Infrared Plasmonics based on doped silicon nanocrystals

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Noble metal nanostructures have long been used in plasmonic-based technology due to their high Localised Surface Plasmon Resonance (LSPR) in the visible spectrum. It was recently discovered that doped semiconductors can support LSPR in the midinfrared, even for small objects. The number of dopants becomes a new parameter used to adjust the resonance position. We present here the experimental realization of plasmonic hyperdoped Si nanocrystals (SiNCs) embedded in silica using low energy ion implantation and rapid thermal annealing. We show that phosphorus dopants are incorporated into nanocrystal cores at concentrations up to six times higher than P bulk solid solubility. We demonstrate that dopant activation enables partial nanocrystal surface passivation, which can be completed through forming gas annealing. Using LSPR as an optical probe, we show the presence of free carriers in surface passivated doped SiNCs with radius ranging from 2.6 to 5.5 nm. Fourier Transform Infrared Spectroscopy combined with numerical simulations allows us to determine the number of electrically active P atoms, demonstrating that LSP resonances can be sustained with only about 10 free electrons per nanocrystal. We observe the appearance of avoided crossing behavior due to the hybridization of the LSPR and the silica matrix phonon modes. Finally, because the diameter of our NC is smaller than the electron mean free path, we show that the scattering time dependence with carrier density in such NCs differs significantly from what is observed in bulk or larger Si nanostructures, and we were able to detect evidence of P aggregate formation.