Graphene Plasmonics for Mid-IR Biosensing

Graphene has the potential to reshape the landscape of photonics and optoelectronics owing to its exceptional optical and electrical properties. In particular, its infrared (IR) response is characterized by long-lived collective electron oscillations (plasmons) that can be dynamically tuned by electrostatic gating, in contrast to conventional plasmonic materials such as noble metals. Furthermore, the electromagnetic fields of graphene IR plasmons display unprecedented spatial confinement, making them extremely attractive for enhanced light-matter interactions and integrated mid-IR photonics. Specifically, biosensing is an area in which graphene tunability and IR light localization offer great opportunities.

The mid-IR range is particularly well suited for biosensing, as it encompasses the molecular vibrations that uniquely identify the biochemical building blocks of life, such as proteins, lipids, and DNA. IR absorption spectroscopy is a powerful technique that provides exquisite biochemical information in a nondestructive label-free fashion by accessing these vibrational fingerprints. Nevertheless, vibrational absorption signals are prohibitively weak because of the large mismatch between mid-IR wavelengths (2 to 6 μm) and biomolecular dimensions (<10 nm). To overcome this limitation, high sensitivity can be achieved by exploiting the strong optical near fields in the vicinity of resonant metallic nanostructures; however, this comes at the expense of a reduced spectral bandwidth and is ultimately limited by the relatively poor field confinement of metals in the mid-IR.

Recently, by exploiting exceptional opto-electronic properties of graphene plasmons we demonstrated a dynamically tunable plasmonic Mid-IR biosensor that can extract complete optical properties of proteins over a broad spectrum [1]. In addition, the extreme light confinement in graphene—up to two orders of magnitude higher than in metals—produces an unprecedentedly strong overlap with nanometric biomolecules, enabling superior sensitivity. The combination of tunable spectral selectivity and enhanced sensitivity of graphene opens exciting prospects for sensing, not only proteins but also a wide range of chemicals and thin films. Still, one of the challenges in graphene plasmonics is the difficulty of exciting its plasmonic resonances with reasonable intensity which is limiting the performance of graphene plasmonic devices. Additionally, graphene electrostatic tuning is bounded by dielectric breakdown and limits the reconfiguration capabilities of graphene optical devices. In our most recent work, we show that stacks composed of multiple graphene layers produce infrared plasmonic resonances that are much stronger than in single–layer graphene and that can be dynamically tuned over significantly broader spectral ranges [2]. We provide a complete theoretical and experimental framework explaining the origin of the superior plasmonic response and tunability of multi-layer graphene. Our technique could be rapidly implemented in a new family of high-performance graphene plasmonic devices, including infrared modulators, absorbers and photodetectors, and will have particular impact in recently demonstrated graphene mid-IR biosensors.

[1] Rodrigo et al, Science 349, pp:165-168, 2015.
[2] Rodrigo et al, accepted for Nature Light Science and Applications, 2016.