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Broadband Extinction of Core-Shell Microspheres

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Abstract: Broad-band, mass-normalized extinction cross-sections up to $1 \text{m}^2/\text{g}$ are demonstrated using chemically modified gold fractal nanostructures grown on silica microparticles.

OCIS codes: (350.2450) Filters, absorption; (310.1860) Deposition and fabrication; (240.6680) Surface plasmons

Previous reports have shown that strong, mid-infrared absorption can be achieved with fractal structures, in comparison to continuous-metal structures [1], due to the unique optical properties of semicontinuous metal films near the percolation threshold [2]. In this research, we have exploited the resonance effects of metallic nanostructures synthesized as a shell on dielectric core. Resonances in a broad spectral range are achieved from localized plasmon modes supported by the fractal metal nanostructures, and very large local-field intensity enhancements are created by these localized resonances. These enhanced intensities are greater than those of propagating plasmons and are referred to as “hot spots” [3]. The resonance frequency of a plasmon oscillation in a metallic nanostructure depends on the metal’s local morphology or geometry, and hence the inherent randomness of a fractal metallic structure ensures a strong, broadband absorption characteristic. Indeed, structures that contain myriad geometries at the nanometer scale can support many resonance frequencies, building to a broad resonance band at the micrometer scale. The resonance band extends from the near-ultraviolet to the short-wavelength infrared (SWIR) depending on structural characteristic of the shells.

In this work, we have used the broadband absorption effect of metallic fractal structures to produce broad-band extinction in chemically modified, fractal-metal structures. We have studied optical response of core-shell structures based on the chemical synthesis of gold (Au) fractal nanostructures formed on silica (SiO$_2$) microspheres. The Au fractal shells on SiO$_2$ microparticles are shown to have reasonable extinction in both the visible and short wavelength-infrared spectral ranges. In our experiments, Au-coated SiO$_2$ were deposited on fused silica substrates for ultraviolet and visible (UV-Vis) spectroscopic analysis. Au-coated SiO$_2$ particles were successfully synthesized, creating reasonable mass normalized extinction in the broad spectral range.

The extinction cross section, $C_{\text{ext}}$, is defined from the equation (1) below for the intensity change in the incident beam under transmission of a single layer of particles. Below, $I_0$ is the incident intensity, while $N_V$ and $N_S$ are the particle volume density and surface density.

$$\Delta I = -I_0 C_{\text{ext}} N_V \Delta I = -I_0 C_{\text{ext}} N_S$$

(1)

Mass normalization is done as the following equation (2).

$$C_{\text{ext}} = \frac{\Delta I}{I_0 N_S m_p} = \frac{1 - T}{N_V m_p} [\text{m}^2/\text{g}]$$

(2)

Where $m_p = \rho V_p$ (material density * particle volume) is the average mass of a particle. Here, $N_S$ has been measured with FE-SEM images, and average particle mass calculated with known particle density and measured mass density.

Figure 1(a) and (b) show field-emission scanning electron microscopy (FE-SEM) images of Au-coated SiO$_2$ microparticles. The mass normalized extinction spectra of Figure 2 show that Au-coated SiO$_2$ particles have sufficiently fractal-like Au coverage, which aids in obtaining the desired broadband extinction. By varying the Au shell structure, we can fabricate a plasmonic shell with a mass normalized extinction cross section up to $1 \text{m}^2/\text{g}$ in the broad spectral range.
Figure 1: Field Emission Scanning Electron Microscopy (FE-SEM) images of Au-coated SiO$_2$ microspheres of 1.5 µm (125R) (a) and 4.7 µm (119R) (b).

Figure 2: Mass normalized extinction cross section of Au-coated SiO$_2$ microspheres of different core diameters.

References:

