Broadband Metamaterial Absorbers in the Visible Spectrum: Effect of Nanoparticle Shape

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Optical metamaterials are defined as structures with electromagnetic properties in the visible spectrum that are unique and not present in nature. An example of such a metamaterial is a Metal-Insulator-Metal (MIM) structure, which is composed of: (*i*) a gold meta-surface layer on the top, (*ii*) silica as dielectric spacer in the middle and (*iii*) a thick gold layer as a bottom reflector. The gold meta-surface at the top of the structure is a thin layer of random and fractal gold islands of different shapes, sizes, and orientations. Such MIM structures are efficient absorbers of light and exhibit a broadband response that can cover the entire visible spectrum (400-750nm). Moreover, the top gold meta-surface layer requires no lithography and is naturally created by tuning the metal-film formation process. Substantial studies have been conducted to explain and quantify the broadband absorption properties of MIM structures. They typically attribute this broadband response to the variations in size of the gold nanoparticles in the top metasurface. However, in this work we show that variations in the shapes and the orientations of the gold nanoparticles in the top gold metasurface layer also contribute to the broadband response of these MIM structures.

In order to quantify shape variations, we used Elliptical Fourier Descriptors (EFD) to describe the complex shape of the gold nanoparticles in the top metasurface layer. By studying the statistics of these EFD, we generated equal sized gold nanoparticles but with different shapes. These size-normalized nanoparticles exhibited shapes similar to those in reported gold meta-surfaces. Computational simulations, based on finite element analysis, demonstrated that these nanoparticles resonate at distinct wavelengths even though they have exactly the same size and material composition. We also constructed numerical MIM structures with a top metasurface layer composed of multiple gold nanoparticles with equal size but with different shapes. We show that these structures also produce a broadband response. Finally, we studied how the broadband response of the MIM structure varied with (*i*) the overall surface coverage of the metasurface, and (*ii*) the randomness in the orientation and the location of the nanoparticles in the metasurface. These computational experiments can be used to guide the design of highly efficient and tunable absorbers in the visible spectrum.