Scaling the Response of Nanocrescent Antennas into the Ultraviolet

Miguel Rodriguez, Cynthia Furse, Steve Blair
Department of Electrical and Computer Engineering
University of Utah
Salt Lake City, UT, USA
ma.rodriguez@utah.edu, cynthia.furse@utah.edu, blair@ece.utah.edu

Jennifer S. Shumaker-Parry
Department of Chemistry
University of Utah
Salt Lake City, UT, USA
shumaker-parry@chem.utah.edu

I. INTRODUCTION

We investigate the scaling of nanocrescent antennas for applications at UV wavelengths. These antennas have been extensively studied at infrared wavelengths due to their relative ease of fabrication [1] and tunability [2] via nanosphere template lithography. Their response at UV wavelengths, however, has not been characterized.

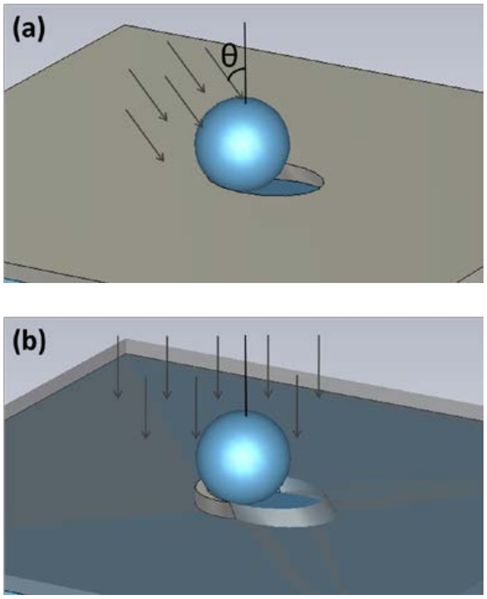
There are numerous motivating factors for investigation of UV plasmonics. One example is improving the intrinsic fluorescence of biomolecules. Biomolecules such as peptides and proteins contain amino acids, three of which are intrinsic fluorophores: phenylalanine, tyrosine and tryptophan. These aromatics absorb at wavelengths between 220-nm and 280-nm and emit at wavelengths between 320-nm and 370-nm. Their fluorescence quantum efficiency is however very low. Nanoantennas could prove useful in more efficiently coupling energy between the far field and the molecule, thus improving absorption cross-section and quantum yield. Increasing intrinsic fluorescence is advantageous in label-free detection to study molecular binding without affecting their kinetic rates.

II. MATERIALS

One of the most important challenges in extending the response into the UV range is the choice of metal used for the antenna. In general, metals are characterized by a frequency dependent complex dielectric function $\varepsilon=\varepsilon'+j\varepsilon''$. In order to obtain a reasonable response, it is desirable to have a large magnitude for the real part of the dielectric function and small imaginary part at the wavelength range of interest. This ratio is often used as a figure of merit (FOM). A comparison of typical plasmonic metals suggests aluminum as the best choice at UV wavelengths. Experimentally, the use of aluminum requires modifications to the fabrication method that has been developed for gold structures.

III. FABRICATION

Nanocrescent antennas are fabricated using nanosphere template lithography. The process begins with placing polystyrene beads on a glass substrate to serve as a template for the crescent antennas. A metal layer is then deposited at a controlled angle, Figure 1(a). The thickness can be controlled by adjusting deposition rate and time. The deposition angle θ is defined with respect to the normal to the substrate and can be used to control the top and bottom widths of the antenna. Increasing the deposition angle, for instance, results in a wider antenna at the base and narrower at the top. Deposition is followed by etching at a normal angle to the substrate, Figure 1(b). The bead's shadow acts to protect the metal underneath so that only metal outside of this area is etched. Finally, the beads are removed by tape-off, leaving only the crescents on the substrate. The result is a crescent of height *H* and diameter *D* equal to the diameter of the bead used to create it, Figure 1(c).



