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Application of Electromagnetic Spectroscopic Sensors

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Abstract

The distinctive optical properties of surface plasmons have led to a number of significant applications in chemistry, biology, materials, renewable energy, and information and technology sciences. In recent years, the rapid growth of plasmonic sensors, which are based on the ultra-sensitivity of surface plasmon resonance to the surrounding medium and the amplifying of local electromagnetic fields, has occurred. The most important sensing techniques are surface-enhanced spectroscopic sensors like surface-enhanced Raman scattering, surface-enhanced fluorescence, and surface-enhanced infrared absorption, as well as SPR sensors, which have already led to the creation of several industrial companies.

Keywords: Plasmonic sensor • Spectroscopic sensors • Metal nanowire • Electromagnetic field • Plasmon resonance

Introduction

The most widely used surface-enhanced spectroscopic sensor is due to its large enhancement factors and capacity to recognize species fingerprints. SPR excitation's significant EM contribution and the charge transfer effect's minor chemical contribution are both responsible for the increase in SERS. In terms of EM enhancement, the SERS-active substrate enhances both the incident and dispersed electric fields. Consequently, the total Raman enhancement is the product of the intensity enhancements at the incident and Raman-scattered frequencies. Under ideal excitation setups, this enhancement can approach 109-1010 and is roughly equivalent to the fourth power of the EM field enhancement. SERS, in addition to the alleged chemical effect [1].

Discussion

The main characteristics of a SERS-active substrate are the sharp features of single nanostructures or the nanogaps between metal nanostructures that significantly increase the EM field during resonant stimulation. Bottom-up or top-down approaches have been used to create aggregates and self-assembled colloidal metal nanoparticles, nanofabricated arrays of metal NPs on substrates, metal island films, and roughened electrochemical metal electrodes thus far.

However, a number of issues frequently arise during SERS measurements on such surfaces. First, the sample may be damaged by heat if the laser power is too high on a substrate with low SERS activity. Second, chemical reactions induced by photons are a possibility, which makes spectral analysis more difficult and reduces or eliminates inherent spectrum information. The reactions could be caused by the photochemical effect of the coming laser or by plasmonic phenomena like hot electrons caused by plasmons. Thirdly, the SERS-substrates cannot be reused because the molecules are typically deposited permanently on the metal surface. This raises the price of SERS sensing devices. To at least partially address the aforementioned flaws, new SERS strategies have been developed.

On the other hand, SPR sensors are based on the resonant peak shift of SPs caused by changes in the environment's refractive index. The refractive indices of the molecules adhering to the surface of metal nanostructures differ from those of the surrounding medium. The movement in SPR peak locations can still be seen, despite the minor change. An SPR sensor's performance is typically characterized by the amount of peak shift per refractive index unit change. Both surface plasmon polaritons sensors and localized surface plasmon resonance sensors have seen significant improvement in recent years.

The sensitivity is divided by the full width at half maximum to account for the effect of peak width on sensing performance, resulting in a more reliable figure of merit. Consequently, narrow peaks are utilized for sensing. The multipolar modes of LSPR have a higher FoM than the dipolar mode, and fano-resonances in plasmonic NP oligomers can also produce high FoM values for sensing. FoM values for SPP-based sensors are slightly higher than 10 A variety of nanostructures and sensing approaches have been investigated in an attempt to enhance the FoM. In order to spread SPPs through metal nanowires, the refractive index sensing technique was utilized.

The wavelength of SPP is determined by the incident wavelength and the dielectric properties of the metal and its surroundings. The quantum-dots imaging method can visually detect the interference of SPP modes in a metal NW of limited length, which controls the near-field distribution of SPP [2]. The environment's dielectric constant determines the near-field distribution's period. The NW's output spectrum is also influenced by the surrounding environment. A novel SPP sensor is the result of these properties [3]. Metal NWs-based SPP sensors, novel SERS sensing approaches, LSPR sensing employing multipolar modes and Fano-resonances, and other recent advancements in plasmonic sensors will all be discussed in this review article [4].

Because of their distinctive optical response, which is triggered by the stimulation of localized surface plasmon resonances, metallic nanoparticles have received a lot of attention. An electromagnetic field induces the coherent oscillation of free electrons in a metallic particle, which results in these resonances. LSPRs are being studied for use in the creation of sensitive biological sensors with ultrasmall detection volumes due to their sensitivity to the medium surrounding the nanoparticle. The resonance shift, normalized by the resonance line width, that results from a change in the surrounding dielectric's refractive index is commonly used to describe plasmonic sensors' figure of merit. The FoM of plasmonic sensors rises as a result of narrow resonances [5].

The refractive index sensing capabilities of LSPRs in gold nanoparticles

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and propagating surface plasmon polaritons on extended gold surfaces, also referred to as surface plasmon resonances, were recently compared experimentally and directly. It was demonstrated that LSPR-based sensing is a highly competitive technology to traditional SPR for the detection of changes in the refractive index close to the surface, despite having a low bulk refractive index sensing figure of merit of usually. The high sensitivity has been linked to the LSPR electromagnetic field's significant confinement of the nanostructures. By connecting plasmonic resonances in systems with two or more nanoparticles, nanoholes, and nanowells, recent advancements in the FoM of gold nanoparticle sensors have been made possible [6].

Wide Fano resonances can arise as a result of interference between a discrete state and a continuum of states due to this connection [7]. This article demonstrates the increased sensitivity of Fano resonances in periodic arrays of metallic particles to minute changes in the medium's refractive index. When compared to LSPRs, we demonstrate that linking these localized resonances with Rayleigh anomalies increases the FoM by more than an order of magnitude. In a grating, the beginning of diffraction can be seen in Rayleigh anomalies. There is a transition between an evanescent diffracted order and a diffracted order that propagates in the plane of the array at the wavelength and angle of incidence that correspond to the Rayleigh anomaly [8].

The array's transmittance and reflectance spectra develop narrow resonances as a result of this connection. Carron et al. first hypothesized these resonances, which are known as surface lattice resonances. in the context of Raman scattering enhanced by the surface. In subsequent research, Schatz and colleagues expanded on this idea. 1D arrays provided the earliest experimental evidence of this phenomenon. The first demonstration of how these resonances can be used for optical sensing and the unambiguous proof that these modes can be stimulated in arrays of microscopic particles and nanoantennas both came about relatively recently. The interference of a large localized surface plasmon resonance caused by Fano resonances is referred to as a surface lattice resonance [9,10].

Conclusion

Fano resonance-specific asymmetric line forms are brought about by this interference. For arrays of low loss metals, we also discover that the FoM is ultimately governed by the frequency difference between the surface lattice resonance and the Rayleigh anomaly. Low loss metals have an imaginary permittivity component that is significantly lower than the real component's modulus. Particle size and the array's lattice constant determine the frequency difference. This universal scaling of the FoM does not occur in disordered nanoparticle arrays that do not exhibit collective behavior. Surface lattice resonances, whose spectrum location is controlled by geometrical factors, offer a great deal of flexibility in the design of plasmonic responses.

Acknowledgement

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Conflict of Interest

None.

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