical Nano-structure by focus ions beams (FIBs) or electrons beams lithograph (EBLs), surfaces homemade of nanoparticle, and bottoms-up nanostructure films transfer technique [11, 12]. This fabrications technology permit for precise controlling over the surfaces morphologies of the nanostructure, additional enhances the performances of the sensor. Additionally, the different bio-application of FOLSPRs sensor is reconnoitered; include their utilizations in the detections and analyzing of biomolecule, like protein, DNAs, and virus [13]. Definite surfaces modifications and detections scheme is deliberated in details. The possible application of FOLSPRs sensor in medicals diagnostic, environment monitor, and foods protection is explored [14]. The challenge and prospect in the developments of FOLSPRs sensor could be highlight. This challenge included improves the sensors sensitivities, optimize the fabrications technique, and enhance the reliabilities and reproducibility of sensors measurement. Possible area is upcoming researches and advancement, like the integrations of FOLSPRs sensor with technology like nanomaterial is outline as well. Generally, the purposes of these review is to afford a comprehensive understand of FOLSPRs sensor, the fabrications technique, and the widely ranges of bio-application. Through discovering diverse geometry, fabrications technology, and application, this reviews aim to contributed the advancements and adoptions of FOLSPRs sensor in field like humans health, drugs screen, foods protection, and environment nursing.

## 2. Principle of SPR

In general, when the lights waves are incident into lights dense mediums from a lights spare medium with the angles larger than critical angles, the phenomenon identified as whole reflections take placed. Within this situation, even if the lights waves not penetrated the critical interfaces among the two medium, it generate an evanescent waves along with the directions comparable to the critical interfaces. As the space from the critical surfaces increased, an exponent declined might be realized in difficult amplitude of the electrics and magnetics field with the waves that is evanescent [15]. Figure1 shows that the incidence of free electrons gas in the metals permits it to behaves like plasma. If the incidents lights interact with the metals, it induces longitudes oscillation in the electrons gas. Resultant in the oscillation, the formations of charges density waves result in the generations of a surfaces plasma waves that travel along the metals-dielectrics contacts [16]. The intensity of the monitor reflects lights are considerably reduced as results of the resonances amongst the metals surfaces plasma waves and the evanescent waves [17]. The SPRs is the names give to this phenomenon. The outline of reflects lights intensity will exhibits a trough when the relate wavelengths (or angles) match the resonances wavelengths (or resonances angles) [18].
Surface Plasmon resonance happens if the photon of incident light hit metal surfaces (usually gold surfaces). At a definite angles of incidence, a slice of the light energy combines over the metal coating with the electron in the metal surface layers, which then transfer due to excitations. The electrons movement is now named Plasmon, and they propagated parallel to the metal surfaces. The Plasmon oscillations in turn produce electrical fields whose range is about 300 nm from the boundaries among the metal surfaces and tester solutions. In a profitable SPRs biosensors conformation, incident light is used by employing a high-reflective index glass prism in the geometry of the attenuate total reflections (ATRs) technique. The definite SPRs angles, at which resonance occurs, on the conditions of the constant light source wavelength and metal thin surfaces, are reliant on the refractive index of the material nearby the metal surfaces. Therefore, when there is a smaller variation in the reflective index of the sensing medium (e.g., over biomolecule attachment), Plasmon not be molded. Finding is thus accomplish by computing the change in the reflect light achieved on a detectors. Additionally, the quantity of surface concentrations could be quantified by monitoring reflects light intensities or tracking the resonance angles shift. Typically, an SPRs biosensors has a detection limits on the order of 10 pg/mL.

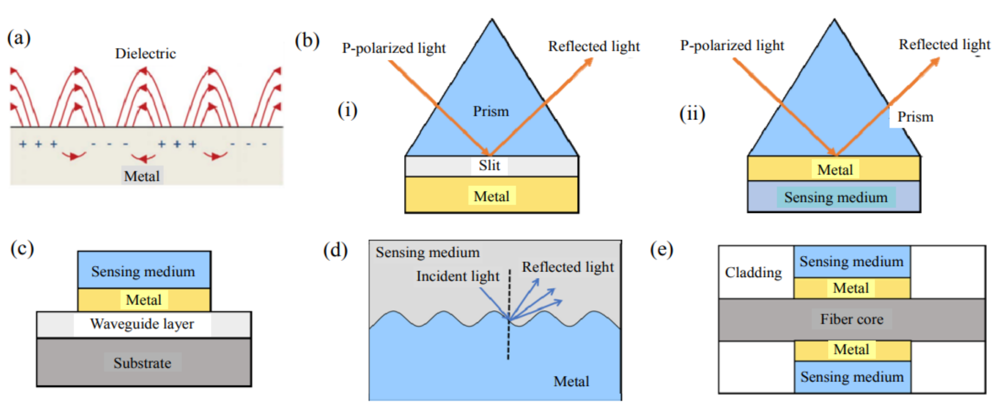


**Figure 1:** Schemes structure of SPRs: (a) SPRs on a planar metals films; (b) prism-couple excitations SPRs: (c) waveguides couplings devices; (d) gratings-couple SPRs excitations structures; (e) optics fibers types SPRs sensors.

The partitioning amongst the wavelengths and angles is mostly base on whether detections systems use wavelengths interrogations or angles interrogations. The sensors are sensitive to RIs of mediums attach to surfaces of metals films, and the resonances angles will be diverse if the property of surfaces mediums changed or if the quantity of attachments changed**.** The incidents lights could be decompose into S-polarize (TEs waves) and P-polarize (TMs waves), and this type of polarize lights is perpendiculars. Surfaces Plasmon wave is not excite by the electrics fields of S-polarize lights due to it is transverses to interfaces and has no impacts on migrations of free electron with the metals; the electrics fields of P-polarize lights is perpendiculars to the interfaces, that could be induced surfaces charge and forms SPRs phenomena, which confine to the surfaces. Consequently, the essential conditions for producing SPRs are the presences of P-polarize lights at incidents lights [17].

## 3. Surface plasmon-based sensors

The advantages of optics fibers-couple SPRs sensor [18] over other SPRs sensor is that they are modest to used, take up relative slight spaces, are high sensitive, and exceptional stabled. Consequently, in current time, further researcher devoted themselves to these studies to advance their performances. Physically improve fibers optics SPRs sensor sensitivity so far, numerous types of optics fibers structure, mostly D-types probe, U-types probe, and taper probe. The key type of optical fiber is singles modes fiber (SMF), multimode fiber (MMFs), photonics crystals fiber (PCF), plastics optical fiber (POF), and fibers Braggs grating (FBG).

### *3.1 Surface Plasmon Resonance*

### *A.Plasmon Oscillation*

There is a thick assemble of negative charge free electron in the conductors and an equal charge positively ions lattices. Then, positively ion have an infinite larger mass compare to this free electron, hence, rendering to jellium models, this ion could be replace by a positively constants backgrounds. Though, the whole charges density in the conductors still remains to be zeros. When the density of free electron is local reduce by apply an externals fields on the conductors, so that the movements of free electron might take places, the negatively free electron is not screen by the backgrounds and they initiate to become attract by the positively ions backgrounds. These attractions act as heavy forces for free electron and they moves to positively regions and accumulated with a density larger than required to attain charges neutralities. Nowadays, at this points, the Coulombs repulsions amongst the move free electron act as a restore forces and produce motions in differing directions. The resulting of these force set up the longitudes oscillation amongst the free electron. This oscillation is recognized as plasma oscillation. A Plasmon is a quantum of the plasma oscillations. The existence of plasma oscillations has been verified in electrons energy-losses experiment [19, 20].

### *B. Surface Plasmon*

The metals-dielectrics interfaces support plasma oscillation. This charged density oscillation in the metals-dielectrics interfaces are recognized as surfaces plasma oscillation. The quantum of this oscillation is denotes as surfaces Plasmon. This surfaces Plasmon is complemented thru the longitude (TMsor p-polarize) electrics fields, that decay exponential in metals and dielectrics. Because of these exponents decline of fields intensity, the fields has its extreme at metals-dielectrics interfaces itself. These property of surfaces Plasmon being TM-polarize and exponent decline of electrics fields are create by solve the Maxwell's equations for metals-dielectrics type of refractive indexes distributions. Through the solutions of Maxwell's equations, one could display that the surfaces Plasmon waves propagations constants is continuously over the metals-dielectrics interfaces

### *C. Surface Plasmon Excitation by Light*

The maximal propagations constant of the light wave at frequencies propagate over the dielectrics mediums is given by frequencies, the propagations constants of surfaces Plasmon is larger than that of the light wave. Therefore, the directs lights not excited the surfaces Plasmon at a metals-dielectrics interfaces and is referred to as non-radiated surfaces Plasmon. Consequently, in order to excited the surfaces Plasmon, the momentums and therefore the waves vectors of the excite lights in dielectrics mediums must be increases. The further momentums should be informed to lights waves to develop the surfaces Plasmon excites at metals-dielectrics interfaces. The common ideas after this configurations is coupling of surfaces Plasmon waves with the evanescent waves, that is setup because of ATRs at the bases of a couple prisms when a lights beams is incidents at an angles bigger than the critical angles at prisms-air interfaces [21]. The natural of evanescent waves is recognized to have the propagations constants along the interfaces and to decline exponential in the dielectrics mediums nearby to metals layers.

