Plasmonics: Manipulating, Trapping and Harvesting Light at the Nanoscale

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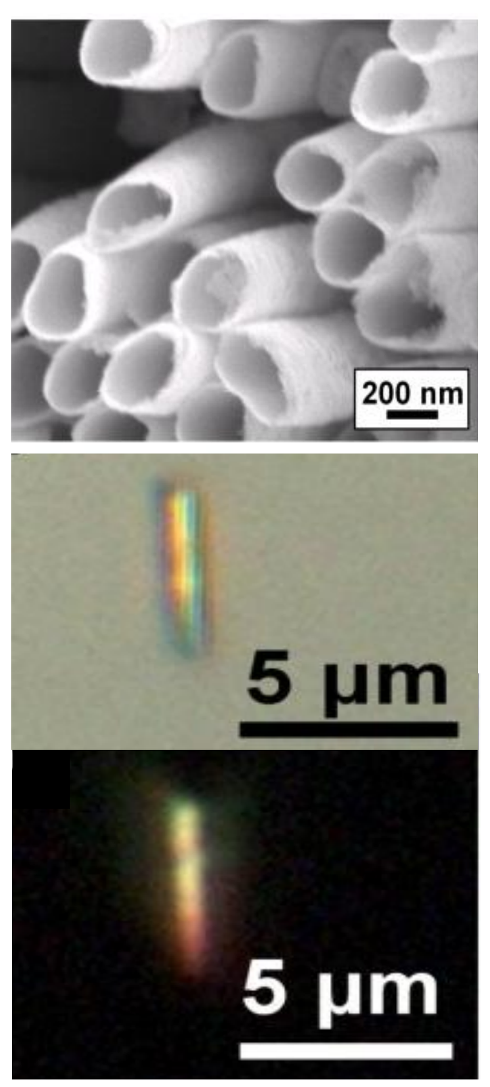
Introduction

Noble metal nanostructures can support surface electron oscillations known as surface plasmons on interaction with light. The desire to control and manipulate surface plasmons has lead to the field of "Plasmonics" which shows promise for the development of sub-wavelength light-emitting and light-harvesting devices such as nanoscale lasers, cavities and antennas.

