Graphene Surface Plasmons for Cavity Quantum Electrodynamics (GraSP)

Graphene is a honeycomb lattice made of carbon atoms. In simplest words, it is a single sheet of graphite – the same material that is found in scribers. Despite the simplicity, graphene is a versatile material of unprecedented properties: excellent thermal and electric conductivities, extreme opacity and absorbance when subject to illumination. It is the strongest and stiffest material ever tested. The plethora of possible applications combined with wide availability and relative fabrication simplicity have brought Andre Geim and Konstantin Novoselov, who re-discovered the material for modern science and technology, a Nobel Prize in physics for their groundbreaking experiments.

The GraSP project aims at a comprehensive exploitation of the unprecedented potential of graphene to control and to tailor interactions of light to quantum systems. Examples of such quantum systems are molecules or more complicated structures, like small defects in crystalline lattices. When illuminated, graphene concentrates light into nanoscopic regions of space, that is regions of size thousands of times smaller than the diameter of human hair, and size comparable to the scale of isolated quantum systems.

It turns out that the hot spots created by a piece of graphene can be sensitively tuned. Not only the spatial location but also spectral properties, that is simply the colour of light that is resonantly enhanced, depend on the shape and size of a graphene piece. Even more importantly, they can be modified, e.g. with electric bias. This unlocks possibilities to dynamically address with light single molecules positioned in the close vicinity of graphene sheets, ribbons or flakes. Called on in this way, molecules might be forced to absorb light or triggered to emit it, or even made to endow light with exotic quantum properties. Due to the tunability of graphene, these molecules might be “turned on and off” by pushing a button or activated gradually by turning a knob. On the other hand, graphene might be used as an interaction carrier over long distances between several molecules, or it could harmonize them to act coherently, in a correlated way.

Our goals within the GraSP project are to establish the theoretical and numerical framework to investigate the coupling of graphene nanostructures to adjacent quantum systems, and finally to apply this framework for a comprehensive analysis of the potential of graphene to control the dynamics and spectral properties of these systems. With such analysis we aim to lay down the ground for diverse applications, including new types of dynamically tuned and on-chip integrated miniaturized quantum logic gates for signal processing, sources of light of unusual properties: for instance bunches of a well-defined number of photons, or devices for on-demand activation of molecules.