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Sensitivity Improvement of Optical Fiber Refractive Index Sensor with Multimode Interference Structure using Localized Surface Plasmon Resonance

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Abstract

In this study, an optical fiber refractive index sensor with a multimode interference structure using localized surface plasmon resonance (LSPR) is proposed. The sensitivity of this device is enhanced by LSPR at gold nanoparticles attached to the surface of the sensing part of the silica fiber.

1. Introduction

Optical fiber telecommunication systems have spread rapidly; this has caused an increase in the quality and decrease in the cost of optical fibers. The use of optical fibers in sensors has received much attention because optical fibers do not use electrical signals, and silica fiber is stable in many chemical environments.

The evanescent waves on the surface of the fiber can be used for sensing the refractive index (RI) of the material around it. One attractive structure is the multimode interference (MMI) structure [1, 2]. The MMI structure is composed of a very simple structure such as a bare multimode fiber (MMF) sandwiched between single mode fibers (SMFs). The evanescent wave around the bare MMF can interact with the surrounding medium; therefore, the transmitting light reflects a change in the RI. On the other hand, because localized surface plasmon resonance (LSPR) changes its resonant condition when the RI around the nanoparticle varies, the evanescent-wave absorption caused by LSPR also reflects a change in the RI. Therefore, combining these two phenomena to measure the RI is expected to increase the sensitivity of sensors.

In this study, gold nanoparticles adhere on the MMF, which acts as the sensor of the MMI structure. Results show that the generation of LSPR in the MMI structure enhances the sensitivity of the RI measurement.

2. Concept

Multimode interference (MMI) structure

It has been observed that the optical interference in a multimode waveguide produces periodic focusing points; this phenomenon is known as MMI [3]. As shown in Fig. 1,

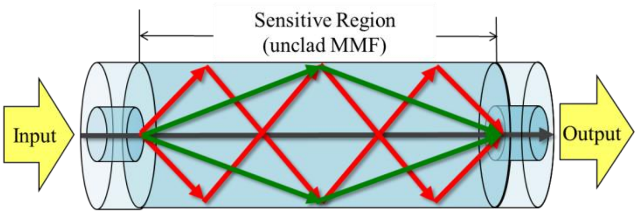

Fig. 1 Multimode interference (MMI) structure.

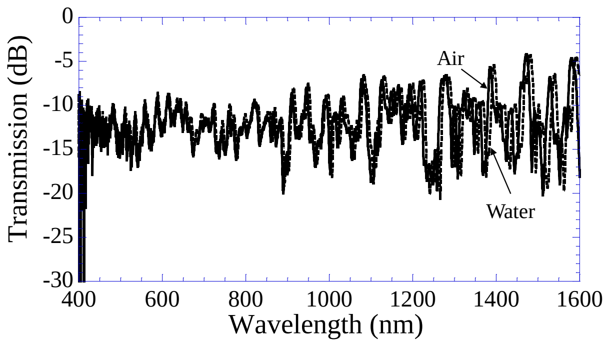

Fig. 2 Output light spectra of MMI structure.

we used an unclad fiber of pure silica with a diameter of 125 μm as an MMF portion sandwiched between SMFs with a small core diameter of 8.2 μm, which work as input and output fibers. The output light from the SMFs shows the interference signal in Fig. 2. Because the surrounding medium of the MMF acts as a cladding layer, variation in the RI of this clad induces a Goos–Hänchen shift (optical phase shift) in the total reflection region, resulting in a change in the interference signal. This change can be attributed to the variation in the RI of the surrounding medium.

***Localized surface plasmon resonance* (*LSPR*)**

LSPR is an optical phenomenon generated by the collective oscillation of the electron gas in metal nanoparticles excited by the evanescent light field. The resonant wavelength of the LSPR depends on the RI of the surrounding medium, the nanoparticle size and shape, the distance between each particle, etc. Figure 3 shows an SEM image of the fabricated gold nanoparticles. In this study, gold nanoparticles were prepared by the citrate reduction of $HAuCl_4$ and adhered on the MMF with using amino functional silane. Figure 4 shows an absorption spectrum of gold nanoparticles adhered on a hetero-core fiber structure [4] in which the evanescent waves generated outside the center absorption occurred around a wavelength (λ) of 550nm, in

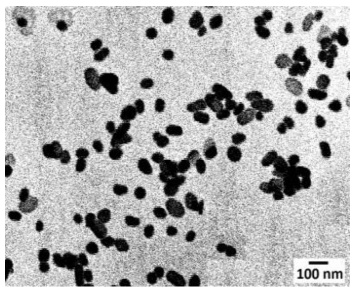

Fig. 3 SEM image of gold nanoparticles.

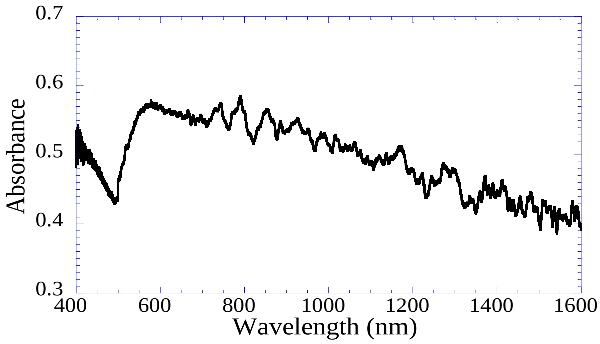

Fig. 4 Absorption spectrum of gold nanoparticles attached on fiber.

addition to raise of absorption in longer wavelength regions. These absorptions at longer wavelengths are thought to be caused by broader LSPR, which is caused by shape, size, and aggregation of nanoparticles .

