Electrically controllable strong light-matter interactions with graphene

K.J. Tielrooij[1], L. Orona[2], M. Badioli[1], L. Gaudreau[1], S. Coop[1], Q. Ma[2], G. Navickaite[1], H. de Riedmatten[1], P. Goldner[3], F.J. Garcia de Abajo[1], A. Ferrier[3], P. Jarillo-Herrero[2], and F.H.L. Koppens[1]

1. ICFO - Institut de Ciéncies Fotoníques, Mediterranean Technology Park, Castelldefels (Barcelona) 08860, Spain;
2. Department of Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA;
3. Chimie ParisTech, Laboratoire de Chimie de la Matière Condensée de Paris, CNRS-UMR 7574, UPMC Univ Paris 06, 11 rue Pierre et Marie Curie 75005 Paris, France.
klaas-jan.tielrooij@icfo.es

The nanoscale interaction between light emitters and graphene can lead to a plethora of novel applications in fields such as sensing and telecommunications. Here we demonstrate a hybrid device containing graphene and near infrared light emitters that play a very important role in modern telecommunications: Er^{3+} ions with stimulated emission at ~1530 nm. By changing the Fermi energy of graphene, we demonstrate, for the first time, the unique capability of in-situ tuning of the optical density of states, experienced by emitters placed nearby the graphene. In particular, we access three distinct regimes of emitter–graphene coupling: i) the non-radiative coupling regime, ii) the reduced coupling regime, and iii) the plasmonic regime. We witness the transition through these regimes by monitoring the lifetime of the emitters and their emission, which are strongly modified by the graphene.

In the first regime, non-radiative coupling leads to energy transfer from the emitter to the graphene sheet, where electron-hole pairs are generated with the same energy as the excited state dipole of the emitter. By increasing the Fermi level in graphene, we suppress almost completely this energy transfer process, and thus the emitter–graphene coupling strength. Therefore, in this second regime the emission and the excited state lifetime approach the same value as for uncoupled emitters. Finally, in the third regime, the very high electron density can give rise to collective excitations (plasmons). We will discuss graphene plasmons in the context of light-matter interactions, for both near-infrared and mid-infrared frequencies.