

Sensing of Microplastics in Water Using Gold Nanoparticle-Coated Multimode Optical Fiber

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Summary:

The detection of microplastics in aquatic environments is significant due to their growing impact on ecosystems and human health. Gold nanoparticles were immobilized on the facet of a conventional multimode optical fiber to create a sensor based on localized surface plasmon resonance for detecting microplastics in water. In aqueous media, the interaction of the evanescent field with the nanoparticle layer produces a distinct plasmonic absorption response. Experimental observations show systematic spectral variation with increasing microplastic concentration. The observed trends are further supported by numerical simulations based on Maxwell–Garnett effective medium theory. The proposed platform demonstrates a promising approach for real-time, label-free environmental monitoring of microplastics.

Keywords: Gold nanoparticles deposition, Multimode fiber, Localized surface plasmon resonance, Maxwell-Garnett theory, Optical fiber Sensing, Microplastics sensing

Introduction, Motivation and Objective

Because of their persistence, bioaccumulation, and possible effects on ecosystems and human health, the pervasiveness of microplastics and nanoplastics in aquatic habitats has become a major worldwide concern [1]. These particles, which are now present in rivers, oceans, and even drinking water systems, are the result of the breakdown of larger plastic debris [1]. Reliable detection techniques are desperately needed because of their small size and intricate interactions with biological systems, which make them challenge to monitor and evaluate. As a result, one of the main goals of environmental research is the creation of sensitive and effective methods for detecting microplastics in water [1, 2].

For the examination of microplastics, conventional detection techniques like spectroscopy and microscopy are frequently employed, however they frequently have serious drawbacks [2]. These methods are not appropriate for real-time or in situ monitoring since they usually involve substantial sample preparation, expert operation, and heavy apparatus. Additionally, it is still difficult for them to identify low concentrations or tiny particles. Compact, label-free, and extremely sensitive sensing devices that can continuously monitor microplastics in aquatic environments are therefore in greater demand.

To overcome these obstacles, we have developed a multimode optical fiber sensor that uses gold nanoparticles immobilization and localized surface plasmon resonance (LSPR) to detect

microplastics in water. The sensing technique is based on how microplastics alter the local refractive index, which in turn affects the nanoparticle layer's plasmonic response. The composite optical behavior is modeled using numerical simulations based on Maxwell-Garnett effective medium theory to corroborate the experimental data. Demonstrating a dependable, label-free sensing method with the potential for real-time environmental monitoring is the goal.

Methodology

A stable amine-terminated layer is produced by silanization utilizing 3-Aminopropyltriethoxysilane (APTES) after the silica optical multimode fiber tip surface is initially activated by plasma treatment to produce hydroxyl groups [3]. Gold nanoparticles with a high optical density can be uniformly and robustly immobilized on the fiber surface thanks to this functionalization. Sensitive detection of refractive index fluctuations caused by microplastics is made possible by the resulting nanostructured interface, which improves the interaction between the guided light's field and the surrounding medium.

When exposed to fluids containing microplastics, the gold nanoparticle layer's LSPR response is modulated, which is how the sensing mechanism works. Measurable changes in the plasmonic absorption spectrum result from the presence and quantity of polystyrene (PS) microparticles in water, which alter the local dielectric environment. Through improved modal interaction and efficient light-matter coupling along the

sensing region, the adoption of a multimode fiber further improves the sensing performance. This method is appropriate for real-time and in situ monitoring since it enables label-free detection without requiring intricate surface chemistry targeting particular analytes.

A numerical model based on Maxwell-Garnett effective medium theory [4] is used to characterize the composite optical response of the gold-silica-microplastic system to validate and interpret the experimental data. The model predicts the spectrum behavior of the LSPR signal after considering the gradual addition of polystyrene to the effective medium. An important development that offers both a qualitative and mechanical knowledge of the sensing process is the integration of theoretical modeling and actual data. Using fiber-optic plasmonic devices, this integrated approach shows a scalable and adaptable platform for environmental microplastic sensing.

Results

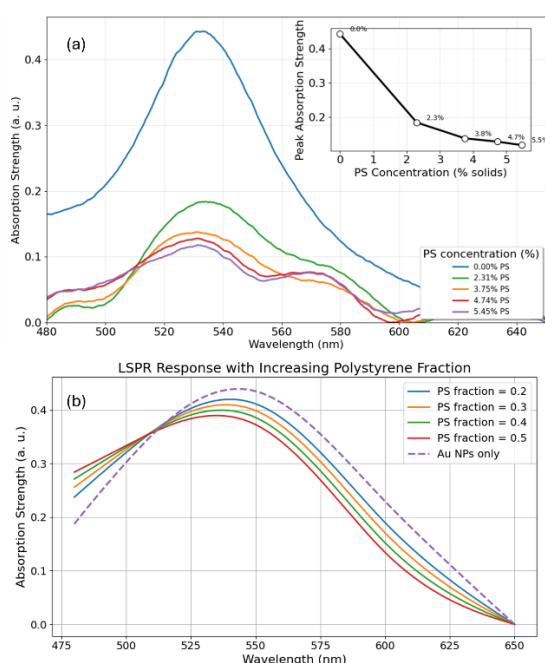


Fig. 1. (a) Experimental measurement of absorption spectrum due to LSPR when the gold deposited multimode fiber is put in water and subsequently immersed in increasing PS solutions. Inset shows peak absorption vs PS concentration. (b) Numerical simulation of the LSPR and its response when added the PS microparticles in the gold-silica composite.

When exposed to aqueous PS microplastic solutions, the gold nanoparticle-coated multimode fiber sensor's experimental response clearly demonstrates a wavelength-dependent absorbance fluctuation. Around the visible area at wavelength of 530nm, a clear localized surface

plasmon resonance characteristic is seen, with predictable variations in spectral intensity (absorption strength) as the concentration of polystyrene microplastics rises as shown in Fig. 1(a). The addition of microplastics causes detectable variation in both peak amplitude and spectral form as shown in Fig. 1(a). These fluctuations confirm the sensitivity of the suggested platform to the presence of microplastics by showing a shift in the effective refractive index surrounding the nanoparticle layer.

Numerical simulations based on Maxwell-Garnett effective medium theory were carried out by modeling PS microparticles inclusion inside the gold-silica composite system to further validate the experimental data. The simulated spectra exhibit a steady trend as the microplastic volume fraction increases, indicating a slow shift in the plasmonic response and spectrum modulation in Fig 1(b). Good qualitative agreement between the simulated and experimental data confirms that refractive index changes brought on by microplastic adsorption. The slight difference in strength is because the simulations neglect water medium. These findings demonstrate the sensor's label-free detection capabilities and offer a potential basis for microplastic monitoring in water environments.

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