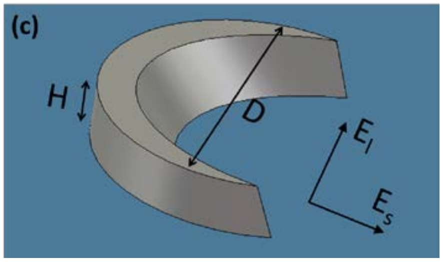


Figure 1 – Fabrication of Crescent Nanoantennas

IV.SIMULATION MODEL AND DATA ANALYSIS

The nanocrescent response was obtained through simulation using Lumerical's FDTD Solutions [3]. The structure was drawn and meshed. The program allows for hexahedral meshing where each dimension can be independently defined. The resolution used was a compromise between accuracy and computational expense. The structure was augmented with a source polarized along the short, E_s, or long, E_l, axis of the crescent. A 3-dimensional monitor was then added to record the fields at the mesh points. Simulations were performed at discrete wavelengths from 200nm to 600nm in steps of 10nm. Simulation was followed by data extraction and analysis. Data was analyzed by averaging the fields over a 1000nm^3 amorphous volume following the highest field intensity around the crescent and plotting the resulting field intensity enhancement as a function of wavelength to determine the usefulness of the crescent. Figure 2 shows the intensity enhancement response of a crescent with H=30nm, D=160nm and a deposition angle of 40° and figure 3 shows the near field pattern at the dipole resonance wavelength.

V.RESULTS

A parametric study was performed to determine the effects of diameter, height and deposition angle on resonance modes of the crescent antenna.

A. Scaling with Crescent Diameter

Reducing the diameter of antennas resulted in blue shifting the dipole and quadrupole resonances. When excited with a short-axis polarized source, the dipole resonance can be brought into the UV range by reducing the diameter to approximately 40nm. The long-axis dipole resonance occurs at much longer wavelengths, but the quadrupole resonance can be blue-shifted into the UV range with diameters less than approximately 120nm.

B. Scaling with Deposition Angle

Increasing the deposition angle resulted in some blue shifting of dipole and quadrupole resonances with the greatest change occurring between 20 and 30 deposition angles. The behavior of the higher-order resonances in general is to redshift with increasing deposition angle, which follows intuition since the backbone width increases with angle.

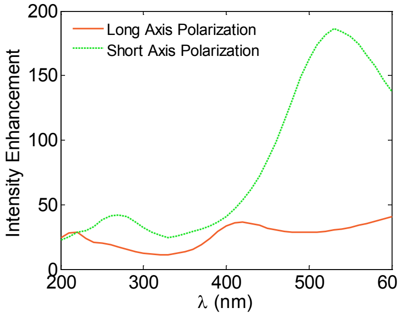


Figure 2 – Field Intensity Response

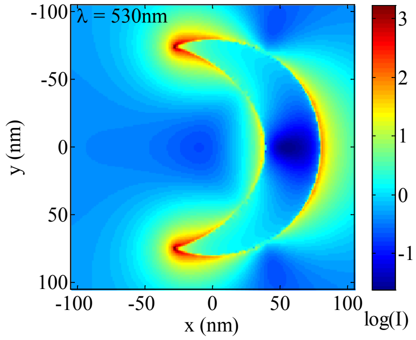


Figure 3 – Near Field Pattern at Dipole Resonance

C. Scaling with Crescent Height

Crescent height has little effect in shifting the resonant wavelengths, but can be used as an optimizing parameter to improve intensity enhancement.

VI.CONCLUSION

Short-axis dipole and long-axis quadrupole resonances of crescent nanoantennas can be shifted into the UV range by using small diameters, but as the diameter decreases so does local intensity enhancement. Higher-order modes, however, are very promising for operating in this range and can produce strong and tunable intensity enhancement below 300 nm wavelength.

REFERENCES

[1] R. Bukasov and J. Shumaker-Parry, "Highly-Tunable Infrared Extinction Properties of Gold Nanocrescents," Nano Letters, vol. 7, issue 5, pp. 1113-1118, 2007.

[2] B. Ross and L. Lee, "Plasmon tuning and local field enhancement maximization of the nanocrescent" *Nanotechnology* vol. 19, issue 27, 2008.

[3] FDTD Solutions, https://www.lumerical.com/tcad-products/fdtd/