PhD Project Description

Title: Coupling light to a single atomic layer: Graphene plasmonics and photonics
Lead Supervisor: Andrey Gorbach
2nd Supervisor: Marcin Mucha-Kruczynski

Graphene, a single layer of carbon atoms arranged in hexagons, is an atomically thin representative of a new class of materials – two-dimensional crystals. Because of the restricted dimensionality and crystal symmetry resulting from the sp2 hybridised carbon-carbon bond, graphene has very interesting physical properties. In particular, it exhibits unusually strong nonlinear optical response and supports low-loss surface plasmons [1,2]. These collective excitations of bound electrons and photons are spatially confined to regions much smaller than the wavelength of the photon with the same energy, providing means for extreme concentration of electromagnetic energy. Moreover, because plasmon wavelength depends on the density of carriers in the material, graphene offers an advantage over other materials as its chemical potential can be easily tuned using electrostatic gating [3]. However, graphene is conceptually different from the usual, three-dimensional bulk materials. The fundamental physics behind light interaction with electrons in graphene is so far not fully understood and requires careful interdisciplinary studies at the intersection of optics, photonics and solid state physics.

In this project, realised under joint supervision of Dr Andrey Gorbach and Dr Marcin Mucha-Kruczynski, the student will develop mathematical models and numerical algorithms to study nonlinear optical effects in various graphene-based plasmonic and photonic setups. A particular emphasis will be put on developing setups to explore and enhance the specific surface nonlinearity of graphene [4], advancing novel schemes for light manipulation at the sub-wavelength scale. Among principle configurations to be explored in this project will be heterostructures of graphene with other two-dimensional crystals [5], where collective excitation of plasmons in multiple layers can lead to a range of novel optical effects including reconfigurable superlensing and negative refraction.

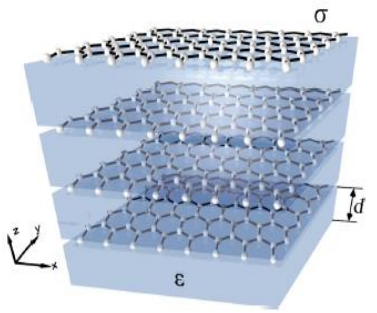

Figure 1 A schematic view of a graphene /dielectric heterostructure.

For more detailed information on the research within this area pursued at the University of Bath, please visit http://people.bath.ac.uk/ag263/ or http://people.bath.ac.uk/mlmk20/

The successful candidate should hold, or expect to receive, a first class or good 2.1 Master's degree (or equivalent) in Physics (Theoretical Physics preferred) or other closely related field. A keen interest in theoretical optics or condensed matter physics and a strong work ethic are essential. Also required is basic programming experience as well as some knowledge of Matlab/Mathematica.

Potential sources of funding include an EPSRC Centre for Doctoral Training (UK/EU citizens) or individual EPSRC/University of Bath scholarships. Candidates are encouraged to contact Dr Andrey Gorbach (a.gorbach@bath.ac.uk) or Dr Marcin Mucha-Kruczynski (m.mucha-kruczynski@bath.ac.uk) with informal enquiries.

References:

[1] F. J. G. de Abajo, *Graphene Plasmonics: Challenges and Opportunities*, ACS Nano **21**, 1086 (2014).
[2] A. N. Grigorenko, M. Polini, K. S. Novoselov, *Graphene plasmonics*, Nature Photonics **6**, 749–758 (2012).
[3] J. Chen, M. Badioli, P. Alonso-Gonzalez, S. Thongrattanasiri, F. Huth, J. Osmond, M. Spasenovic, A. Centeno, A. Pesquera, P. Godignon, A. Z. Elorza, N. Camara, F. J. G. de Abajo, R. Hillenbrand, F. H. L. Koppens, *Optical nano-imaging of gate-tunable graphene plasmons*, Nature **487**, 77 (2012).
[4] A. V. Gorbach, *Nonlinear graphene plasmonics: Amplitude equation for surface plasmons*, Physical Review A **87**, 013830 (2013).
[5] J. R. Wallbank, A. A. Patel, M. Mucha-Kruczynski, A. K. Geim, V. I. Fal'ko, *Generic miniband structure of graphene on a hexagonal substrate*, Physical Review B **87**, 245408 (2013).