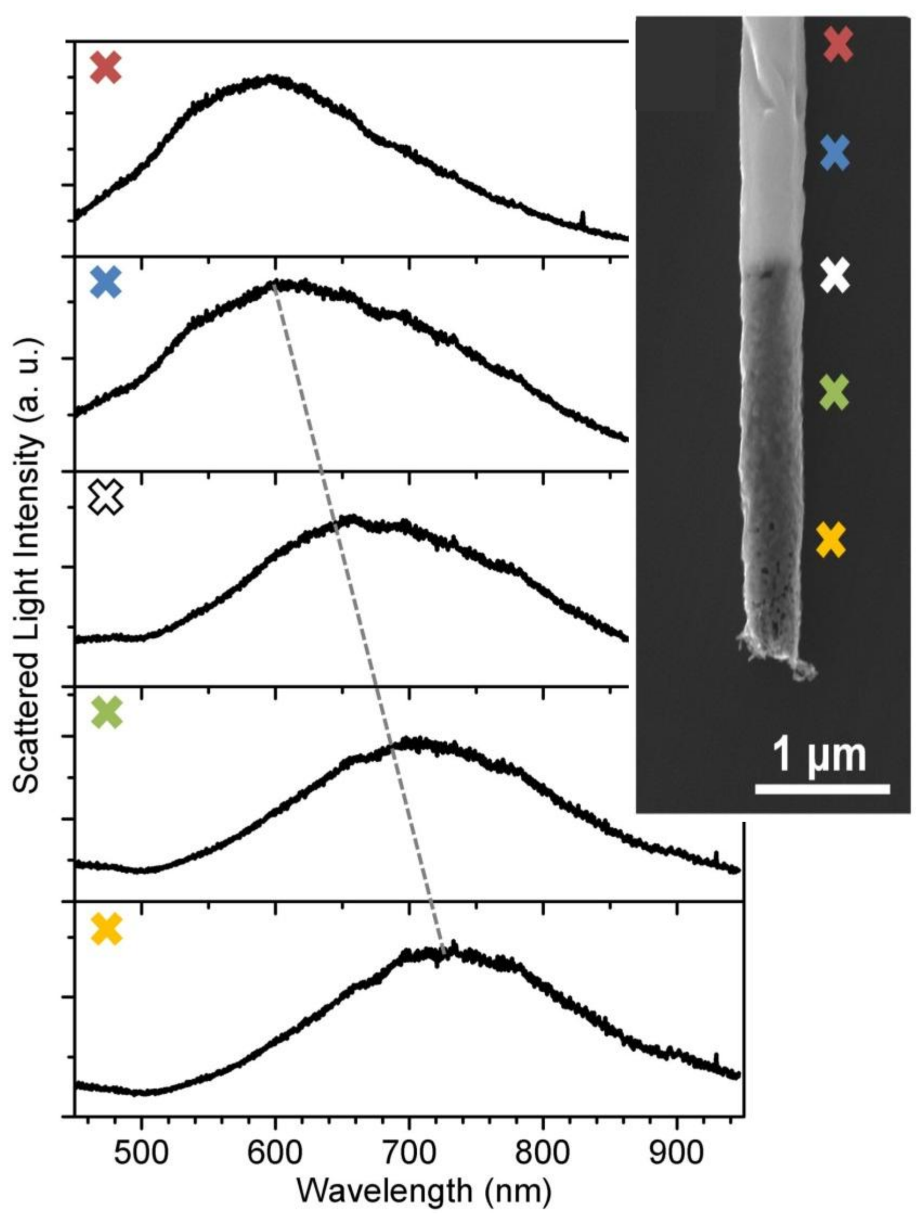
We are developing tubular plasmonic nanocavities and nanoantenna structures for integration into large-area organic semiconductor solar cells and solid-state light-emitting diodes (LEDs) so that nanoscale structure phenomena can be utilized on macroscopic length scales for efficient light-management in the semiconductor active layer.

Large-Area Gold Nanotube Arrays with Tunable Resonances for Anisotropic Light Confinement[1]

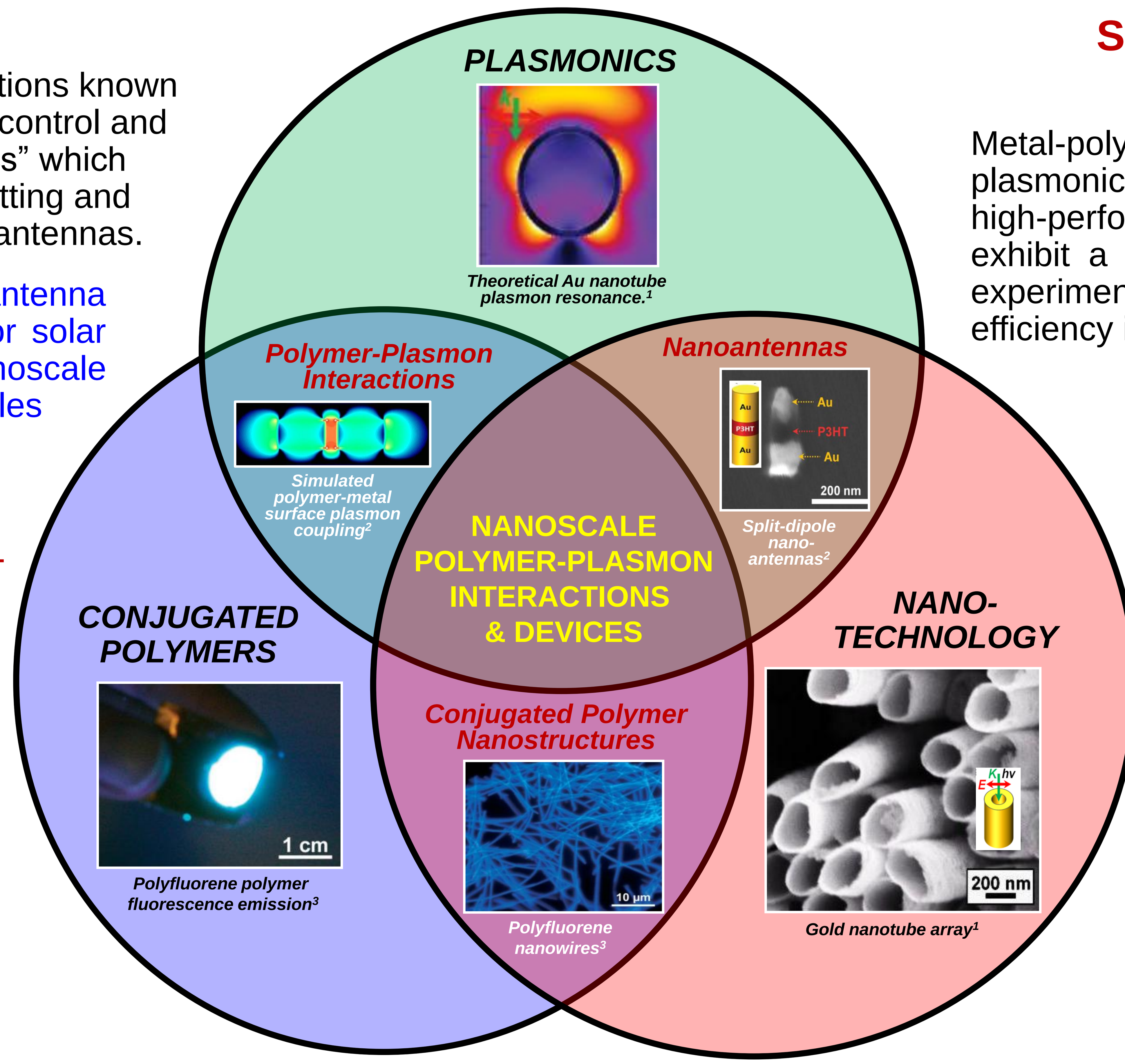
Metal nanotubes are being explored as light out-coupling structures for high-efficiency white-light LEDs, and as nanocavities for sub-wavelength lasers because of their ability to support both tunable surface plasmon resonances and propagating surface plasmons polaritons.



Scanning-electron microscope image (top) of an array of Au nanotubes. Bright-field (center) and dark-field (bottom) microscope images of single nanotube/ nanowire hetero-structures.