### *3.2 Fibers-Optics SPRs Sensors*

Outline of optical fiber in the SPRs sense systems are depend on the logic reasons that direction of lights in optic fiber is also depend on total internals reflections (TIRs). Meanwhile, a prism is use in SPRs sense systems to produce TIRs at the prisms-metals interfaces; hence, couple prisms use in the SPRs theories could be convenient replace by the cores of an optical fiber to designing the fibers-optics SPRs sensors. Amongst another main reason are the advantage of optical fiber by couple prisms like modest and flexible designing, miniaturizes sensor systems, and ability of remotes sensor. Generally, the silicon clad from a definite smaller portions of the fibers cores is eliminate and is coated with a metals layers, that additional enclosed by a dielectrics sense layers. The TIRs take place for the ray propagation with an angle in the ranges changing from the critical angles (depend on the numeric apertures of the fibers and the lights wavelengths) around 90. Therefore, the evanescent fields are produced, that excite the surfaces Plasmon at the fibers cores-metals layers interfaces. These couple of evanescent fields with surfaces Plasmon intensely depends on lights wavelengths, fibers parameter, fibers geometries, and metals layers property. As an example, couplings mechanisms will be unlike for singles-mode and multimode optic fiber because of have many modes of transmissions property depend on a numbers of mode in fibers which will supporting. Likewise, straights fibers and taper fibers will shows changed strength of lights couple due to this fiber will display many penetrations depth of evanescent fields because of have many geometric configuration. The taper fibers show a substantive variant in evanescent fields penetrations along the taper sense regions lengths while an un-taper fibers exhibit uniforms penetrations of evanescent fields along the sense regions. Additional, penetrations of the evanescent fields and, hence, strengths of lights couple with surfaces Plasmon depend on an important fibers parameters recognized as numeric apertures that relate to lights reception limits of the fibers. Besides, different prisms-bases SPRs geometric, the numbers of reflection for utmost of the angle is larger than one for fibers-bases SPRs sensors geometric. Nearby its angles, the numbers of reflection for some rays depend on another fibers parameter, specifically, sense regions lengths, and fibers cores diameters. The numbers of reflection straight affect the SPRs curves widths, hence, performances parameter (SNRs and sensitivity) of the sensors depend on fibers property. This different aspect relate to fiber optic and geometric property along with their advantage and disadvantage Lastly, the spectrums of lights transmits after pass over SPRs sensor regions is detects at the other ends. The sense is accomplish by observe the wavelengths correspond to the dips in the spectrums. These wavelengths are named as the resonances wavelengths. Plots of resonances wavelengths with the refractive indexes of the sense layers give the calibrations curves of the fibers-optics SPRs sensors. Different prisms-bases SPRs sensors where angular interrogations technique is usage, the spectral interrogations technique is uses in the fibers-optics SPRs sensors due to the fibers-optics sensors all the guide mode is launch in the fibers [22].

## 4. Geometric structure of folsprs sensor

FOLSPRs sensor is commonly usages for sensitive detections and analyzing of bio-chemical reaction. The LSPRs occurrence happens if the light interacts with Nano-scales metals structure, resultant in spectral shifts in the resonant frequencies that is sensitivity to the RIs change in adjacent mediums. To growth the sensitivities, selectivity, and versatilities of LSPRs sensor, the geometric configurations of fibers probes is continuous modify. Classically, the LSPRs' sensing performance could be efficiently realized by using diverse types of optical fiber, optimizing the geometric structures of fiber probes, and adopting diverse optical transmission modes. This geometry provides unique advantage in term of sensitivities, stabilities, and multiplexes capability, depend on the definite designing. Generally, the geometric formations of FOLSPRs sensor play vital roles in determine the sense performances and enable preparation application in biomedical sense, environment monitor, and chemical analyzing.

### 4.1 Propagations paths of lights

A LSPR phenomenon in a fiber-optic sensor is created by the interactions among light and metallic nanoparticles or nano-arrays immobilized on a fiber. The LSPRs' effects occur if the incident lights match the resonant frequencies of the nanostructure in the passing fields, resulting in a robust absorption or light scattering. These interactions are determined by the plasmatic property of the nanostructure and could be quantified by using the Mie theories. Through monitor the spectral responses of the scatter lights, change in the nearby RIs could be detects, enable the sensitive detections of many analytic or environment parameter. The two key formations for FOLSPRs sensors are based on the propagation paths of light: straight transmissions [23] and flathead reflections [24]. Figure 1 shows the straight trans missive FOLSPRs sensor system. Incident lights are coupled into one end of the fibers and propagated over the fibers' cores. The LSPRs-active nanostructure is immobilized on the side-outers surfaces of fibers as the sense zone. The lights are received by signals-receive devices at the other ends. As the lights interact with nanostructure along the transmission paths, the LSPRs effects induce a change in the transmitted light's intensity or wavelengths, which could be measured at the output ends.

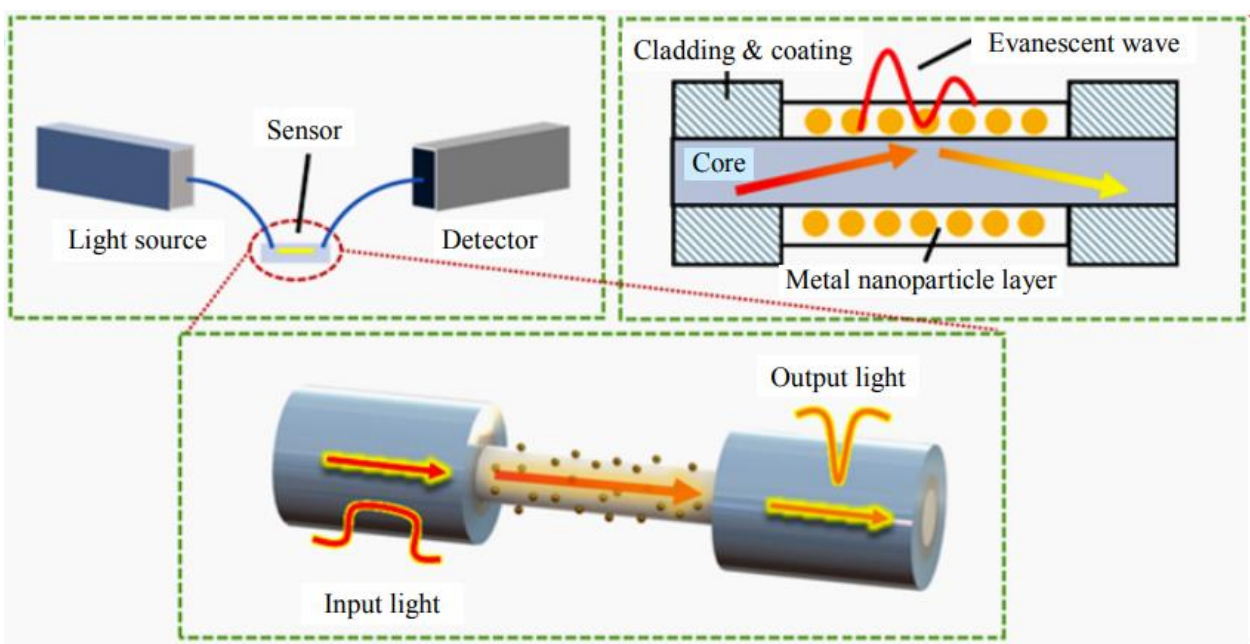


**Figure 2:** Configuration of straight Tran's missive [24]

In difference, as shown in Figure 3, the flat head reflected configurations use one side of fibers to transmitted the incidents lights and received the end-faces reflects signals over a fibers-optics couplers. The LSPRs-active nanostructure is immobilize on the fibers ends-faces or on the side-outers surfaces nearby the ends of the fibers probes, while the reflect lights from the sense areas are collects and analysis to determined change in the intensity or wavelengths. The flats head reflective configurations allow for integrations with external system, like spectrometer or detector, and is appropriate for application where directs accessing to the samples are desire, such as in implantable medical diagnostic [25].

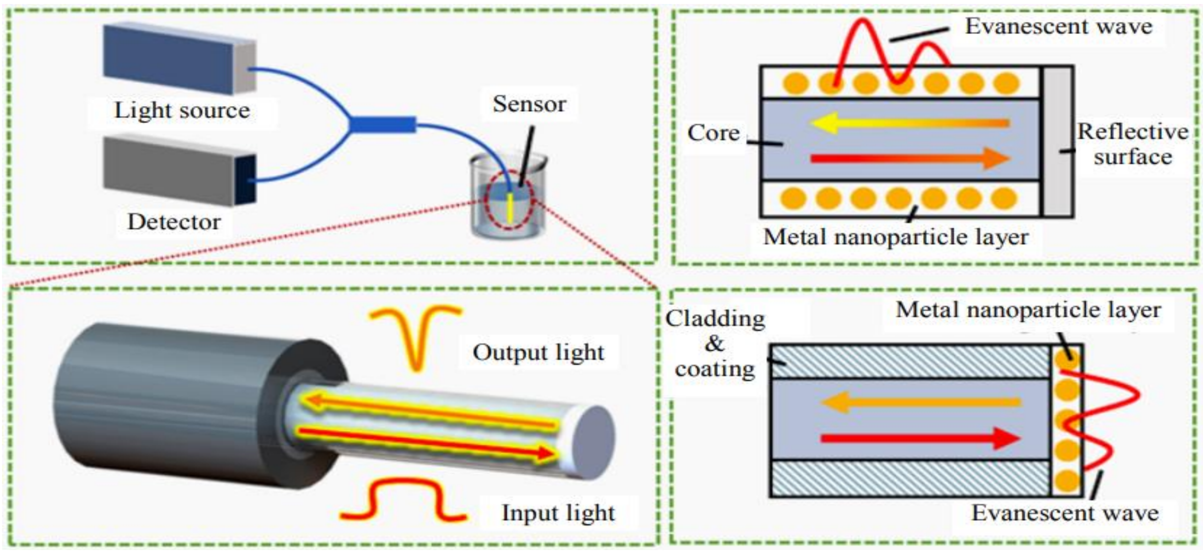


**Figure 3:** Configuration of flat head reflected FOLSPRs sensor [25]

The selection between these structures depends on numerous aspects. One vital aspect to deliberate is a characteristic of samples being analyzing. As examples, if the samples are sensitive to contact or require non-invasive approaches, the straight transmission structure will be more appropriate as it permits sensing over long distances without direct contact with the samples. These are mainly advantage in biological or hazardous environment. When a direct access to the samples is preferred, like in implantable medical diagnostics, the flat head reflector structure will be desired. These structures allow for easy integration with an outward system, like a spectrometer or detector, enabling effective analysis of reflected light from the sensing areas on the end faces or side surfaces of the fiber probes. Other serious considerations in case of selecting the structure are the definite sense requirement. All configurations could be measured by the change in the transmit lights' intensity or wavelengths induced by LSPRs effects. Though, the straights transmissions structure might offer improved stabilities and repeatability's because of a long interactions paths of lights with the LSPRs-actives nanostructure beside the fibers cores. The flat head reflects structure might offer improved sensitivities in measurement, as it relies on the precise assembly of reflected lights from the smaller bottom sense areas. Compatible with measurements system is vital factors. The straight transmission configuration is moderately simple, requiring signal-receiving devices at one end of the fibers to measure changes in transmitted light. The flat head reflect configurations with the addition Y-shape fibers-optics couplers impose high requirement on the smoothness of the fibers ends faces to ensures the suitable optic couple effectiveness.

