SPR Biosensor Sensor principle and application progress

Ziyi Guo *

College of Chemical Engineering, HuaQiao University, Xiamen, China

* Corresponding author: 1910732115@mail.sit.edu.cn

Abstract. SPR Biosensor, full name Surface Plasmon Resonance Biosensor, is an instrument used to detect biomolecular interactions. It has the advantages of high sensitivity, high selectivity and real-time to monitor the interaction between substances in real time by optical principle. The working principle of SPR biosensor is based on surface plasmon resonance effect. When there is a certain refractive index difference between the metal surface and the medium, the incident light will be reflected and transmitted. When a biological molecule or chemical molecule binds to a metal surface, it changes the refractive index of the surface, which causes the Angle and intensity of the reflected light to change. By monitoring the changes in reflected light, the binding process and properties of substances can be obtained. SPR biosensors can be widely used in biomedical fields, such as drug screening, disease diagnosis, protein interaction research and so on. Its simple principle, high sensitivity and strong real-time performance make it one of the indispensable tools in modern biological science research. The development direction of SPR biosensor mainly includes improving sensitivity and selectivity, expanding application field, reducing cost and so on. At present, many improved technologies and methods have emerged, such as the introduction of nanomaterials, microfluidic technology, etc., to improve the performance and practicality of sensors. In conclusion, SPR biosensor is an important bioanalytical instrument with broad application prospects and plays an important role in biomedical research and clinical diagnosis.

Keywords: SPR biosensor, surface plasmon resonance, optical principle, sensitivity.

1. Introduction

With the increase in the use of ultra-efficient pesticides and the increase in the number of samples to be examined, there is a greater demand for techniques to analyze pesticide residues. This includes more demanding requirements for the sensitivity, specificity and rapidity of the techniques. Therefore, the improvement of pesticide residue analytical techniques has received widespread attention and emphasis. Long-term consumption of agricultural products containing pesticide residues poses a serious threat to human health, but the detection method with the help of antibodies as the recognizing molecule is currently the most widespread and common way in the world. With the continuous development of science and technology, the specific binding of antigen and antibody through surface plasmon resonance (SPR) technology is more and more widely used in the field of drug residue detection, and its detection limitations continue to be reduced, and the scope of detection is also expanding. The use of antibodies as recognition molecules for pesticide residue detection can improve the accuracy and reliability of detection [1]. Antibodies are highly specific and can accurately recognize and bind to the target pesticide residues for quantitative and qualitative determination. By reacting samples with specific antibodies and monitoring changes in antigen-antibody binding with the help of SPR technology, pesticide residues in agricultural products can be detected quickly and accurately. With the advancement of science and technology, the specific binding of antigen-antibody by SPR technology is widely used, which makes the detection range of pesticide residues increasing. Currently, hundreds of common pesticide residue substances can be detected by this method, and new detection methods and techniques are constantly being developed to cope with new types of pesticides that keep emerging. By using antibodies as recognition molecules, combined with SPR technology for pesticide residue detection, the safety of agricultural products consumed by people can be guaranteed. However, in order to further improve the quality and safety of agricultural products, in addition to the development of detection methods, it is also necessary to strengthen the management and monitoring of pesticides in agricultural production, reduce the amount of pesticides used, and promote organic agriculture and other measures to minimize the risk of pesticide residues in agricultural products [2]. In addition, SPR biosensors can be used in the field of bioanalysis, such as protein interaction studies, enzyme kinetic studies, drug screening and so on. By immobilizing specific biomolecules, such as antibodies, proteins or nucleic acids, on the surface of the sensor and reacting with the target substances in the samples to be tested in a specific binding reaction, the presence and concentration changes of the target molecules can be monitored and quantitatively analyzed in real time. SPR biosensors have an important application value in the field of medical diagnosis. For example, SPR biosensors can be utilized to detect biomarkers in patients' blood for early cancer screening, detection of infected viruses, and diagnosis of heart diseases. As SPR biosensors are fast, sensitive and do not require markers, rapid and accurate diagnostic results can be achieved. SPR biosensors can be used in the field of environmental monitoring, such as the detection of water pollutants, food safety and so on. By immobilizing specific biomolecules on the surface of the sensor and reacting with the target substances in the samples to be tested in a specific binding reaction, rapid detection and quantitative analysis of harmful substances in the environment can be realized [3].

