Plasmonic resonances of metallic nanoparticles in arrays and in isolation

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to the University of Exeter
as a thesis for the degree of

Doctor of Philosophy in Physics

October 2010

I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other university.

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Abstract

Plasmonics is the branch of photonics that is concerned with the interactions which take place between metallic structures and incident electromagnetic radiation. It is a field which has seen a recent resurgence of interest, predominantly due to the emerging fields of metamaterials and sub-wavelength optics. The original work contained within this thesis is concerned with the plasmonic resonances of metallic nanoparticles which can be excited with visible light. These structures have been placed in a variety of configurations, and the optical response of each of these configurations has been probed both experimentally, and with numerical simulations.

The first chapter contains some background and describes some recent advances in the literature, set against the broad background of more general concepts which are important in plasmonics.

The best starting point in describing the response of plasmonic systems is to consider individual metallic particles and this is the subject of the second chapter. Three separate modelling techniques are described and compared, and dark-field spectroscopy is used to produce experimental scattering spectra of single particles which support dipolar and higher order modes. Mie theory is used as a starting point in understanding these modes, and finite element method (FEM) modelling is used to make numerical comparisons with dark-field data.

When two plasmonic particles are placed close to each other, interactions take place between them and their response is modified, sometimes considerably. This effect can be even stronger if particles are placed in large arrays. Interactions between the dipolar modes of gold particles form the basis of the third chapter. The discussion begins with pairs of particles, and the coupled dipole approximation (CDA) is introduced to describe the response. Ordered square arrays are considered and different modelling techniques are compared to experimental data. Also, random arrays have been investigated with a view to inferring the extinction spectrum of a single particle from a carefully chosen array of particles in which the inter-particle interactions are suppressed.

The fourth chapter continues the theme of particles interacting in arrays, but the particles considered support quadrupolar modes (and they are silver instead of gold). The optical response is strongly modified, and an explanation is provided which overturns the accepted explanation.

The final chapter of new results is somewhat different to the others in that a very different structure is considered and different parameters are extracted. Instead of far-field quantities, here, near-fields of composite structures are of interest; they can generate greatly enhanced fields in the vicinity of the structure. These enhanced fields, in turn, enhance the fluorescence and Raman emission of nearby dye molecules. A novel field integration technique is proposed which aims to mimic the experiments which were carried out using fluorescence confocal microscopy.

Contents

List of Figures