Plasmonic tuning of optical fibers for biosensing

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Novel colored fibers for optical sensors were developed by depositing nanoparticle layers in microstructured optical fibers.

Plasmonic nanoparticles, typically but not exclusively comprised of silver or gold, offer much potential for novel optical sensor device development. Their interesting plasmonic properties are based on the collective oscillation of their conductive electrons. This oscillation results in a strong plasmon band, known as localized surface plasmon resonance (LSPR). LSPR spectral position and properties (i.e. extinction) can be adjusted by varying the material, particle size, and shape of chemically-synthesized colloidal particles. In this manner, spectral properties from ultraviolet (UV) to near-IR wavelengths are realized (see Figure 1).

Plasmonic nanoparticles are extremely sensitive to their local environment, e.g. analyte binding to the nanoparticles. Changes in the refractive index (RI) in the vicinity induce a shift in the LSPR peak position. Sensors for detecting this RI change can use nanoparticles in an ensemble, such as in solution or monolayers, but also at the single-particle level. Furthermore, a local field enhancement is observed, which is the basis for applying plasmonic nanoparticles for surface-enhanced Raman spectroscopic (SERS) techniques.

Plasmonic nanoparticles are also suitable for analysis of small sample volumes in a closed system. One could design sensors for this purpose by using the holes of microstructured optical fibers (MOFs)—such as suspended or fluidic core fibers—for analyte transport and detection. A combination of MOF and chip-based microfluidics can take advantage of both technologies. When the hole surfaces are modified, i.e. by attaching nanoparticle layers by the nanoparticle layer disposition technique (NLD), these fibers can be plasmonically-tuned. NLD enables preparation of dense and extremely homogeneous inner coatings of hollow fibers over a length of several meters. The spectral properties of such plasmonically-tuned fibers are similar to the extinction of the nanoparticle solutions (see Figure 2) and are independent of the longitudinal position in the fiber.

With a MOF modified by NLD with 30nm gold nanoparticles, we measured a spectral sensitivity of approximately 80nm/refractive index unit (RIU). This value is in good agreement with other LSPR references for this kind of nanoparticle. Given this successful test of sensor fundamental properties, we next demonstrated a bioanalytical measurement with our sensor: species-specific detection of the phytopathogenic micro-organism Phytophtora kernoviae in a modified MOF (see Figure 3(a)). We demonstrated the potential of plasmonically-tuned fibers for SERS field-enhancement in a proof-of-principle experiment (see Figure 3(b)). An optimized Raman amplification could be reached through further measurements using other particle types.

In summary, plasmonic nanoparticles are very useful in optical sensors. We have extended their utility by designing a sensor based on a combination of MOF and chip-based microfluidics. The sensor’s spectral properties and spectral sensitivity are similar to conventional nanoparticles. Even though our sensor was

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Figure 2. Top: Colloidal nanoparticles in solution and in nanoparticle layer disposition (NLD) fibers: silver triangles (120, 50, and 26nm edge length) and gold spheres (30nm diameter). Transmission electron microscopy insets are 200nm × 200nm. Bottom: Spectra of the particle solutions and NLD fibers, with a cross-section of selected fibers.

Figure 3. (a) Localized surface plasmon resonance detection of a phytopathogenic microorganism. (b) Demonstration of the surface-enhanced Raman spectroscopy capability of the same fiber with a Raman-active dye. CCD: Charge-coupled device.
not optimized, it was still capable of detecting a microbial plant pathogen. Our future research is focused on studying the binding kinetics of both the capture and analyte molecules in our sensor design relative to commercial surface plasmon resonance techniques.

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References