## 4.2 Category of Optic Fibers

Substituting the traditional prisms with the optical fibers as Plasmon component could overcome the limitation of the relative bulk sizes, complex optical and mechanical structures, and incapability for remote and on-site sensing. In addition, it offers advantages like mobility and implant situ detection. Subsequently, the major reports of the fiber-based SPR sensors were introduced in 1993 with many types of optical fibers as presented in Figure 4 (a), which applies in the Plasmon resonances sense, containing SMF, MMF, hollow-core fibers (HCFs), PCF, micro/Nano fibers (MNF), and FBG. The conventional SMFs and MMFs are extensively use because of their matured manufacture processing. Though, these types of sensors primarily realize LSPRs sense by use the method of cores mismatches, decreasing the width of the clad, or use the fibers ends faces, then the passing field cannot penetrated the entreats big width clad to excited the metals nanoparticle on the surfaces of the fibers to produce the LSPRs. A metallic particles monolayers act as a plasma nanostructure that enhance the passing field interactions with the targets analytic. The geometric could varying, include straight, tapered, or U-shape configuration, depend on the preferred sense outcome. Compared to another fibers structure, the SMFs-LSPRs sensors utilize the passing fields of guide modes to interrelate with the analytic, provided solidity, simplicities, and compatibilities with present fibers-optics system. Though, the elimination of SMFs clad requires the uses of robust acid design or polished procedure that hazardous and composite. This process has the probable for resultant in rough on the sense surfaces, afterward decreasing the sensitivities of the sensors. Else, the MMFs are the greatest wide uses in LSPRs sensor since it offers numerous benefits over the conventional SMFs-LSPRs sensors. The MMFs allow for propagations of multiples mode of lights, resultant in enhance sense capability as illustrated in Figure4 (c). The collective processing of eliminating the plastics coat from MMFs only required a modest physic strip. Compare with SMFs-LSPRs sensors, these simplify processing is beneficial in attaining a stabled structures for senses performances. In addition, its greater cores diameters facilitate the couple of lights to the sensors, make it more effectual and improve the signals-to-noise ratio (SNR) [26].

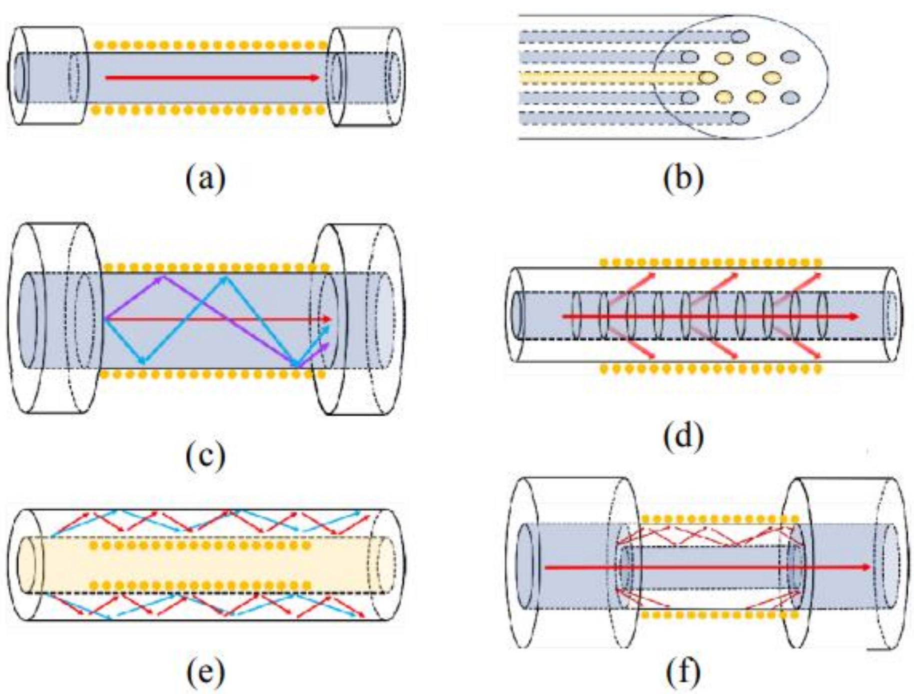


**Figure 4:** fiber optics types (a) SMFs, (b) PCFs, (c) MMFs, (d) FBGs, (e) HCFs structures fibers [26]

The HCFs is a field fiber with not solid cores structures. The sense structures of HCFs-LSPRs sensor considerably different from the other, as shown in Figure 4(e). Moreover being capable to create sense regions on the outer surfaces of fibers, which allow for the alteration of metals nanoparticle on inners walls of the HCFs [27]. The single structures of HCFs enable the internals air channels to serve as the fluid flows channels [28]. These designing help to minimize the influences of the externals environments on the fluid. Particularly, for PCFs-LSPRs sensor in Figure 4(b), the mixture of PCFs with LSPRs could converts the transverse magnetics (TMs) model establish in conventional plan waveguide into hybrid mode. These transformations could be facilitating by adjust the air hole-base structures of PCFs itself, permitting for easy phases match among the cores modes and LSPRs modes, and thus producing the LSPRs under exact wavelengths condition [29]. Additionally, PCF offers the advantage of the compacts sizes and different internals air holes design. The sense regions of this fiber could be configures to accommodates metals nanoparticle with diameter lesser than or significant small than the air hole [30]. Otherwise, metals nanoparticle could be place outsides the PCFs or selective occupied within parts of the air hole [30-35]. Though, the fabrications processing for satisfying the air hole present enormous challenge, and the detections ranges are narrow. Consequently, the present researches on PCF-LSPRs sensor is mainly in the theoretic analyzing [36]. There are an sufficient scopes for enhance structure designing and detections stabilities. In its place of eliminating a sections of clad to accessing the cores-guide lights, grating that have been photo-inscribe in the cores could instead be utilize to diffracts a portions of the lights into the clad as show in Figure 4 (d). in this case the major advantage utilized the FBGs are least impacts on mechanic resistances of the fibers and couple of grating is a resonant spectacle that only occur at definite wavelength in guide configuration. Then the related to a couple resonators systems, diverse fibers mode coupled at diverse wavelength where the gratings couple two fibers mode and the metal particle layers couple a fibers modes to a localize surfaces Plasmon portion. If the two resonance overlapping and gratings resonances becomes sensitive to change in the LSPRs, therefore, because of mode couple limitations, longer periods fibers grating (LPFG) and tilted FBG (TFBG) could be direct use for LSPRs sense, while conventional shorted periods fibers grating required clad detached. The FBGs-bases LSPRs sensor [37] could offer the greatly narrow bandwidths compare to the traditional FOLSPRs sensor. Nevertheless, it is challenge to stimulate the LSPRs in the communication wavelength range use metals nanoparticle, requiring the uses of unusual design like nanowire or periodically array. The LPFG base LSPRs biosensors operate in the noticeable spectral ranges reaches a limitation of detections (LODs) lower than to 0.02µm for glyphosates [38]. The interactions of cyst amine and glyphosates lead to the changes in the operative RIs of LPFGs clad mode, producing spectral shifts in LPFGs attenuations band. The entire effects are bases on the resonances among the LPFGs attenuations band and LSPRs induce by nanoparticle that increase the sensitivities. Additionally, some strategy utilize honorable metals nanoparticle to improve the sense signal of TFBG base sensor is claim as FOLSPRs sensor. The surfaces modifications of TFBG with golden nanoparticle or golden Nano cages could realize many-folds to numerous ten-fold enhancements in the detections sensitivities of molecule, like protein and glucoses [39-42]. Though, because of the important differences in excitations wavelength among the detections spectral ranges (classically about 1500nm) and LSPRs of metal nanoparticle (classically in the observable lights ranges), we prefers to refers to this strategies as the localize electromagnetic fields enhancements for sense. Presently, some superior optical fiber or hetero-cores fiber show in Figure 4(f) are uses in the creation of LSPRs sensor. The MNFs-based LSPRs biosensors offer larger fraction of evanescent field and higher surfaces fields intensity, creating it high sensitive to disturbance in the nearby mediums, particularly for the LSPRs sense structures [43-45]. These structures facilitate the formation of a Plasmon-enhance is nearby-fields fibers probes for LSPRs sensors. Through adjusted the tips designing, the resonances wavelengths of the probes can be tune in the ranges of (500 – 850) nm, exhibit a smaller full widths at half supreme (FWHMs) of 90nm. Also, the hetero-cores fiber such as MMFs-SMFs-MMFs [46], MMFs-PCFs-MMFs [47], PCFs-FBGs [48], and curved fibers-taper seven-cores fibers-convex fibers [49] splice structure adopting the cores mismatches schemes to realized higher sensitivities exterior biomasses sense, and numerous usual hetero-cores fiber base on LSPRs sense structure is show in Figure 4 [50]. The LSPRs excite by nanoparticle play significant roles in improve the sensitivities and reduced the LODs for bio-sense. A fragment of the multicores fibers comprise 7 core arrange in a hexagonal shapes splice with SMFs is employ as LSPRs biosensors for cancer cell detection as show in Figure 5(a). The propose sensors structures is etch in a controlling manners to increases the evanescent waves and couple of mode among the core of the multicores fibers. The sensitivities are added increase by immobilize diverse nanomaterial, like optimize sizes of gold nanoparticle, grapheme oxide, and coppers oxides Nano-flower on the multicores fibers.

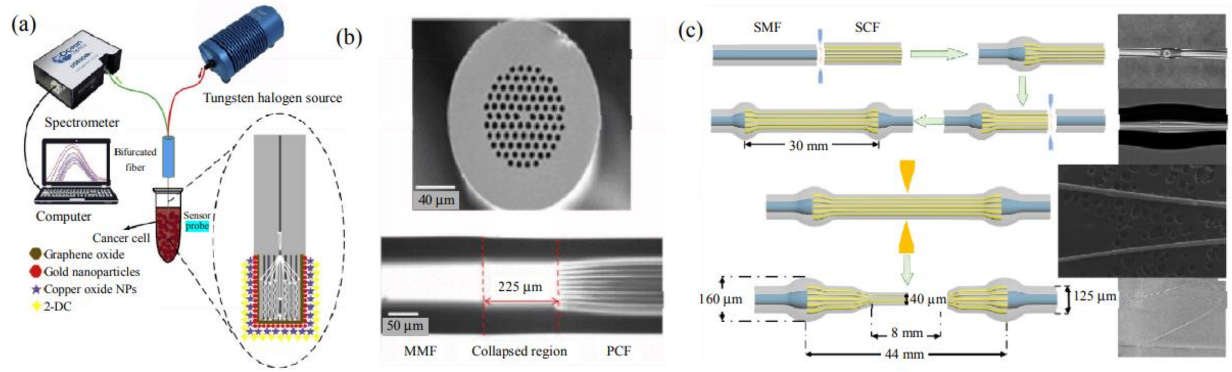


**Figure 5:** Hetero-cores fiber base LSPRs sense structure: (a) multicores fibers and SMFs base structures [46], (b) MMFs-PCFs-MMFs structures [47], and (c) convex fibers-taper 7-cores fibers-convex fibers structures [48].