2. SPR Sensor advantages

SPR (Surface Plasmon Resonance) is a real-time, label-free, non-destructive biomolecular interaction analysis technique based on optical principles. SPR takes advantage of the difference in optical properties between a metal (usually a metallic film) and a medium (usually a liquid). When light of a specific wavelength passes through a metal film and strikes the interface where the film is in contact with the dielectric, the light interacts with the free electrons on the metal, resulting in the formation of a surface plasma wave. This surface plasma wave propagates along the metal-dielectric interface and scatters some of the energy back to the metal. The intensity of this scattered light is greatest at a specific angle (resonance angle).

When a molecule in the sample interacts with the surface of the metal film (e.g., the binding of a protein to an antigen), the introduction of the molecule will change the conditions for the propagation of the surface plasma wave, and thus the resonance angle and intensity. By measuring the changes in resonance angle and intensity, the interaction between the molecules in the sample and the surface of the metal film can be determined [4]. This makes surface plasmon resonance an optical technique with great potential. The specific uses are as follows.

Interfacial resonance: SPR is based on the phenomenon of interfacial resonance between a metal and a medium. When the incident angle, wavelength and refractive index of the metal film happen to meet certain conditions, light triggers a surface plasmon resonance on the metal surface. The electromagnetic field generated by this resonance couples strongly with the light wave, resulting in energy loss and abnormal changes in the intensity of reflected light [5].

Reflected light signal detection: The metal film on the sensing chip is irradiated by incident light on one side and is in contact with the sample to be tested on the other side. When molecules in the sample interact specifically with biomolecules or other molecules on the surface of the sensing chip, this can lead to a change in the refractive index of the interface, which in turn affects the occurrence of interfacial resonance. By detecting the intensity change of reflected light, the interaction process between the sample and the surface of the sensing chip can be recorded and analyzed in real time [6].

Real-time dynamic monitoring: SPR technology has the ability of real-time dynamic monitoring, which can observe the immediate changes in the interaction between the sample and the surface of the sensing chip. By recording the intensity change of the reflected light signal in real time, information on the binding situation, affinity and binding rate between the sample and the biomolecule can be obtained. This makes SPR valuable for a wide range of applications in biomolecular interaction studies, drug screening, biosensors and other fields [7].

Compared with other traditional bioanalytical techniques, SPR has the advantages of no need for labeling substances, real-time monitoring, high sensitivity, rapid analysis, no need for pre-treatment and so on. It can not only be used to study the interaction of biomolecules, but also widely used in biomedicine, pharmaceuticals, food safety and other fields, providing an important tool and method for scientific research and practical applications [8].

3. Application

SPR biosensors can monitor the interaction process of biomolecules such as proteins, antibodies, nucleic acids, etc. in real time, including the determination of parameters such as binding constants, binding kinetics and affinity, which is of great significance for the study of the function, structure and interaction mechanism of biomolecules [9]. SPR biosensing technology (Surface Plasmon Resonance) is a biosensing technology based on optical principle, which can monitor the interaction between biomolecules in real time. It has a wide range of applications in the field of agriculture, mainly including the following aspects: Pesticide Residue Detection: SPR technology can be used for rapid and accurate detection of pesticide residues in agricultural products. By immobilizing the sample to be examined with a specific biomolecule (e.g., antibody) on a metal film, when the target pesticide residue is present in the sample, it will cause the biomolecule to bind with the target substance, thus changing the surface plasma resonance phenomenon of the metal film. By monitoring the changes in this resonance phenomenon, the presence of pesticide residues in agricultural products can be rapidly detected [10]. Heavy metal detection: SPR technology can also be used to detect heavy metal contamination in farmland soil or water sources. Similar to pesticide residue detection, SPR technology can use specific biomolecules to bind to target heavy metal ions and monitor changes in surface plasmon resonance. With the advantages of rapidity, high sensitivity and no need for complex sample processing, this method can effectively detect heavy metal levels in agricultural soils and water sources [11]. Biological infection detection: SPR technology can also be applied to the early detection and diagnosis of crop diseases. By immobilizing biomolecules related to crop pathogens on the SPR sensing chip, specific biomolecule binding reactions will occur when pathogens infecting crops are present, leading to changes in the SPR signal. By monitoring such signal changes, early detection and diagnosis of crop diseases can be realized, helping farmers to take timely control measures [12]. Protein interaction studies: SPR technology is also often used in agricultural research to study protein interactions during crop growth and development. By immobilizing different proteins on SPR sensing chips and monitoring their binding with other proteins, the mechanism of different proteins in crop growth can be understood, which can help optimize the productivity and quality of crops [13].

