Narrow linewidth surface lattice resonances in plasmonic aluminum nanoantenna arrays

Bhera Ram Tak, Kamonpan Chumpol, Robert O'Meara, Nebras Alattar, Richard G. Hobbs
School of Chemistry, Trinity College Dublin, Ireland, D02W085
Advanced Microscopy Laboratory, Centre for Research on Adaptive Nanostructures and Nanodevices, Trinity College Dublin, Ireland, D02DA31
takb@tcd.ie

Plasmonic metal nanoparticles can amplify optical fields locally within nanoscale volumes making them attractive materials for enhancing light-matter interactions in fields of photocatalysis, sensing and nanoscale light sources. [1,2,3] However, localized surface plasmon resonances (LSPRs) in metal nanoparticles typically exhibit low quality factor resonances arising from optical losses and plasmon damping. Surface lattice resonances (SLRs) can be generated by arranging plasmonic nanoparticles in periodic arrays and can support higher quality factor resonances than in LSPRs by suppressing radiative damping.[4] The narrow linewidth, higher quality factor resonances present in SLRs are suited to applications in surface-enhanced Raman spectroscopy, lasing and strong coupling to molecular resonances and quantum emitters. [5] In particular, SLRs in arrays of aluminum nanoparticles are interesting as they provide a route to access resonances in the blue and UV region of the spectrum and do not require noble metals. The coupling of LSPRs and SLRs with guided mode substrates can generate narrow linewidth features in optical extinction spectra that lend themselves to the applications listed above.[6]

Here we have fabricated periodic arrays of Al bowtie nanoantennas and simulated and measured their optical extinction spectra, which show promise to produce narrow linewidth SLRs in the green and blue region of the spectrum. Previously, surface plasmon resonances have been reported in this spectral region using silver nanostructures, however, the plasmonic properties deteriorated with time due to

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oxidation and sulfidation of silver in air.[7,8] For Al bowtie SLRs in the blue region of the spectrum, equilateral triangles with side length of 85 nm, a bowtie gap of 15 nm and Al thickness of 20 nm was simulated. These structures were fabricated on a 100-nm-thick ITO substrate, which has been reported to exhibit a waveguided mode. A narrow SLR peak of 3-4 nm was observed for bowtie nanoantennas with pitches of 338-388 nm as displayed in figure 1(a). The scanning electron microscope images of these nanoantennas are shown in figure 1(b). A red shift in SLR peak was observed from 446 to 505 nm with increasing bowtie period. A quality factor of about 150 could be estimated for the peak at 446 nm with a narrow spectral width of 3 nm, which is the among the best reported Al nanoantenna arrays in blue spectrum range.[9] The most intense SLR peak (linewidth 4 nm) was observed at the maximum of the bowtie LSPR peak. The simulated extinction spectra shown in figure 1(c) show SLR peaks that appear to red-shifted by approximately 80 nm relative to experimental spectra. The red shift is expected due to the difference in excitation angle (normal incidence simulated, NA 0.55 lens used experimentally). Overall, this report provides a route to obtain tunable SLRs in the blue region of the spectrum with narrow SLR modes within the broad LSPR modes. These systems may support studies requiring both broadband field enhancement provided by LSPRs as well as narrow linewidth features suited to strong coupling studies in photocatalysis and quantum emitter array development.

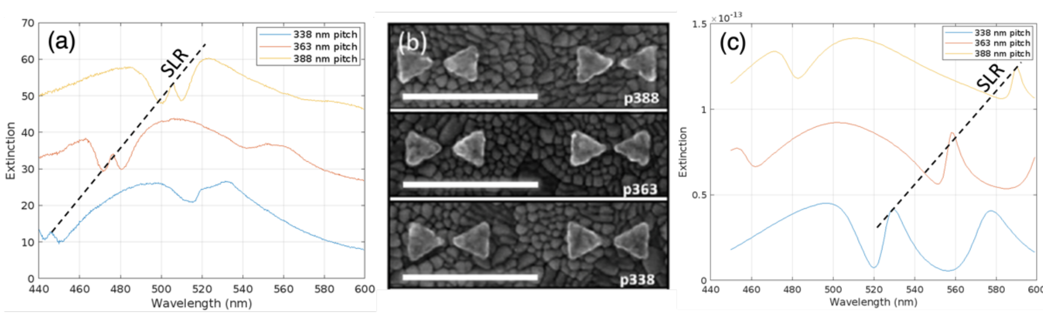

Figure 1: (a) Experimentally measured extinction spectra for arrays of Al nanoantennas with different pitches. The surface lattice resonance peak at 446 nm for 338 nm pitch has an observed FWHM of 3 nm. Arrays excited via 0.55 NA condenser lens. (b) SEM images of nanoantennas with different pitches (scale bar 300 nm). (c) Calculated extinction spectra by finite element method using COMSOL Multiphysics.

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