## 4.3 Geometrical of Optical Fibers Probes

Altered method of splice numerous diverse type of optical fiber collected, the methods of properly modify the geometrical shapes and structures of optical fibers to improves the performances of LSPRs fibers-optics biosensor is attract widely attentions. Depend on this distinct shape, LSPRs biosensor with superior geometry could be mostly categorize into numerous commonly type: the tapering, U-types, Ω-types, and D-types. Figure 6 shows the classifications of LSPRs biosensor with singular geometric, and an example of a representative structure corresponds to every class. The SMFs are strongly able to restrict the incident lights. The energies carried by high-order modes leak into the clad as a passing wave propagates. Though, this high-orders mode carrying lower energies and it is hard to forms strongly passing fields [51]. Therefore, the intensities of the passing wave produced by the feeble passing fields are lowest; creation the phenomenon of excited the LSPRs lesser clearly. In contrasts, if a fibers is taper as illustration in Figure 6 (a), the capability of cores to confined lights is importantly reduces, resultant in a massive changes in the modes of the transmit lights. The energies of the transmit lights are couple into the clad, creating a strongly passing fields with a larger penetrations depths, that in turns excite the LSPRs [51]. Three main techniques for fabricating taper optical fiber include grinding [52], chemical etching [53], and fusion taper [54, 56]. Amongst that, the grinds technique is relative primitives, solitary utilize mechanic tool to polishes and creation a taper shapes nonetheless with high mechanic strengths. Though, it suffering from deprived repeatable that required high processing accuracies. The chemicals etch methods are involve by uses a fluorides-base solvents with a accurate ratio for corrosions. Regardless of its simplicities and costly-effective, accurate control the tapers angles prove challenge, leads to dispersions issue. In disparity, the fusions taper methods, the greatest effectual and wide employ techniques for creating taper fiber. It involves heat the fibers to a melted states by use flames or arcs discharges, shadowed by gradual taper under the apply tensions. These approaches facilitate detailed controlling over tapered and shapes, remnants modest by externals factor, and yield the greatest repeatability and accuracies. Besides, academics have openly explore the SMFs-LSPRs sensor with numerous design base on the solitary tapers units [57-60], include the periodical taper structures, tapers-in-tapers structures, truncate semi-tapers structures, and even serials quadruples tapers structures [61]. The sensor structure offers high sensitivities, though, as a numbers of taper increased, the fibers become further breakable and easy to breaks than the origin fibers structures, that need to more overcomes.Structures of U-shape fibers LSPRs sensor appearance in Figure 6(b) is bend the sense region to U-shapes and the angles of lights perpendiculars to the cores-clad interfaces could be changes. In order to optimizing and enhancing the sensitivities, the outers bend radius could be attuned. As the bend radius of the fibers decreased, the RIs sensitivities increased also. When the radius decreased to definite values, the sensitivities reach to maximal. Though, additional reducing the bend radiuses could results in a decrease of the sensitivities. Then, explore the optimum bend radius could efficiently improves the sensitivities of U-shapes fibers LSPRs sensors [62].

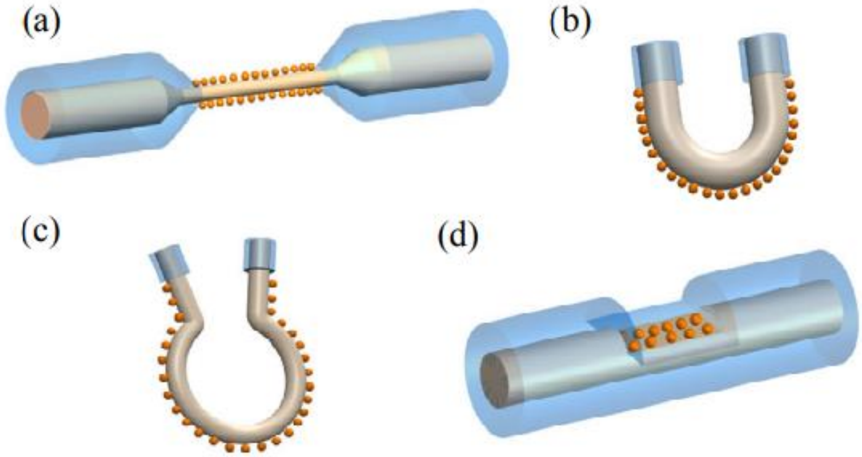


**Figure 6:** Classifications of LSPRs biosensor and geometric with classic structure: (a) taper, (b) U-types, (c) Ω-types, (d) D-types [61].

This approaches propose U-shape LSPRs sensors depend on AuNP which is proficient of detects bulks refractive indexes change with sensitivities and a resolutions of 540nm/RIs and $3.8\times10^{-5}$ RIUs, correspondingly. The result achieves in biosensors application is promise with slightest LODs of 0.8nM of anti-IgG. The U-shape fibers sensor is informal to fabricated and appropriate for penetrate in a narrows gap. Though, they could easy breaks throughout the bend processing, and the smallest bend diameters are limits, make it hard to more improve the sense performances. Depend on the sensitivities enhancements principles of the U-shape optical fibers sensors, to more increase the bend radius and bend lengths; S-shape sensor was projected by [63]. Compare with the solitary bend structures of U-shape sensors, the S-shape sensors with two bend structure has high sense sensitivities because of the small bend radiuses and long bend lengths. Rendering to the experiments conclusions in [64], an RIs sensitivities S-shape fiber are about 1.5 times the U-shape fibers as illustration in Figure 6. While S-shape fibers are high sensitive, its breakable structures with numerous bend make it easy damage by faster fluid flows, resultant in deprived practical. Additionally, the Ω-shape LSPRs sensors show in figure 6(c) exhibit enhance performances with small radiuses and long bend lengths, meanwhile the Ω-types fibers cause lights attenuations in bend parts because of its interactions with nearby environments, resultant in the bend losses [65].

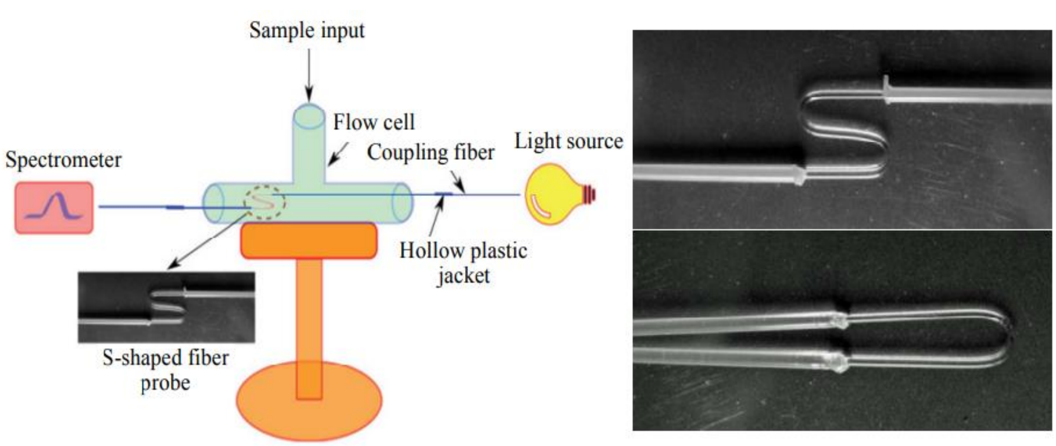


**Figure 7:** S-shape FOLSPRs sensors and SEMs image of S-shape fibers and U-shape fibers [66-70]

Amongst to another bents fiber like U-shape and S-shape, the Ω-shape fibers permits further fundamentals mode to transfers from the fibers cores into the clad and induce a transitions of the propagation modes from fundamentals modes to a high-orders modes, thus considerably enhance the excitements of LSPRs to attain 2.5 time peak RIs sensitivities than the U-types [66-70].

The type of fiber explained above contains stretch and bend fibers into diverse shape without varying the fibers structures. In disparity, D-shape fiber is shaped by partly removes the clad or removes the clad and portions of fibers cores to forms the structures [71] as show in Figure 6(d). These structures could exposed further passing fields and provided a flat detections planning to the investigative environments, thus induce a strong LSPRs signals and offer a steady platforms for bio-molecular analyzing [72]. Though, the grind and polish of the D-shape fibers might introduce surfaces unevenness, that cause a possible decreases in the sensitivities. In addition, conducts taper treatments on D-shape fibers could be more enhanced the sensitivities, increases it to over 10 times that of a consistent fibers LSPRs sensors [73]. Besides, the expand planar sense zone of D-shape fibers enable the creations of periodical nanostructure [74] or the gathering of 3-dimension (3Ds) mixture multilayers structure [75] to facilitated sensitize and multiplexes in LSPRs sensors. This numerous type of optical fiber, geometrical structure, and transmissions scheme mention overhead could be free combine, and even multiples geometrical structure and type could be uses to realize high sensitivities and encounter the definite applications requirement. In practice application, we also want to considered factor like manufacture costs and complexities, sensors stabilities and durable, and transmissions distances, and then adapt the designs of LSPRs sensor systems according to these conditions.

## 5. Fabrication techniques of lsprs sensor area

Additional to the geometrical parameter of the optic fibers, the performances of the optic fibers LSPRs sensors are influence by the nanostructures configurations of the sense regions. The nanostructures configurations of sensor regions include the shapes, sizes, and arrangements of the metals nanoparticle that plays vital roles in regulation the interactions among the nanoparticle and lights, therefore impacts the intensity and frequencies of LSPRs effects. Through the optimization of nanostructures configurations, the sensitivities, choosiness, and constancy of sensors could be attuned, assisting further accurses and reliable bio-analyze and environment observing. Diverse applications requirement might need many nanostructures configuration. Therefore, in case of design optic fibers LSPRs sensors, it is vital to widely considering the relationships among the nanostructures parameter and sensors performances to chance particular applications requirement.