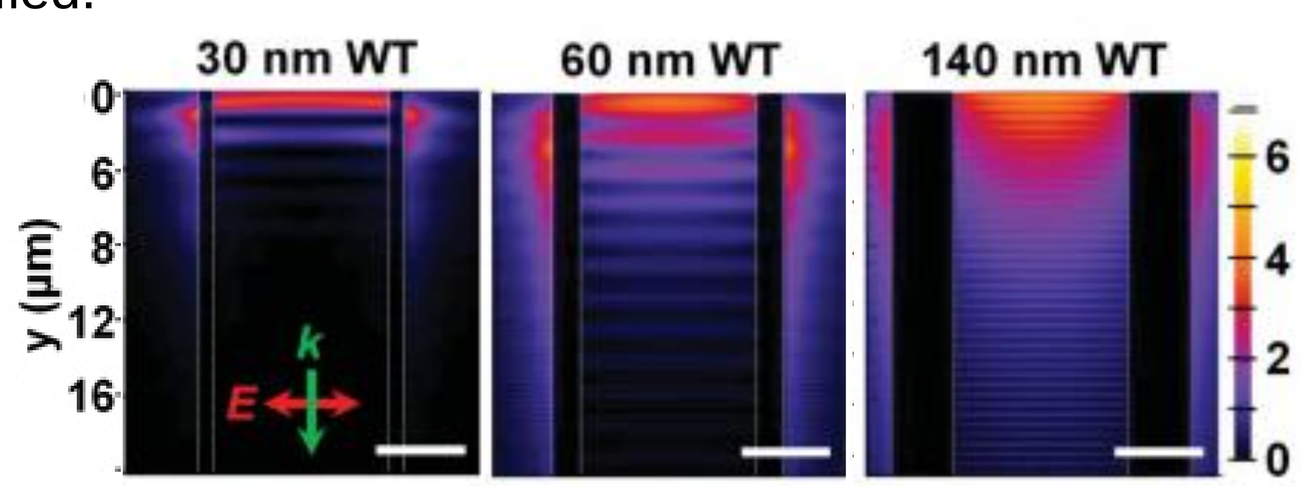


Scattered-light spectra collected along the single nanotube showing a red shift in the plasmon resonance wavelength as a function of decreasing wall thickness.



Theoretical Study of Plasmon Propagation Nanotubes[1]

Propagation of surface plasmons in a metal nanotube is analogous to propagation of light in an optical fiber. As the thickness of the nanotube wall changes, both wavelength and propagation length of the surface plasmons are modified.



Theoretical 2D electric-field intensity cross-sections of single gold nanotubes of varying wall thickness. (WT)

Split-Dipole Nanoantennas for Improved Light Management in Organic LEDs[2]

Metal-polymer-metal nanoantennas such as our gold-P3HT-gold plasmonic split-dipole nanoantennas may enable a new generation of high-performance organic conjugated polymer LEDs. Our structures exhibit a radiative emission rate enhancement factor of 29 for P3HT, experimentally (> 550 theoretically). Modified luminescence quantum efficiency is also shown to increase from 1% up to 45% (theory).

