Hybridization of Surface Plasmon Resonance Modes in Sierpinski Fractal Triangles

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Nano-antennas can absorb infrared or visible light through the phenomenon of surface plasmon resonances (SPR), which concentrate the energy of the light into nanoscale 'hotspots'. These hotspots are regions of high localized electromagnetic field density and are beneficial to applications such as surface enhanced Raman scattering (SERS), in which they enhance the Raman scattering signal and allow the detection of very low concentrations of analytes [1].

With high spatial resolution, electron energy loss spectroscopy (EELS) is ideal to study the nature of SPR hotspots, giving information on where high field localizations occur and the energy of light that each SPR mode will absorb. With simple structures, light absorption is typically limited to several discrete energies corresponding to the SPR modes. To expand the spectral range in which the nanostructure can absorb light, fractal geometries can be used, as is done in macroscale antennas.

The Sierpinski fractal triangle is an example of a fractal geometry used to increase the bandwidth of a nano-antenna without increasing its spatial footprint, also exhibiting polarization independence in its absorption characteristics due to its threefold symmetry. As the fractal order is increased (first three orders shown in Figure 1 a-i, b-i, c-i), the SPR modes hybridize and split in energy and the plasmonic response of the nanostructure becomes increasingly more broadband. The Sierpinski triangle is particularly interesting as the fractal order is increased by dividing existing triangles into smaller and smaller triangles, filling the same space, but increasing the complexity of the spectral response. It may be expected that high order modes in this structure will depend on both the triangles and the 'hole' triangles added with increasing fractal order.

Using electron beam lithography, we fabricated the first three fractal orders of the Sierpinski triangle (Figure 1a-ii, b-ii, c-ii) and, on a monochromated FEI Titan scanning transmission electron microscope, we performed electron energy loss spectroscopy (EELS) to probe the plasmon modes. The first two SPR modes of each fractal iteration are shown in the figure (a-iii, a-iv, b-iii, b-iv, c-iii, c-iv). We show the self-similarity of the SPR modes as the fractal order is increased, as has been shown in similar work on the Koch fractal [2], and the hybridization of all of the SPR modes as the fractal order is increased. Using EELS experiments and finite-difference time-domain simulations, we apply the hybridization model to the fractal structure and discuss how the results compare with expectations from the Babinet principle, as applied to the holes in the higher fractal orders.

References

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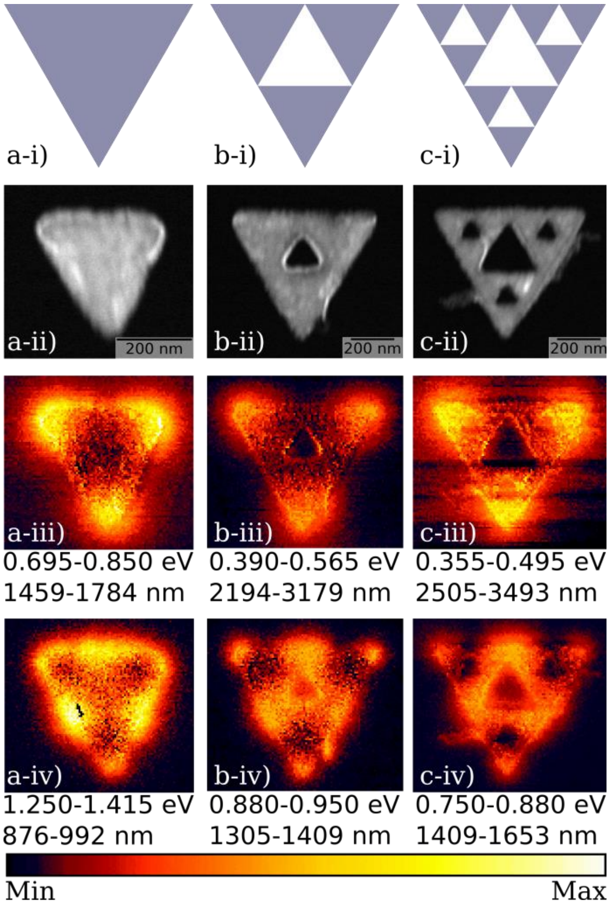

Figure 1: Sierpinski fractal triangle. a) Schematic (a-i) and high-angle annular dark-field (HAADF) image (a-ii) of zeroth order fractal; EELS map of first order (a-iii) and second order (a-iv) SPR modes. b) Schematic (b-i) and HAADF image (b-ii) of first order Sierpinski triangle fractal; EELS map of first order (b-iii) and second order (b-iv) SPR mode. c) Schematic (c-i), HAADF image (c-iii) of second order Sierpinski triangle fractal; EELS map of first order (c-iii) and second order (c-iv) SPR mode.

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