### 5.1 Nanoparticle Self-assembly

Presently, honorable metals nanoparticle, like AuNP [76], gold Nano rod [77], and silvers Nano-particle [78], are common use for optic fibers LSPRs sensor. Amongst this, gold-base nanoparticle is particular advantage because of their outstanding structure steadiness, oxidations resistances, and bio-compatible. As results, they are extensive utilize in experiment study. The predominates approaches for immobilize nanoparticle in the sensor regions of fibers involve chemical bond the nanoparticle to the modify sense surfaces by use chemical reagent and function group, therefore realizing the self-assemble of sensor structures. In current year, there is considerable report on the applications of self-assemble old nanoparticles layer in optic fibers LSPRs sensor, and all study mainly relying on two method. The furthermost common employ approaches involve hydroxyl salinization on a glasses substrate by use saline couple agent. That permits the captured of AuNPs over the amino or Thiel terminals group of self-assemble films, facilitate the preparations of the sensor regions as show in Figure 8(a). The saline methods encompass two modifications scheme: amine salinization and Thiel salinization. The mine salinization is depend on the principles of positives and negatives adsorptions effect. It involves the uses of solution like (3-aminopropy) [79] (APTESs) or (3-aminopropy) trim [80] (APTMSs) to amino functionalizes the surfaces of the optic fibers over an animation reactions, therefore impart a positives charges. Therefore, the negative charge nanoparticle could be bounds to the positive charge optic fibers surface over electrostatics forces, particular the interactions of ionic bond. Thiel salinization, involve functionalize sensors regions by usage (3-mercaptopropy) MPTMSs [81]. The principles of these methods are as follow: the methyl group (Si-OCH3) of MPTMSs could be hydrolyze into silently group (Si-OH). The interactions amongst Si-OCH3 and moderately hydrolyze silanol group result in the realization of a self-assemble films with Thiel group cover the surfaces of the optics fibers. The AuNP could be captures by the thiol group on surfaces to monolayers on optics fibers. Other frequently use technique rely on electrostatics adsorptions effects, utilize electrostatics layers-by-layers self-assemble of polyelectrolyte and surfaces charges of nanoparticle for self-assemble of nanostructure [82] as show in Figure 8(b).

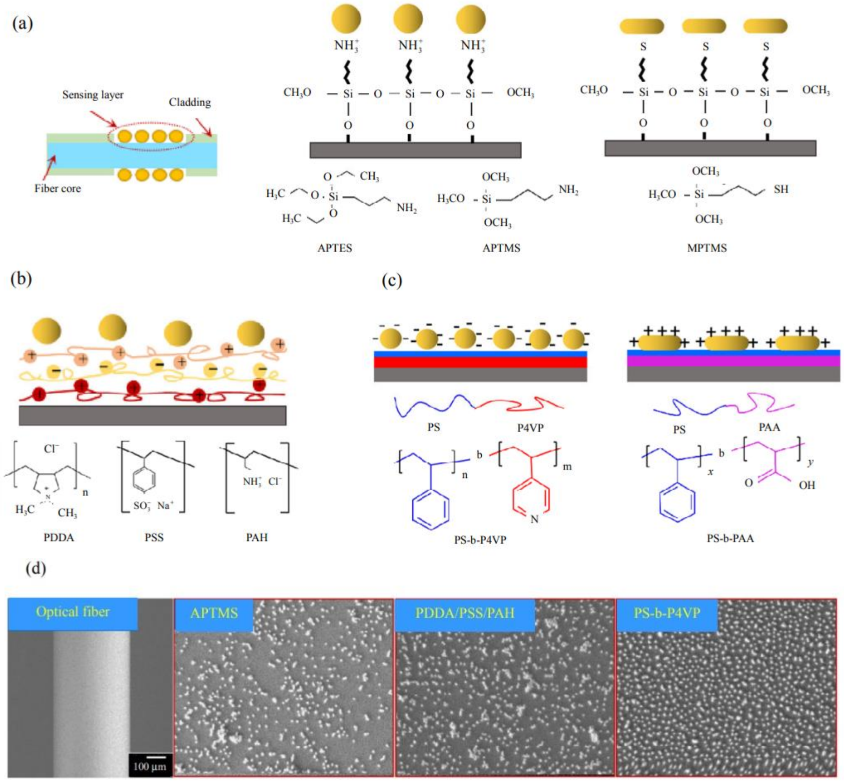


**Figure 8:** Nanoparticle-based self-assemble method for fibers optics LSPRs sensors fabrications [82]

Additionally, experiments data indicates a relative lower analysis of nanoparticles monolayer gotten via self-assemble, that slightly restrict its possible for applications in fabrications of highs-performances, larger-scales, and costs-effectives fibers sensor. Equally, the layers-by-layers self-assemble technique employ polyelectrolyte demonstrates a fast electrostatics adsorptions rates, resultant in a considerable reductions in depositions times and operation difficulty whereas improving the particles surfaces coverage's. These procedures capably addressed the limitation of these methods [83]. Though, it is connected with challenges like an unpredictable particles diameters and added additional difficulty preparations processing. A novel and multipurpose self-assembling method was recommended for the fabrication of fiber LSPR sensors by [84]. Their method utilize blocks copolymers-base templates to conductor the self-assemble of nanoparticle on the templates surfaces, resultant in the higher analysis, lower aggregations, and control nanostructure as illustrated in Figure 8(c). As the solutions concentrations decreased, the copolymer follow to the substrates as Nano-scale film, enabling the uniforms self-assemble of nanoparticle on the polymers films surfaces which lead to lower aggregations and higher analysis monolayers nanostructure. The well-behaved and detailed self-assemble is depend on facts the multiples hydrogen bond site on the hydrophilic segment binds to the hydroxylase substrates, whereas the metals nanoparticle is bounded to the hydrophilic segment over surfaces charge, like electrostatics adsorptions and ionic bond. The incidence of freely hydrophobic polystyrenes (PSs) chain prevents particles aggregations. These approaches result in nanostructure with wanted surfaces morphologies characterize by higher attention and lower aggregations. It is value mention that it permits for uses of numerous type and blocks lengths ratio of blocks copolymer for templates fabrications. For example, PSs-b-P4VPs and PSs-b-PAAs could be employ to yield order template where P4VPs chain binds negative charge nanoparticle via protonate amino group, and PAAs chain binds positive charge nanoparticle over deprotonate carboxyl group, correspondingly [85]. Therefore, these enable operative surfaces self-assemble of negative and positive charges golden Nano-sphere-Nano-rod [86]. If this compare to the conventional method mention above in Figure 8(d), the result demonstrated that golden Nano-spheres assemble by use APTMSs or PDDAs/PSSs/PAHs could covers the whole surfaces nonetheless exhibits non-uniforms dispersions and aggregations. In difference, golden Nano-spheres assemble by use PSs-b-P4VPs don't realize the completed surfaces treatment, nonetheless exhibits uniforms dispersions without particles aggregations and forms monolayers nanostructures. In term of surfaces treatment, the PSs-b-P4VPs methods demonstrate the significant high performances compare to another method for APTMSs and for PDDAs/PSSs/PAHs. The blocks copolymers templates methods efficiently reduce particles aggregations, enhance particles surfaces coverage, and hold abundant possible to improve sensor sensitivities and stabilities, simplify the preparations processing, and reduce cost.

## 5.2 Aassemblies and transfers of periodical arrays of nanostructures

From the traditional chemical self-assembly method, academics have examined non-chemical bond strategies to fabricate a sensor region. Technique like focused ion beams (FIBs) milling, micro-electromechanical systems (MEMSs), and electron beams lithography (EBLs) were employed to generate periodic nano-arrays, which could be efficiently utilized in fiber LSPRs sensors.

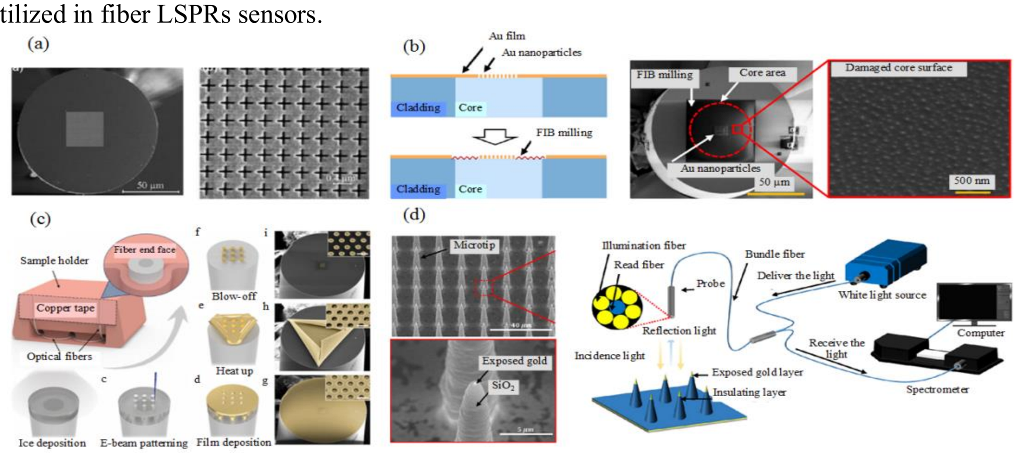


**Figure 9:** Non-chemicals bond strategy to fabrications of sense region: (a) cross-shape Nano-array [79], (b) AuNP array [80], (c) Nano-disks array [81], (d) arrays of metal nanostructure micro tips [82], ends and faces of fiber.

