Dirac-Like Plasmons in Honeycomb Lattices of Metallic Nanoparticles

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Abstract

Light has inspired science and art for millennia. The interaction of light with metals resulted in remarkable technological as well as artistic breakthroughs, like the invention of mirrors and of stained glass windows. In fact the colour of the latter is generated from light interacting with small metallic particles embedded within the glass, and can be controlled by changing the shape, size and material of these particles. This interaction has been explored further, with the discovery that individual nanoparticles can be used to trap light to the nano-scale. Along this direction the rapid evolution of nano-physics allowed control over the production of arrays of metallic nanoparticles that can trap light and transport it over macroscopic distances [1].

In this theoretical project, inspired by the unique properties exhibited by graphene [2], we analytically explore two-dimensional honeycomb arrays of metallic nanoparticles (see figure 1). Each of these nanoparticles supports a localized surface plasmon. We study the quantum properties of the collective plasmons (CP), resulting from the near field dipolar interaction between the nanoparticles, which transport energy through the system. These CPs behave as peculiar relativistic quantum particles (massless Dirac bosons, see figure 2) whose behaviour can be tuned by the polarisation of light (see figures 3 and 4).

We analytically investigate the dispersion, the effective Hamiltonian and the eigenstates of the CPs for an arbitrary orientation of the individual dipole moments. When the polarization points close to the normal to the plane the spectrum presents Dirac cones, similar to those present in the electronic band structure of graphene. We derive the effective Dirac Hamiltonian for the CPs and show that the corresponding spinor eigenstates represent Dirac-like massless bosonic excitations that present similar effects to electrons in graphene, such as a non-trivial Berry phase and the absence of backscattering off smooth inhomogeneities. We further discuss how one can manipulate the Dirac points in the Brillouin zone and open a gap in the CP dispersion by modifying the polarization of the localized surface plasmons, paving the way for a fully tunable plasmonic analogue of graphene.

The remarkable fact that the plasmonic dispersion can be tuned could open new horizons in high-definition microscopy and in ultrafast electronic devices that will benefit from the unimpeded propagation of information carried by the novel CP [3].

References

[1] C. F. Bohren and D. R. Huffman, *Absorption and Scattering of Light by Small Particles* (Wiley-VCH, Weinheim, 2004)
[2] K. S. Novoselov et al., Science **306** (2004) 666
[3] G.Weick, C. Woollacott, W. L. Barnes and E. Mariani, Phys. Rev. Lett. in press (2013) arXiv:1209.5005v2

Figures

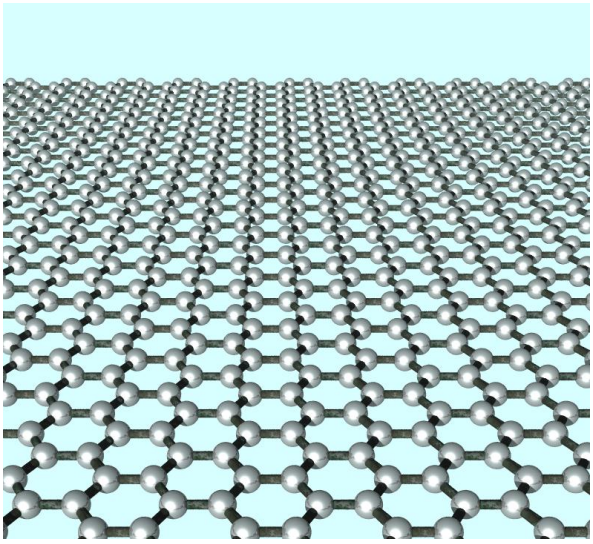

Fig. 1: A honeycomb lattice of metallic nanoparticles, the same structure as carbon atoms in graphene.