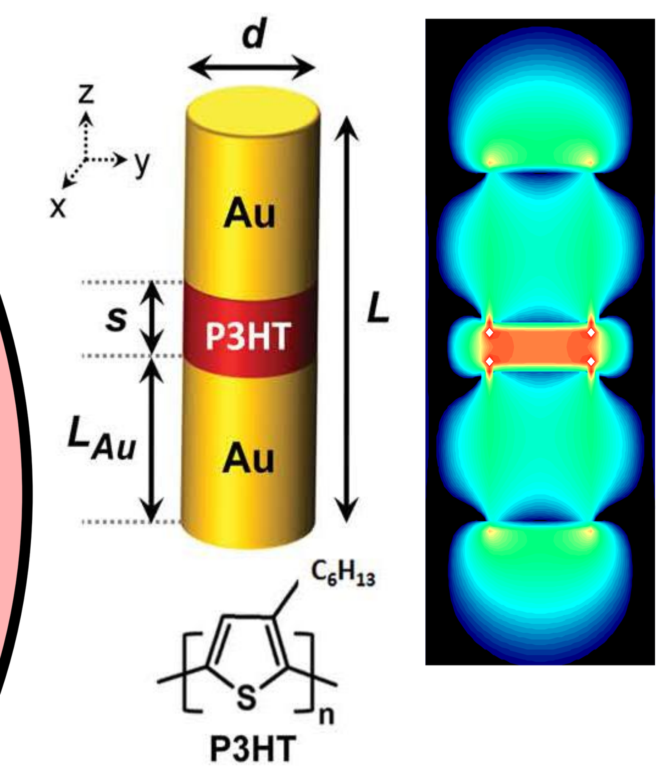
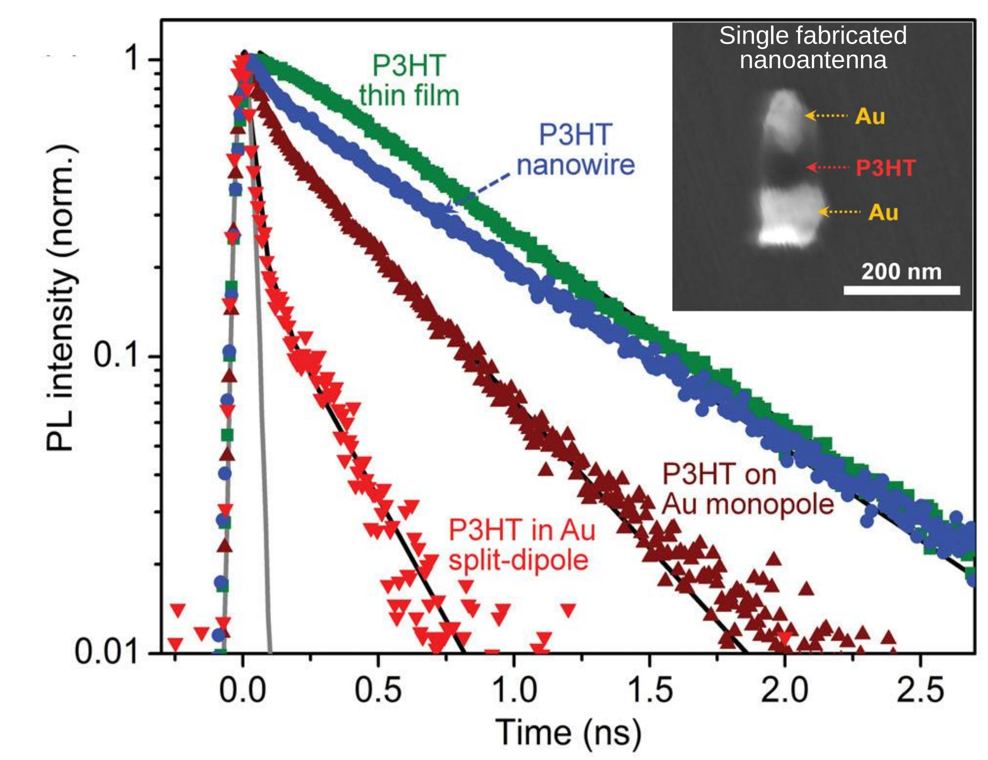


Diagram of a gold-P3HT-gold nanoantenna and the molecular structure of poly(3-hexylthiophene), P3HT. Theoretical electric-field intensity of the nanoantenna is shown in cross-section (right).



Photoluminescence lifetime decays from a P3HT thin film, P3HT nanowire, single resonant gold-P3HT monomer nanoantenna and single resonant gold-P3HT-gold split-dipole nanoantenna. Instrument response function is shown in grey.

Conclusion

Modifying semiconductor optical properties using plasmonic nanostructures enables confinement and manipulation of light on the nanoscale, which has implications for next-generation light-emitting and light-harvesting devices.

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[1] J. Kohl, M. Fireman, D. M. O'Carroll, "Surface Plasmon and Photonic Mode Propagation in Gold Nanotubes with Varying Wall Thickness" *Phys. Rev. B* 84, 235118 (2011).
[2] D. M. O'Carroll, J. Fakonas, D. M. Callahan, M. Schierhorn, H. A. Atwater, "Metal-Polymer-Metal Split-Dipole Nanoantennas," *Adv. Mater.* accepted (2012).
[3] D. M. O'Carroll, D. Iacopino, A. O'Riordan, P. Lovera, É. O'Connor, G A. O'Brien, and G. Redmond, "Poly(9,9 dioctylfluorene) Nanowires with Pronounced b-Phase Morphology: Synthesis, Characterization, and Optical Properties," *Adv. Mater.* 20, 42 (2008).

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