Amongst this strategy, FIBs millings is mainly utilize for fabrications of periodical nanostructure like Nano-holes, disk, and pillar on ends faces of optic fiber. The crosses-shape nanostructures are fabricates on the ends faces of fibers, as show in Figure 9(a) [87-90] successful employ FIBs millings to produce an AuNP array on the cores ends faces of an optic fibers as show in Figure 9(b), realizing a refractive indexing sensitivities of 5700/RIUs. Though, FIBs millings enable the productions of uniform structure Nano-array with stabled sense performances and its lower succession rates, higher costs, and difficult manufacture processing limits appropriateness for larger-scales process application. Y. Hong et al. [91] propose a solvent-freely Nano-fabrications methods depend on the emerge ice-assist electrons beams lithograph (iEBLs) techniques, that offer a streamline and eco-friend approaches for implement e-beams pattern on substrate with arbitraries shape as show in Figure 9(c). They effectively fabricate periodical Nano-structure; include silvers concentric ring, V-shapes Nano-antenna array, bowtie array, and rings array. This technique allow for productions of varied and high uniforms structure, and offer low costs and high successes rates compare to FIBs millings. Though, the fabrications processing remain relative difficult. The MEMSs techniques is employ to fabricates a uniform distribute arrays of nobles metals nanostructure on a silicon micro tips on the ends faces of an optic fibers [92], as exposed in Figure 9(d). The resultant LSPRs sensors demonstrate the outstanding reproducible, steady reliabilities and promising optic property in measurements systems. The periodical and longer-lasts particles arrays achieve over MEMSs skill position it promise methods for commercialize LSPRs application. In decision, self-assemble and periodical arrays assemble method have advantage and disadvantage. The self-assemble technique is characterizes by simplest preparations processing and low costs. Though, it is challenges to precise controlling the self-assemble of nanoparticle throughout the bind processing, resultant in distributions of particle in disperse and disorder structures. Additionally, issue like locally particles sheds and aggregations could have impacts on the performances of sensors. Hence, the periodical arrays assemble methods enable the making of high order periodical Nano-array, lead to sensor with higher sensitivities, repeatable, and stabilities. Conversely, this technique needs the utilizations of advance micro/Nano fabrications technique, that significant elevate the manufacture cost. Moreover, the substrate use in these methods is most flat, that restrict the fabrications of structure to D-types or fibers ends face, thus presented implementations challenge.

## 6. Folsprs biosensors applications

The FOLSPRs sensors have emerge as a promise tools for biosensors application. It offer numerous advantage over others sensor configuration. The LSPRs is a phenomenon occurs in case of nobles metals nanoparticle is excite by lights, resultant in strongly absorptions and scatter at precise wavelength. Through immobilize biomolecule on surfaces of this nanoparticle, change in locally RIs cause by bimolecular interaction could be detects. The single property of FOLSPRs sensors made it appropriate for numerous biologic detections scenario. The smaller sizes and flexibilities of optics fiber enabling relaxed integrations into complexes biologics system, like implant device or labs-on-a-chips platform. These allow for real-times, distant, and slightly aggressive monitor of bio-molecules interaction.

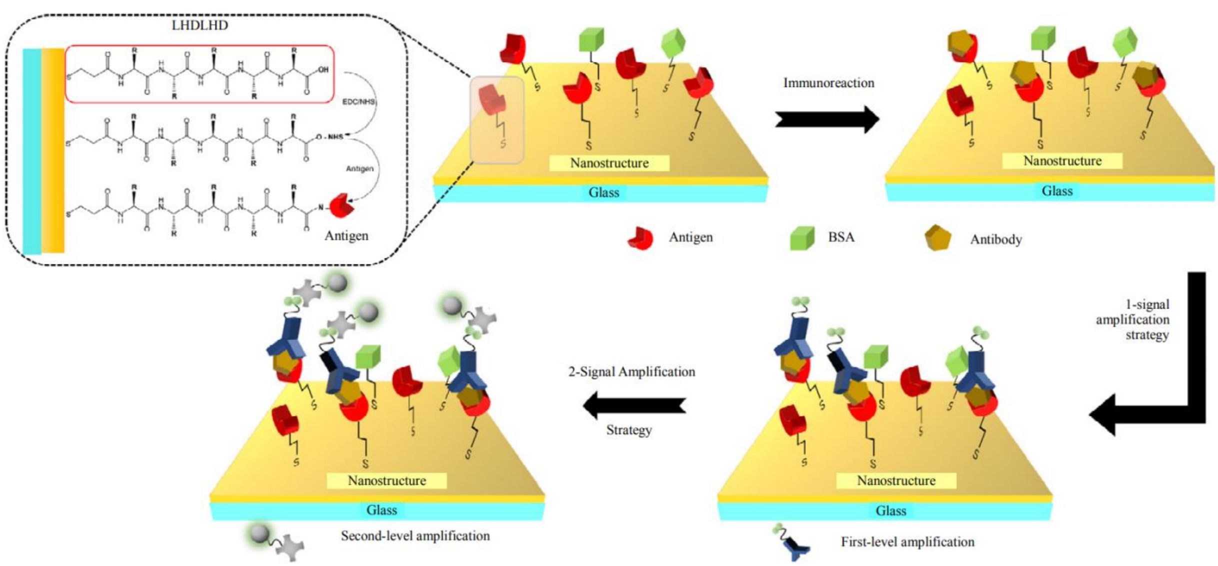


**Figure 10:** Schematics diagrams of classic antigen-antibody immunoassaying sense processing.

Furthermore, the localize natures of LSPRs in Nano-scales region ensure a higher sensitivities and labels-freely detections. These eliminate the needs for bulk label or tag makes it appropriate techniques for multiplex assay and higher-throughputs screen. Moreover, the tailor designs and fabrications of metals nanoparticle or Nano-array could improve the sensitivities and selectivity of sensors for exact targets molecule. The adaptability of fibers optics LSPRs sensor allow for detections of a widely ranges of analyses, include protein, pathogen and cell, nucleic acid (DNAs and RNAs), and another smaller biomolecule (organics compound and heavy metals ion). Proteins immunoassaying is presently the almost wide studies applications of FOLSPRs biosensor. The overall proteins molecular detections and signals amplifications strategy is show in Figure 10. Naturally, the sensor regions of the nanoparticle/periodical structures surfaces are modify by thiol via golden sulfur bonds with a carboxyl groups at another ends.
sulfur bonds with a carboxyl group at the other end.
The anti-bodies or antibodies fragments is immobilize as a bio-recognitions elements on monolayers throughput the carboxyl groups that has been pre-activate by use EDCs/NHSs carbodiimide hydrochlorides (EDCs), N-hydroxysuccinimide (NHSs) solutions. If the correspond antigens are bounds to the surfaces-immobilize antibodies inside the electrics fields ranges, these interactions disrupt the Plasmon and consequences in a changed the reflections intensity, permitting to determine the analytic concentrations. Additionally, to thiol, other reagent like peptide and dextran are modify on the sense regions surfaces to produce further anchor point. Because of larger difference in the molecular weights of numerous protein, the locally fields change induce by binds a targets protein with captured probe also differ, leads to altered detections sensitivity. For larger protein, like IgG, their higher masses are adequate for sensitive sense and could be direct monitor [93, 94]. Equally, a smaller molecules immunoassaying presentation is challenge. The smaller sizes of targets proteins itself is incapable to produce adequate LSPRs signals, the antibodies-antigens bind induce a smaller masses variations, that cannot offer sensitive analyzing. Consequently, amplifications strategy, like sandwich assay [95], is requiring improving the signals [96]. H. M. the report of sandwiches assays for ultrasensitive thyroglobulin (Tg) detections via implementation of second antibodies and a second golden nanoparticles signals amplifiers, as illustrated in Figure 10 [97]. The limitation of detections (LODs) is improved by around 15 times from (97.6fg- 6.6fg)/mL Nucleic acid served as reservoirs of genetics data in the humans bodies, and their polymorphisms analyze and mutations detections could efficiently identify condition such as tumor and infectiousness disease. Naturally, the doubles-strand structures of dioxin ribonucleic acids (DNAs) is disrupt via higher temperatures or higher PHs, and the classification is determine over hybridizations with singles-strand DNAs fragment. Therefore, the FOLSPRs has been introduce as a movable and high sensitively sensors for labels-free detections of DNAs, yield capable result. In these techniques, the capture DNAs is immobilizes on sensors surfaces thru golden-sulfur bond. When the conforming complementary targets DNAs are presents in the samples, it will hybridize with captured DNAs [98].

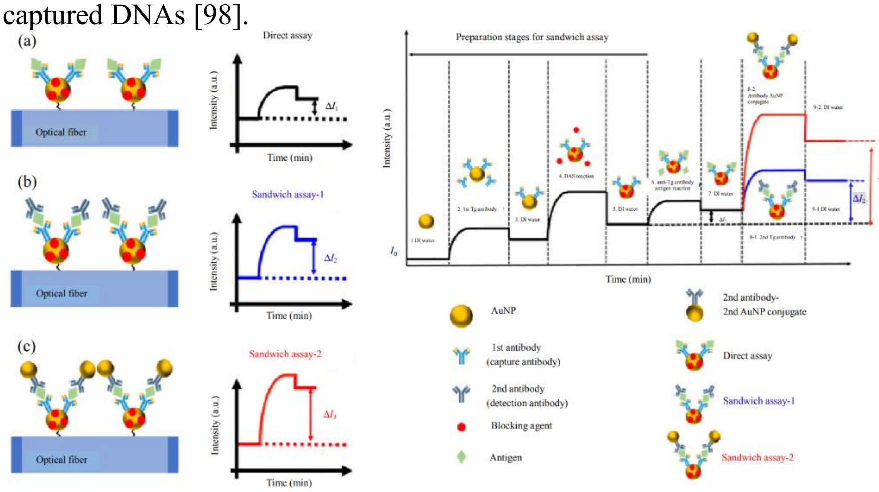


**Figure 11:** Schematics diagrams of thyroglobulin by directs antibodies, secondary antibodies sandwiches assays, and antibodies-golden nanoparticles conjugated sandwiches assays [98]

These binds happening on nanoparticle disturb localize surfaces Plasmon, varying the resonances condition and producing change in optical signal. Though, when the quantities of targets DNAs is inadequate to induced the LSPRs, a sandwiches construction is employ to improve the detections signals. Figure 11 shows the captured DNAs only hybridizes with one half of the targets DNAs, whereas another half of the targets DNAs is then hybridizing with other probes DNA. The probes DNA is pre-modify with signals amplifications molecule on one ends to realize the secondary signals amplifications. The signals amplifications molecule could be glowing dye, protein, AuNP, or other substance, depend on the definite requirement of spectroscope, image, and another detections method [99]. Furthermore, certain reports nucleic acids detections strategy shows in Figure 11 use for SPRs sensor is appropriate to fibers LSPRs sensor, include modest detections of micron ribose nucleic acids (miRNAs), sandwiches-base detections of DNAs, and tamer-base detections, amongst other [100]. As show in Figure 12(a), in attendance of targets cfDNAs, the hairpin H1-AuNP and H2 is trigger by the hybridizations chains reactions (HCRs), and then the Ω-shape FOLSPRs biosensors fabricate with the captured DNAs capture the HCRs products for synergistically amplify the LSPRs signals [101]. As in [102], they suggested a phenyl moronic acids (PBAs) probes for miRNAs detections, as show in Figure 12(b), the targets miRNAs and subsequent opposite DNAs were hybridize with captured DNA. The PBAs-AuNP can added binds with ribose in miRNA rather than dioxin ribose in balancing DNA to amplified the sense signals.