MMI + LSPR

As described above, the transmission light intensity through MMI varies with RI. In other words, the wavelength spectra shift when the RI of the surrounding material changes. This effect produces the difference in the light intensity at fixed wavelengths for different RI values. In addition, the adhesion of the gold nanoparticles on the MMF produces LSPR with evanescent light, resulting in a decrease in the light transmitted at the LSPR wavelength. The combination of these two phenomena induces an increase in transmission light intensity change at the fixed wavelength at which MMI and LSPR are present simultaneously.

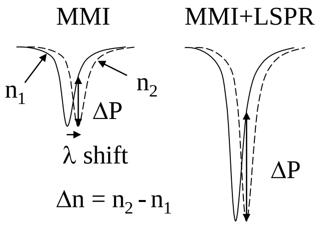

Fig. 5 Sensitivity evaluation.

When we measure different RI media with RI differences (Δn) between them, the spectral change can be shown schematically, as in Fig. 5. Using the transmission light intensity difference (ΔP) between the two spectra at a fixed value of λ, the sensor sensitivity (S) can be estimated using the following equation for a given optical power resolution (δP) of the power meter. High sensitivity is obtained when ΔP increases. Therefore, if we can obtain a high ΔP value when combining MMI and LSPR, a higher sensitivity can be realized.

3. Experimental results and discussion

$$S = \Delta n \frac{\delta P}{\Delta P} \qquad (1)$$

The measurement system comprises a white light source and an optical spectrum analyzer. This system was used for evaluation the transmission spectra of the sensor fiber. The spectral change caused by the MMI structure was observed in the 400–1600 nm wavelength range.

We measured the transmission spectra of the fabricated sensor fiber with a sensor length (L) of 80.45 mm. The surrounding medium was either water (RI = 1.3325) or ethanol (RI = 1.3591). The transmission difference, defined as the difference between the transmission spectrum of

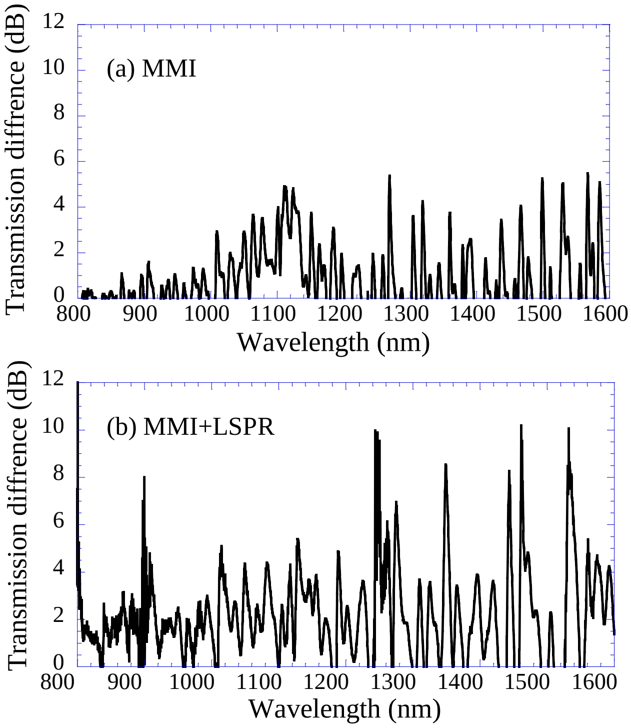

Fig. 6 Transmission difference (ΔP) at the sensor with (a) MMI only and (b) MMI + LSPR.

ethanol and the transmission spectrum of water, at the sensor with (1) MMI only and (2) MMI + LSPR is shown in Fig. 6 (a) and (b), respectively. These signals correspond to the intensity difference (ΔP) under the condition in which the RI value changes in the transition between water and ethanol, which is equal to a Δn value of 0.0266. Because the light intensity below a λ value of 800 nm from a white light source was insufficient to allow evaluation in this experiment, ΔP is presented from a λ value of 800 nm and higher. Sensitivity is estimated from this ΔP using the conventional optical power resolution δP of 0.01 dB. The maximum sensitivity is 4.9×10^{-5} at a λ value of 1567.4 nm with the MMI sensor. However, the sensitivity changes to 2.6×10^{-5} at a λ value of 1461.7 nm with the MMI + LSPR sensor. The sensitivity is roughly twice as high when using LSPR.

4. Summary

The sensitivity of an MMI structure optical fiber refractive index sensor is successfully improved using LSPR by coating the fiber with gold nanoparticles. The sensitivity is roughly two times higher when using LSPR.

Acknowledgements

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References

[1] Y. Jung, S. Kim, D. Lee, K. Oh, Meas. Sci. Technol. 17 (2006) 1129.

[2] Q. Wang, G. Farrell, Opt. Lett. 31 (2006) 317.

[3] L. B. Soldano, E. C. M. Pennings, J. Lightw. Technol. 13 (1995) 615.

[4] M. Iga, A. Seki, K. Watanabe, Sensors and Actuators B 106 (2005) 363.