Asymmetric dot dimers – optical properties and interactions

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Abstract: We present a study of the rich optical behaviour of the dark (grey) modes exhibited by asymmetric dot dimers and how this behaviour is modified upon interaction between dimers.

Over the last decade there has been considerable interest in the dark, or rather grey, modes of plasmonic nanostructures, which have an (almost) vanishing net dipole moment and are therefore associated with narrower linewidth than dipolar plasmon resonances [1]. One way of turning completely dark modes grey and thus making them radiative is to break the symmetry of the plasmonic nanostructures to prevent complete cancellation of the contributing dipole moments [2,3].

We study asymmetric dot dimers (ADDs) comprised of two silver nanodisks of different diameters, that exhibit grey modes in the visible. Starting from the mode-hybridisation in indivdual ADDs we continue to discuss their rich behaviour when interacting in ADD ensembles, chains and arrays, based on spectroscopic experimental data which are complemented and extended by numerical modelling.
The individual ADDs show the expected splitting into a symmetric and an antisymmetric mode and we observe a marked difference in the overall lineshape for excitation parallel or perpendicular to the symmetry axis of the dimer. For collections of ADDs one has to distinguish between the metamaterial limit, where the unit cell is small compared to the resonance wavelength and invididual building blocks cannot couple diffractively via their scattered fields, and the diffractive regime, where such interaction is possible. In both cases we find the collective response of ADD chains and arrays to be different from the simple sum of the individual ADD spectra: in the metamaterial limit sufficiently large ensembles show a more pronounced splitting of the two modes while the onset of diffraction results in surface-lattice resonances, which are sharper than for a lattice based on single disks [4,5] and for given geometry and polarisation conditions also exhibit the asymmetric double-line shape of the ADD elements giving rise to them.

Such narrow resonances based on grey modes are often mentioned in the context of strong coupling and lasing where they are believed to be of some advantage. We therefore complete our study of the optical properties of ADDs by in investigating the response of ADD ensembles coupled to dye (Rhodamine) molecules embedded in a polymer matrix.

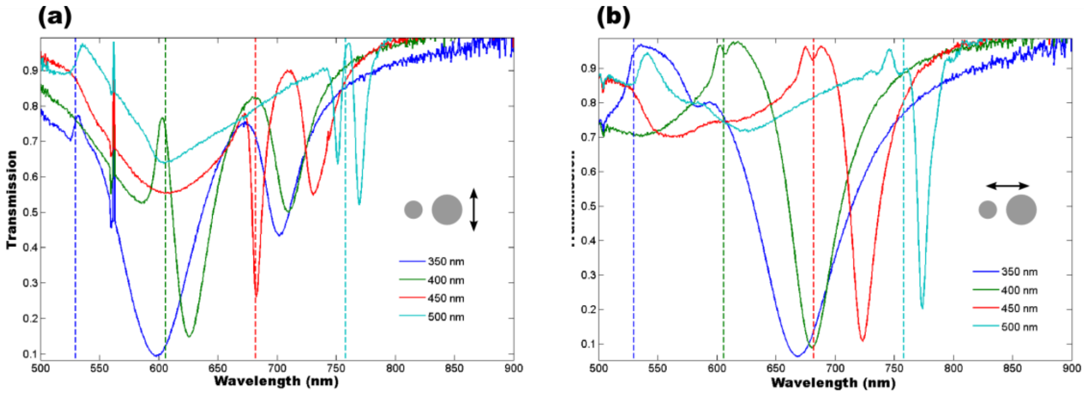

Figure 1: Transmission spectra of asymmetric dot dimers made from silver, have nominal diamters of d_1 =70 nm and d_2 = 90 nm with a centre-to-centre separation of 150 nm. The ADDs are arranged in square arrays with different lattice constants a = 350 nm (blue), a = 400 nm (green), a = 450nm (red) and a = 500 nm (cyan) with the corresponding diffraction edges marked as dashed lines. (a) Incident polarisation perpendicular to the symmetry axis of the ADD, (b) incident polarisation parallel to the ADD axis.

References

[1] B Luk'yanchuk *et al.*, Nature Mater. **9**, 707-715 (2010).
[2] J Zhang, KF MacDonald, and NI Zheludev, Opt. Express **22**, 26721-26728 (2013).
[3] Y Moritake, Z Kanamori, and K Hane, Opt. Lett. **39**, 4057-4060 (2014).
[4] B Aguié and WL Barnes, Phys. Rev. Lett. **101**, 143902:4 (2008).
[5] VG Kravets, F Schedin, and AN Grigorenko, Phys. Rev. Lett. **101**, 087403:4 (2008).