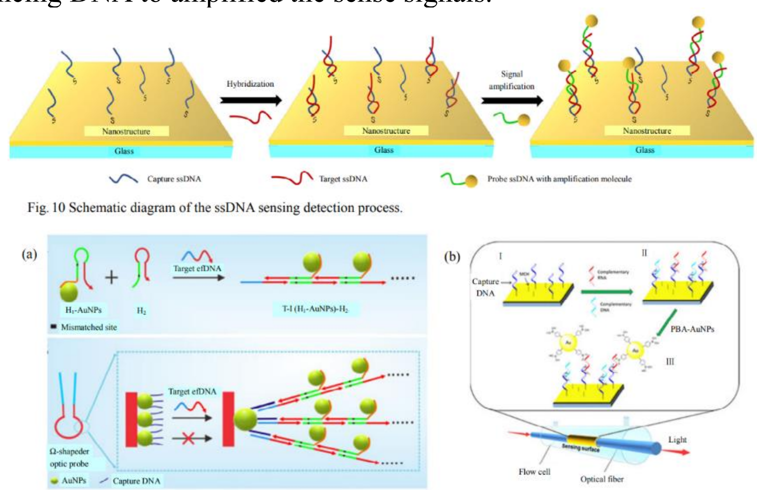


**Figure 12:** Scheme of signals amplifications strategy for nucleic acids detections: (a) multi stage nanoparticles amplifications [101] and (b) boric acid-golden nanoparticles sandwiches assays [102].

Additionally, detections strategy for another molecule is comparable to protein and nucleic acid as mentions before. The detections strategies can determine depend on size of targets molecule. Particularly, detections of microorganism like living cell, bacteria, and worms could be used to direct capture them onto the surfaces of fibers sensors for detections. The development of a U-shape FOLSPRs biosensors for the colorectal cancers cells detections have been proposed by [103] as show in Figure 12(a), the cells can captures by immobilize Con A onto the fibers over exact binds amongst Con A and the N-glycan expressions on the cells surfaces. The crypto sensors afford the ultra-sensitivities for cancers cells detections with the LODs of 30cells/mL with high linearity in widely ranges of 1×102 –1×106 cells/mL. Moreover, the FOLSPRs biosensors could be employ to inactivate tumors cell by in-site lasers heats or another photo thermal therapy, therefore realizing therapeutics purpose. The Ω-shape FOLSPRs biosensors show in Figure 12(b) is design for real-times and label-freely microscopic detections [104]. The surfaces-immobilize a tamers explicitly captured the salmonella type hymenium, resultant in LODs down to 128 CFU/mL in a linear ranges from 5×102 -1×108 CFU/mL, that demonstrate an improved selectivity for the salmonella type hymenium detections compare to another microbes. The LSPRs biosensors that uses MCFs with 7-core organized in a hexagonal patterns proposed by [105] which splice with SMFs for shigella bacteria detections, and display a widely linearization detections ranges from [106] CFU/mL with a lower LODs of 1.56 CFU/mL. Figure 12(c) show the design processing of increase passing wave and model couple among MCFs core, whereas the coatings with AuNP and molybdenum disulfides improves the excitations of localize Plasmon's. The J-shape optic fibers is gotten by fold an Ω shapes as illustrated in Figure 12 (d), a spacers nucleic acids with shorter stems-loops structures are adopts to controlling concentration and additional improve the LSPRs signals responses .

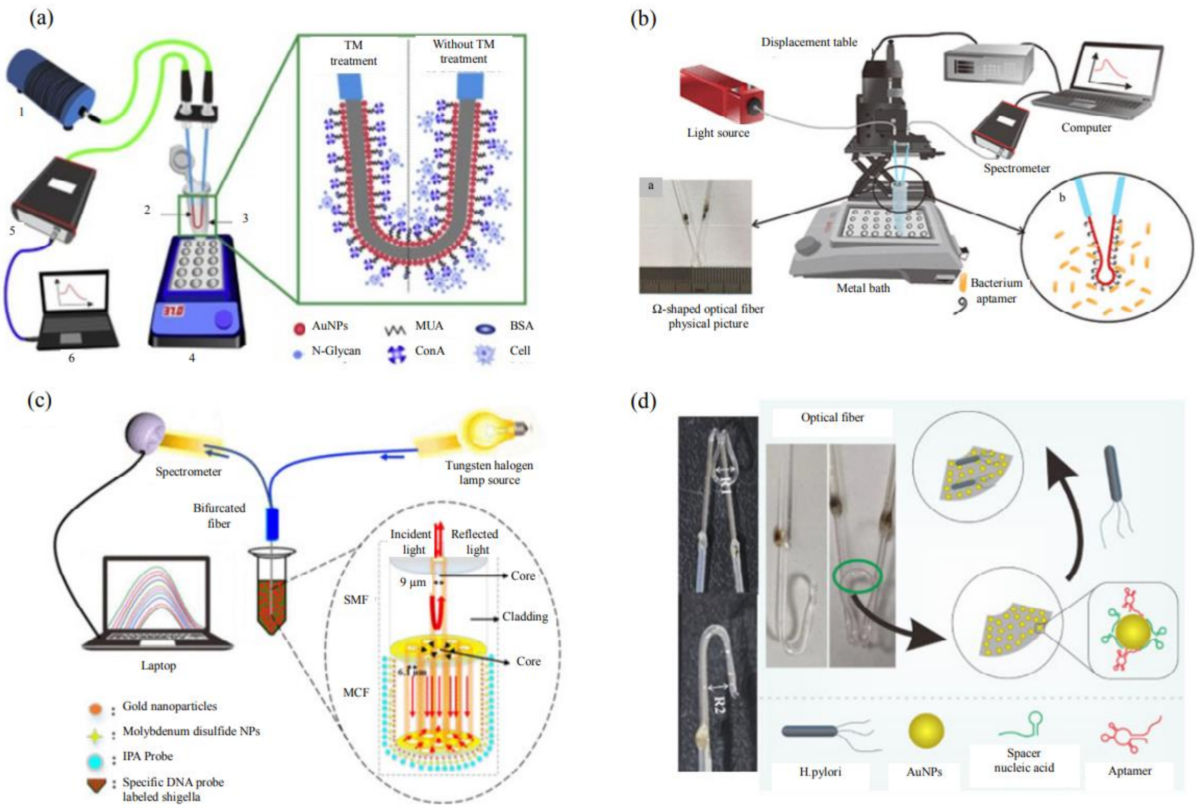


**Figure 13:** FOLSPRs biosensor diagrams for the microorganism detections: (a) U-shape FOLSPRs biosensors for the cancers cells detections [83], (b) Ω-shape FOLSPRs biosensors for the salmonella type hymenium detections [105], (c) MCFs-SMFs FOLSPRs biosensors [106].

In smaller molecule like cholesterols, ascorbic acids, cretonne, and glucoses, definite captures probe could directs immobilize on the surfaces of fibers to attain the detections by exact bindings among the captures probes and targets molecules. Usually use captures probes molecule in this case included the boronics acids, streptavidin, and enzyme. Through select the suitable enzymes as recognitions elements for targets molecules, high specificities and selectivity could be realized. Glucoses oxidase is an enzyme that catalyzes the oxidations of glucoses. Through immobilize glucoses oxidases on the surfaces of a U-shape FOLSPRs sensors, blood glucoses level could be measure quickly in shorter periods of times [107]. These methods required around 150 μL of blood samples. For small molecule like weighty metals ion, secondary signals amplifications strategy is necessary to detects molecular interactions at ultra-lowest concentration. Comparable to nucleic acids detections structure, sandwiches assay, nanomaterials improvement approach, and more technique could be utilize to attain the detections of molecular interaction at very little concentration. An wavelengths-modulate FOLSPRs sensors coating by golden Nano-sphere for high sensitively $Hg^{2+}$ detections (LODs: lower to 0.7nM) base on thymines-$Hg^{2+}$-thymine based couple mismatch systems have been proposed by [108] as show in Figure 14 (a). an ZENs nucleic acids antimere is modify on cross-sections of FOSPRs ends to ZENs detections illustrated in Figure 14 (b) with lower LODs of 0.102ng/mL.

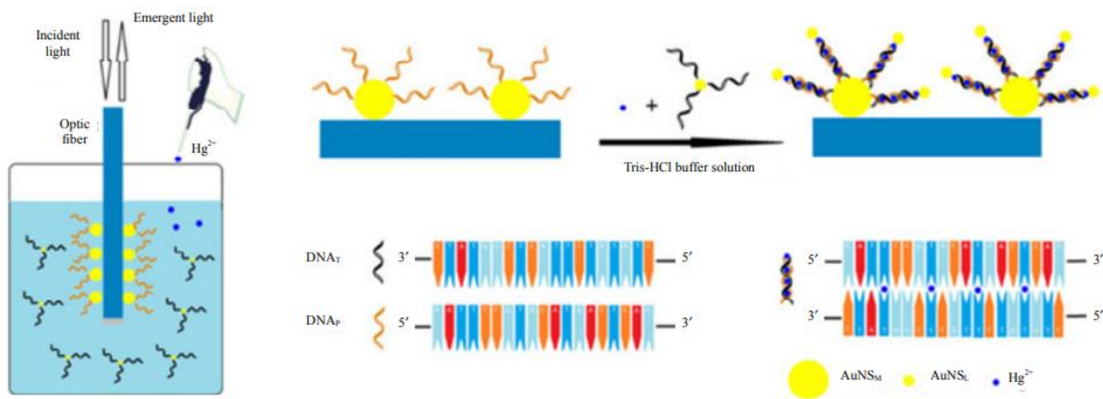


**Figure 14**: Schematic diagram of FOLSPR biosensors for small molecules including (a) heavy metal ion Hg2+ and (b) food toxin ZEN [108].