SPR biosensing technology can be used in drug screening work. By immobilizing a drug candidate molecule on a metal surface and then introducing a specific receptor molecule, the interaction between the receptor and the drug is utilized to cause changes in the optical signals so that drug candidates with high affinity and effective binding ability can be quickly screened. SPR biosensing technology also interactions between the study. By immobilizing a receptor on a metal surface and then introducing a known drug molecule, important parameters such as affinity and dissociation constants between the junction of the drug and the receptor can be monitored in real time. This helps in understanding the mechanism of action of the drug, evaluating the efficacy of the drug and selecting the optimal drug treatment regimen. In addition, SPR biosensing technology can be used for drug metabolism studies and drug safety assessment. By immobilizing drug metabolites with specific enzymes on a metal surface, the drug metabolism process can be monitored in real time and the stability and metabolic rate of the drug in the body can be assessed. Meanwhile, by immobilizing the drug with possible non-specific cell membranes on the metal surface, the effect of the drug on cytotoxicity can be assessed [14].

SPR biosensors can monitor the process of cell-substrate surface interaction in real time, including cell adhesion, cell proliferation, cell migration, etc., which is of great significance for the study of cell adhesion behavior, cell signaling, and cell movement mechanisms [15]. cell-substrate interaction studies: SPR biosensors can be used to study the interaction between cells and their surrounding substrates. By immobilizing cells or matrix molecules on the sensor surface, the dynamic changes of their interactions can be monitored in real time to understand the processes of cell adhesion, migration, and differentiation [16]. Receptor-ligand interaction studies: SPR biosensors can be used to study the interaction between receptors and ligands. By immobilizing receptor proteins on the sensor surface, the binding kinetic parameters of ligands, such as affinity, binding rate and dissociation rate, can be monitored in real time, so as to assess the activity and affinity of the receptor [17].

4. Summary

SPR biosensors are a cutting-edge bioanalytical technology that utilizes optical principles to detect and analyze interactions between biomolecules in real time with high accuracy. This technology has found wide applications in various fields such as biomedicine, environmental monitoring, and food safety, and has achieved impressive results. SPR biosensors work by immobilizing active molecules on a metal film, such as gold or silver, to form a sensing chip. When a biomolecule in the sample interacts with the immobilized active molecule, it causes a change in the plasma resonance angle on the surface of the metal film. This angle change can be recorded and analyzed in real time by an optical detection system. The basic principle involves placing a metal sensing chip in a specific medium and using an incident beam to create a unique electromagnetic field coupling with the metal surface. When a biomolecule interacts with the sensing chip's surface, it causes a change in the refractive index, which alters the angle of resonance of the incident beam and the intensity of the reflected light. By measuring these changes, information about the biomolecule can be obtained. SPR biosensors have the following advantages: first, they provide real-time, label-free bioanalysis, avoiding the process of labeling samples in traditional methods, making experiments simpler and faster. Second, SPR biosensors have high sensitivity and selectivity for detecting biological samples such as small molecules, macromolecules, and cells, which can meet the needs of different research and application areas. In addition, the technology is characterized by high throughput and automation, enabling rapid analysis of large-scale samples. SPR biosensors are widely used in several fields, with the biomedical field being one of its main applications. It can be used for protein interaction studies, drug screening, disease diagnosis and treatment monitoring. For example, the binding between drugs and receptors can be monitored in real time by SPR biosensors to further assess the activity and affinity of drugs. In addition, SPR biosensors can be applied to environmental monitoring, such as water quality testing and soil pollution analysis. In terms of food safety, SPR biosensors can be used for the detection of harmful substances in food or food quality assessment. Although SPR biosensors have a wide range of applications in the field of bioanalysis, there are some challenges and limitations. First, the high cost of equipment for SPR biosensors limits their diffusion in some laboratory and application environments. Second, the functionalized modification and stability of the sensing chip surface remains a challenge that needs to be further improved and optimized. In addition, sample preparation and processing have an important impact on the results of SPR biosensors, and reasonable sample pretreatment and optimization of experimental conditions are needed. In conclusion, SPR biosensors, as an advanced bioanalytical technology, have a wide range of application prospects in biomedicine, environmental monitoring, food safety and other fields. With the continuous progress and improvement of the technology, it is believed that SPR biosensors will bring more breakthroughs and development for life science research and biomedical applications.

