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Advanced Optical Sensors

Noble Metal-Based Hybrid Composites

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Noble-Metal-Based Composites for High-Performance SPR Sensors

Archana Yadav, M. A. Ibrar Jahan, Sarita Kumari, R. Srujana, Boris A. Malomed, and Shatrughna Kumar

Abstract Surface plasmon resonance (SPR) is a very captivating sensing technology because it can find molecules without labels and analyze their interactions in real time. This chapter explores the fundamental principles of SPR, its components, and its applications in various fields. This chapter also explores the noble metal-based composites, particularly incorporation of Gold and Silver have attracted extensive attention of scientific research due to its exceptional abilities to improve the performance parameter of surface plasmon resonance (SPR) sensor. These noble materials possess unique photoelectric properties, good stability and low biotoxicity, which makes SPR sensors highly sensitive and selective detection for the various applications such as biosensing, chemical sensing, environmental sensing etc. Various noble metals, such as gold, silver, platinum, and palladium, are discussed, highlighting their unique optical and electrical properties, stability, and biocompatibility. Furthermore, the chapter explores using composite materials to further enhance the sensing parameters. During the process, different problems are discussed, such as fabrication challenges and cost efficiency. Future issues are also discussed, such as how to combine artificial intelligence (AI) and the internet of things to make advanced sensing possible. The chapter ends with a discussion of how SPR sensing could be

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used for personalized medicine, smart agriculture, and security purposes. This highlights the need for people from different fields to work together to get around current problems and encourage new ideas.

Keywords Surface plasmon resonance · Noble metals · Nanomaterials · Sensitivity · Plasmonic biosensors

1 Introduction

An extremely sensitive and potent optical method for studying molecular interactions in real time without the use of labels or markers is surface plasmon resonance, or SPR. Optical surface plasmon resonance (SPR) biosensors are the most advanced and complex optical label-free biosensor technology, with a wide range of uses in biotechnology, drug screening, medical diagnostics, environmental protection, and food safety and security [1]. It is used to measure the changes in the refractive index (RI) near the surface of a sensor chip, usually because of the binding of molecules such as proteins, nucleic acids, or small molecules to a surface that is immobilized with a target molecule. Surface plasmon waves, which are collective oscillations of electrons at a metal–dielectric interface (often gold or silver) when light strikes the surface at a particular angle, are the basis for SPR.

When a biomolecule (analyte) binds to a molecule (ligand) that is immobilized on the sensor surface, the local RI near the surface changes, leading to a shift in the angle at which the plasmon resonance occurs. This shift is proportional to the amount of bound analyte and can be measured in real-time. It is used extensively in biosensors and chemical sensors [2–5] (Fig. 1).

Surface plasmon resonance happens when light energy is converted into the surface plasmon. (A) When molecules bind, the refractive index near the surface changes, generating a shift in the angle (1 → 2) that is proportional to the mass of bound material [6].

The Components of an SPR System includes—

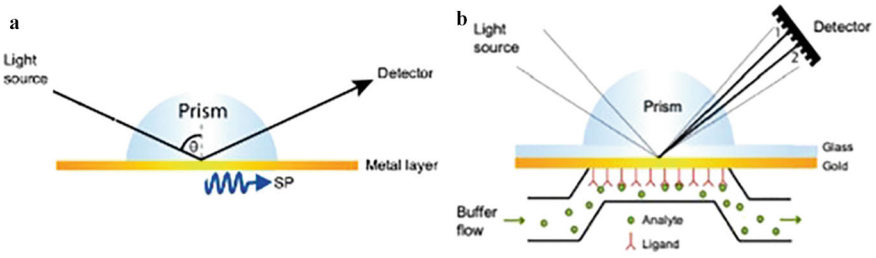

Fig. 1 An illustration of the Kretschmann-Raether setup for SP optical excitation is as follows

- **Sensor Chip**: The surface where molecules are immobilized. This is typically a thin layer of metal film, usually silver or gold, coated over a glass or plastic surface.
- **Light Source**: A monochromatic light source, typically a laser, directs light at the sensor chip at a range of angles.
- **Prism**: A coupling prism directs the light toward the sensor chip at the required angle.
- **Detector**: The detector measures the intensity of reflected light as a function of angle. The resonance angle shift can be observed here.
- **Flow Cell**: A chamber that allows the injection of liquid containing the analyte (test solution) over the sensor surface.

SPR is widely used in drug discovery and basic research to study protein–protein interactions for antibody-antigen binding, can be used to monitor DNA/RNA hybridization and interactions, Small Molecule Screening, Environmental Monitoring etc. The benefits of SPR encompass label-free detection, real-time monitoring, high sensitivity, and the provision of quantitative data that can be utilised to ascertain interaction parameters.

1.1 Noble Metals

Noble metals play a critical role in the various functions of SPR sensors. These sensors are extensively utilized in biosensing, chemical detection, and material science because of their ability to identify the changes in the refractive index (RI) near a sensor surface. Noble metals like platinum, silver, and gold are integral to SPR technology because of their unique electrical and optical properties. A detailed discussion is presented in the following sections:

1.2 Noble Metals in Surface Plasmon Resonance Phenomenon

Noble metals are responsible for the generation of surface plasmon polaritons (SPPs). SPPs are collective oscillations of electrons at the interface of a metal and a dielectric. The idea behind SPR sensing is that these oscillations are very sensitive to changes in the refractive index close to the metal surface. Gold and silver, especially, can support surface plasmon resonances at visible and near-IR wavelengths, making them ideal for SPR applications. Noble metals like gold and silver exhibit excellent electrical conductivity. This property is fundamental because the oscillating electrons needed for plasmon resonance require good conduction to keep the resonance going and make the device more sensitive. Noble metals are chemically stable and resistant to oxidation, which makes them durable in real-world sensing