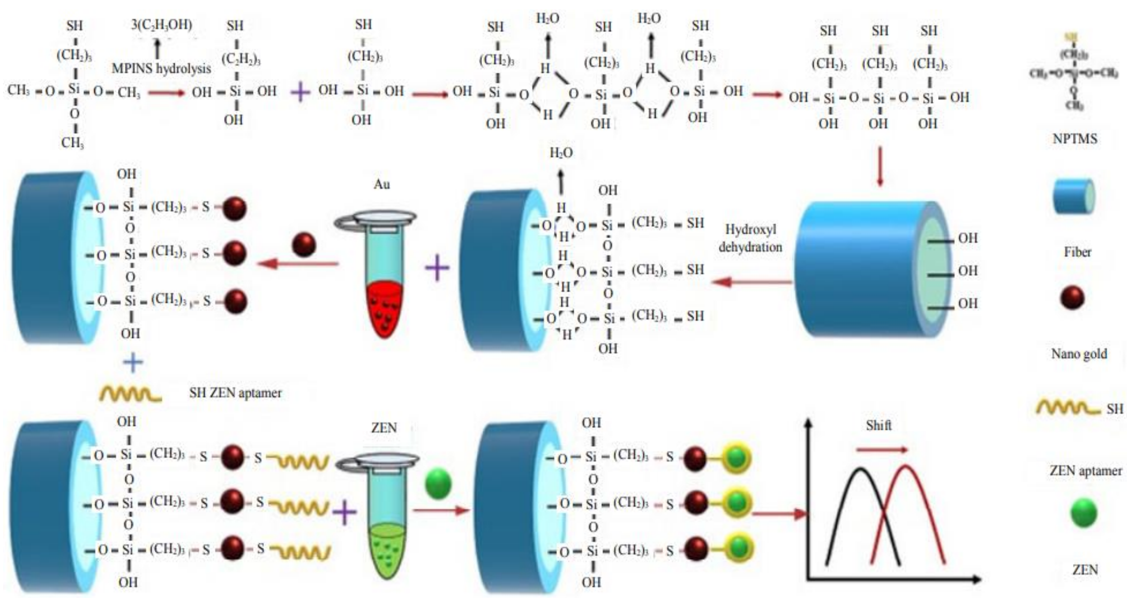


**Figure 15:** FOLSPRs biosensor scheme for smaller molecule include (a) heavyweight metals ions Hg2+ (b) foods toxin ZENs [109].

Amongst them, the grapheme oxides (GOs) has receive the utmost wide attentions. The developing GOs have been widely presented into FOLSPRs bio-sense due to their plentiful oxygen functional groups and larger surface areas, which efficiently enhance the functionalization of biomolecules and improve the sensing performance of biomolecules. Higher tilt fiber grating LSPRs sensors by decorating golden Nano-shell on ExTFGs surfaces and depositing functionalized GOs on sensor surfaces to identify PD-L1 monoclonal antibody in human serum of liver cancer patients have been proposed [110]. Table 1 shows the performances of recognition techniques with different fiber-optic LSPRs biosensors. Many other approaches have been introduced in this field, such as [111-117].

**Table 1:** Performances of recognition techniques with different fibers optics LSPRs biosensors approaches.

| References | performance | Techniques | Target | Direction |
|---|---|---|---|---|
| [79] | LOD: 14.0 pM | Ω-type MMF | MCF-7 cancer cells | Direct |
| [50] | LOD: 12 cells/mL | Ω-type MMF | E.coli B40 | Phage T4 |
| [91] | LOD: 1.56 CFU/mL | U-bend MMF | Shigella bacteria | MoS2-DNA |
| [77] | LOD: 25.5 µM | SMF-PCF | Cholesterol | Sandwich |
| [80] | LOD: 15.12 µM | Ω-type MMF | Ascorbic acid | enzyme |
| [89] | LOD: 128.4 µM | SMF-HCF | Creatinine | enzyme |
| [88] | LOD: 1.06 nm/mM | SMF-photosensitive | Glucose | enzyme |
| [67] | LOD: 0.8 nM | Straight MMF | Human IgG | Direct |
| [93] | LOD: 0.85 ng/mL | U-bend MMF | AFP | Direct |
| [20] | LOD: 14.0 pM | HCF | Transferrin | Direct |
| [94] | LOD: 0.19 pg/mL | Straight MMF | Thyroglobulin | Direct |
| [95] | LOD: 100 fg/mL | SMF | f-PSA | Direct |
| [39] | LOD: 96 ng/mL | MMF | Cardiac troponin I | Sandwich |
| [82] | LOD: 67 pM | Straight MMF | rop B DNA | Sandwich |

## 7. Conclusions

The fibers optics LSPRs depend on well-order nanoparticle monolayers or periodical nanostructure under definite condition lead to better improvements of localize electrics field compare to SPRs without the Nano-material and provide the suitable solutions for micro-smarts biologic integration sensors. To improve the sense performances of FOLSPRs sensor, numerous methods could be use include diverse type of fiber with optimize geometrics structure and the shape include taper U-types, Ω-types, and D-types) and utilize advance surfaces assemble scheme to realize order monolayer of nanoparticle or periodical nanostructure to improve the sensitivities and constancy of sensors, and customize recognitions and measurable analyzing strategy could be design to definite biomolecule. In fields of biomedical diagnostic, they could be used for labels-freely detections of biomarker, DNAs hybridizations, proteins-proteins interaction, and pharmaceutical analyzing. Furthermore, the current developments of the compacts, portables, and costs-effectives instrumentations are expects to facilitated the widely adopt of those biosensor in numerous field. Therefore, FOLSPRs biosensor is composed to revolutionize the fields of biosensors, permitting the quick and correct biomolecule detections, diseases diagnosing, and environments monitor in real times. Though FOLSPRs biosensor has originated widespread structure, manufacture, and bio-application, there are ongoing researches to more improve their performances. Resultant in much area in developments of FOLSPRs biosensor is expected.

1. Progress and applications of the multi-channels FOLSPRs biosensor. Presently, utmost bio-application required measurable detections of multiples biomolecule or removal of interference from un-relate molecule. To decrease the complexities and costs of measurements system and enabling simultaneousness assessments of multiples parameter relate to disease or the environments, the designing of FOLSPRs biosensor that could concurrently measures multiples biomolecule or performs multiples measurement of similar biomolecules in a multi-channels FOLSPRs biosensors will be an operative developments approaches in practice application.

2. Utilizations of newer material and technology innovation for improving the sensitivities of FOLSPRs biosensor. We discuss the promise advancement in enhancing the sensitivities of FOLSPRs biosensor by use two dimensions material, like molybdenum disulfide and graphene oxides. Through joining advance

material likes carbons nanotube, it is probable to improve the contacts areas among the sense surfaces and targets molecule over the optimize designing of the sense layers structures. In addition, thru manipulate the parameter of sense layers of two-dimension material like tunable bands gaps and outstanding electronics transportation property of blacks phosphorus, the locally electromagnetic fields effects on the sense surfaces which could be intensify. Those methods have the possible to offers newer possibility for more improving the sense performances.

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# الاستشعار بواسطه الالياف البصرية المعتمدة على الرنين البلازمي السطحي: مراجعة شاملة

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**الخلاصة:**

تستخدم أجهزة استشعار الطلاء البلازماني Surface Plasmon على نطاق واسع في مجالات الكيمياء والأحياء والبيئة. ينبع هذا النوع من أجهزة الاستشعار من الآثار الناتجة عن الاهتزازات السطحية للبلازما (SPRs) أو الاهتزازات المحلية للبلازما السطحية(LSPRs) ، والتي لها تطبيقات تجارية. في هذه المراجعة، نقدم التقدم الحالي في مجالات أجهزة استشعار البلازما السطحية، ولا سيما في تكوين البنية المستوية المتراصة والموجهات الضوئية الألياف البصرية. في منصات البنية المتراصة، يعتمد المستشعر الضوئي على آثار LSPRs والانتشارات الفائقة والاهتزازات فانو والتكامل مع مواد ثنائية الأبعاد .(2D) يتم تلخيص دمج المستشعر الألياف البصرية مع هياكل LSPRs/SPRs ومواد الأبعاد الثنائية. بالإضافة إلى ذلك، نقدم التقدم الحالي في مستشعرات البلازما الكمومية ما وراء قيود الضوضاء الكلاسيكية. تم مناقشة التحديات والفرص في هذا المجال. تمكن مستشعرات LSPR البيولوجية من الحد النطاقي النانوي وتلاعب الضوء، مما يؤدي إلى زيادة الحساسية وتركيز الطاقات الكهرومغناطيسية. إن الجمع بين LSPR وتقنيات الألياف البصرية قد ساعد في تقدم المستشعرات المدمجة وخفض الكشف عن بُعد. تستكشف هذه المراجعة الشاملة العديد من تكوينات المستشعرات وفئات الألياف والتخطيطات الهندسية، وتسلط الضوء على فوائدها من حيث الحساسية والتكامل وتحسينات الأداء. تُناقش جهود تقنيات التصنيع المتعلقة باستراتيجيات الروابط غير الكيميائية والتجميع الذاتي للجزيئات النانوية، وتوفر التحكم في أشكال النانوهياكل وتحسين أداء المستشعرات. يُغطى التطبيق البيولوجي لمستشعرات LSPRالألياف البصرية (FOLSPRs) بالتفصيل، خاصةً في تفاعلات البيومولكولات وتحليل البروتينات والجراثيم والخلايا والأحماض النووية DNA) و .(RNA يتم التركيز على تعديلات السطح وهياكل التعرف لإمكانياتها في أنظمة الاستشعار البيولوجي بدون علامات وفي الوقت الحقيقي. يتم معالجة تحديات وفرص مستشعراتFOLSPR ، مع التطورات في الحساسية وتقنيات التصنيع وموثوقية القياسات. يتم تسليط الضوء على التكامل مع التقنيات الناشئة مثل المواد النانوية كاتجاه واعد للأبحاث المستقبلية. توفر هذه المراجعة رؤى في التقدم والتطبيقات المحتملة لمستشعراتFOLSPR ، وتمهد الطريق لمنصة استشعار بيولوجي بصري حساسة ومرنة في العديد من المجالات.