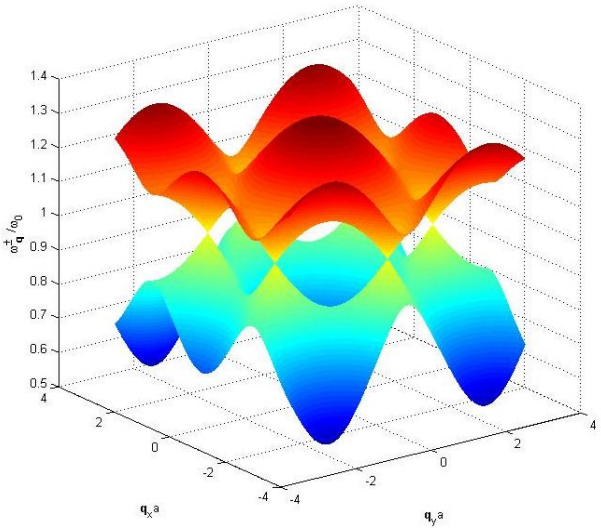

Fig. 2: The CP dispersion for a honeycomb array of metallic nanoparticles, with polarisation normal to the plane, showing the emergence of pseudo-relativistic physics.

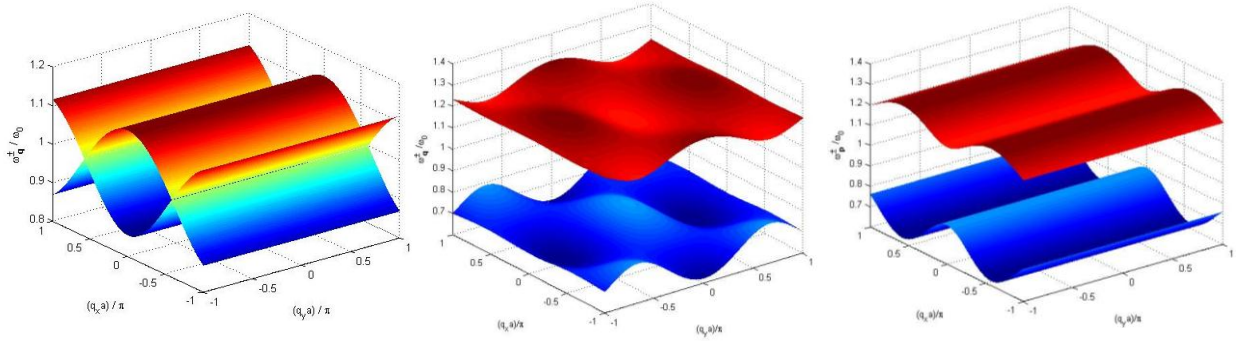

Fig. 3: The CP dispersions for a honeycomb array of metallic nanoparticles for three different light polarisations.

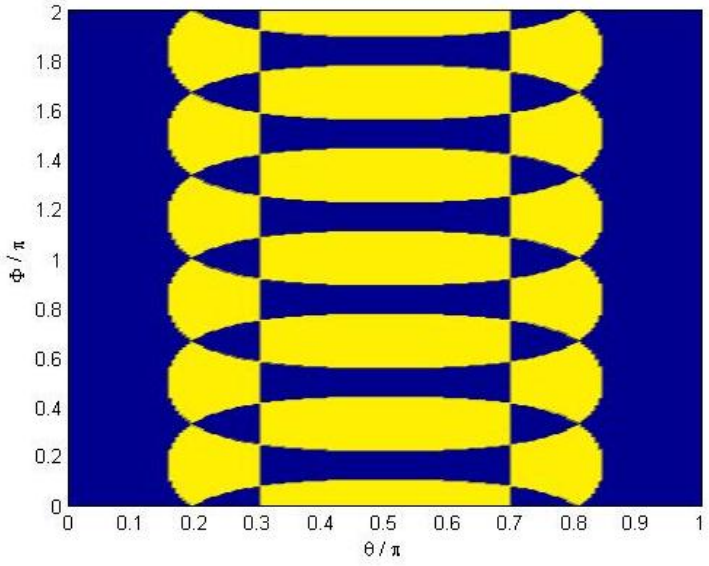

Fig. 4: By changing the in-plane angle (ϕ) and out-of-plane angle (θ) of the orientation of the dipole moments of the localized surface plasmons on the metallic nanoparticles, the CP dispersion can either be gapless and graphene-like (blue) or have a gap (yellow).