References

[1] Gopal G, Roy N, Mukherjee A. Recent Developments in the Applications of GO/rGO-Based Biosensing Platforms for Pesticide Detection. Biosensors (Basel). 2023 Apr 19; 13 (4): 488.

[2] Jiří Homola, Sinclair S. Yee, Günter Gauglitz. Surface plasmon resonance sensors: review. Sensors & Actuators, B. Chemical.1999, 54 (1-2).3 - 15

[3] Lyon LA, Musick MD, Natan MJ. Colloidal Au-enhanced surface plasmon resonance immunosensing. Anal Chem. 1998 Dec 15; 70 (24): 5177 - 83.

[4] Kwangoo, RHA, Hyun, et al. Commercialization of Miniaturized Surface Plasmon Resonance (SPR) Biosensor Based on the Modulation of Light Source by a Rotating Mirror. 2010: 94 - 94.

[5] Rasooly A. Surface plasmon resonance analysis of staphylococcal enterotoxin B in food. J Food Prot. 2001 Jan; 64 (1): 37 - 43.

[6] Lee SJ, Youn BS, Park JW, Niazi JH, Kim YS, Gu MB. ssDNA aptamer-based surface plasmon resonance biosensor for the detection of retinol binding protein 4 for the early diagnosis of type 2 diabetes. Anal Chem. 2008 Apr 15; 80 (8): 2867 - 73.

[7] Dong, Yiyang, Wang, Sai, Liang, Xingguo. Development of a SPR aptasensor containing oriented aptamer for direct capture and detection of tetracycline in multiple honey samples.Biosensors & Bioelectronics: The International Journal for the Professional Involved with Research, Technology & Applications of Biosensers & Related Devices.2018.1091 - 7.

[8] Bianco, M., Sonato, A., De Girolamo, A.An aptamer-based SPR-polarization platform for high sensitive OTA detection.Sensors & Actuators, B. Chemical.2017.241314 - 320.

[9] Lili Zhang, Cuicui Zhu, Changbao Chen. Determination of kanamycin using a molecularly imprinted SPR sensor. Food Chemistry.2018.266170 - 174.

[10] Olaru A, Bala C, Jaffrezic-Renault N, Aboul-Enein HY. Surface plasmon resonance (SPR) biosensors in pharmaceutical analysis. Crit Rev Anal Chem. 2015; 45 (2): 97 - 105.

[11] Nasrin, Fahmida, Chowdhury, Ankan Dutta,Takemura, Kenshin.Single-step detection of norovirus tuning localized surface plasmon resonance-induced optical signal between gold nanoparticles and quantum dots. Biosensors & Bioelectronics: The International Journal for the Professional Involved with Research, Technology and Applications of Biosensers and Related Devices. 2018. 12216 - 24.

[12] Hu, Jiandong, Wang, Tingting, Wang, Shun.Development of a Surface Plasmon Resonance Biosensing Approach for the Rapid Detection of Porcine Circovirus Type2 in Sample Solutions. PLoS ONE.2014, 9 (10).1 - 6.

[13] Wang Xiaoping, Pang Kai, Zhang Bing. A Performance-Enhanced Bimetallic Chip for the Detection of Cadmium Ions with Surface Plasmon Resonance.Plasmonics.2016, 11 (4).

[14] Sobota, J.,Vlcek, J., Otipka, P.Design of MO-SPR sensor element with photonic crystal. Photonics & Nanostructures: Fundamentals & Applications.2018.3177 - 80.

[15] Nabok, A., Al-Rubaye, A. G., Al-Jawdah, A. M. Novel optical biosensing technologies for detection of mycotoxins. Optics & Laser Technology.2019.109212 - 221.

[16] Jiandong, Hu, Ruipeng, Chen, Shun, Wang. Detection of clenbuterol hydrochloride residuals in pork liver using a customized surface plasmon resonance bioanalyzer. PLoS ONE.2015.10.

[17] Wonju, Lee, Taehwang, Son, Changhun, Lee.Ultra-Sensitive Surface Plasmon Resonance Detection by Colocalized 3D Plasmonic Nanogap Arrays. Methods in molecular biology (Clifton, N.J.). 2017, 1571 (Spec).15 - 29.