Tuning metamaterial properties by a single-layer of graphene

N. Papasimakis[1,], A. E. Nikolaenko[1], Z. Luo[2], Z. X. Shen[2], F. De Angelis[3,4], E. Di Fabrizio[3,4], S. Boden[5], T. Uchino[5], and N. I. Zheludev[1]*

[1]Optoelectronics Research Centre and Centre for Photonic Metamaterials, University of Southampton, SO17 1BJ, UK

[2]School of Physical and Mathematical Sciences, Nanyang Technological University, 637371 Singapore

[3]Italian Institute of Technology, 16163 Genova, Italy

[4]University of Magna Graecia, 88100 Catanzaro, Italy

[5]Department of Electronics and Computer Science, University of Southampton, SO17 1BJ UK

[*]Email:N.Papasimakis@orc.soton.ac.uk, web: http://www.metamaterials.org.uk/

Abstract: We report on the observation of strong, nontrivial interactions between a plasmonic metamaterial and a graphene single-layer. We argue that these result from the periodic physical deformation of the graphene by the structured metamaterial substrate.

Graphene, a flat monolayer of carbon atoms, has recently emerged as a promising candidate for nanoscale optoelectronics due to its unique electronic, electromagnetic and mechanical properties that allow substantial control of its response. Here we study the electromagnetic behaviour of a single-layer graphene deposited on a metamaterial (see Fig. 1a) consisting of asymmetrically split-ring slits on a gold film that are known to support Fano (feature (α) in Fig. 1b) as well as dipole resonances (feature (β) in Fig. 1b). As illustrated by the near-infrared transmission spectra of Fig. 1c, both types of resonances experience significant damping and a red shift after graphene deposition; the latter being, much stronger for the Fano resonance. The dependence of this substantial red shift on the unit cell size is shown in Fig. 1c, indicating that it is closely related to the characteristic scale at which the metamaterial is patterned. This effect can be attributed to different mechanisms including the enhanced local fields at the resonances [1], but also the effect of periodic corrugation that is known to affect the band structure of graphene [2]. Such deformation is clearly visible in Figs. 2d & 2e, where the results of He-ion imaging are presented: the graphene layer bends substantially and fills the slits in the metal film (see Figs 2d & 2e), resulting in alternating flat and curved graphene regions. We argue that this corrugation contributes to the observed changes in the graphene polarizability, and, consequently, to the red-shift and damping of the metamaterial resonances. Combining this behaviour with the gate-variable absorption of graphene will allow to modulate the metamaterial properties. Such investigations are currently underway and results will be reported at the time of the conference.

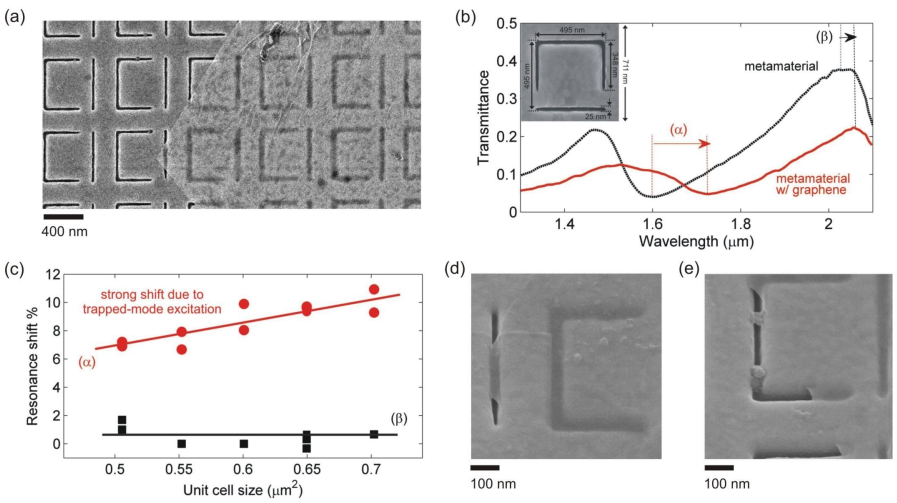

Fig. 1: (a) He-ion imaging of a metamaterial array partially covered with graphene (b) Typical transmission spectra before (black) and after (red) graphene deposition. The dashed lines mark the positions of the two resonances names as (α) and (β). (c) Wavelength shifts of resonance (α) (black) and (β) (red) as a function of the array unit cell size. (d) & (e) He-ion images (at 25 degrees tilt) of the partially graphene covered split-rings.

[1] N. Papasimakis, Z. Luo, Z. X. Shen, F. De Angelis, E. Di. Fabrizio, A. E. Nikolaenko, and N. I. Zheludev, "Graphene in a photonic metamaterial", Optics Express 18, 8353-8359 (2010).

[2] F. Guinea, M. I. Katsnelson, and M. A. H. Vozmediano, "Midgap states and charge inhomogeneities in corrugated graphene", Physical Review B 77, 075422 (2008).