Graphene-based material platforms for quantum and terahertz nonlinear technologies

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One of the many interesting properties of graphene is that it can be integrated into hybrid structures, where graphene is in atomically close proximity to other material systems. This property can be exploited to open up novel device capabilities. This talk will discuss two recently demonstrated implementations of such novel hybrid material platforms based on graphene – one with relevance for quantum technology; and one relevant for nonlinear signal processing.

The first hybrid material platform consists of a nanolayer of erbium emitters (~10 nm thick) in direct contact with a gate-tunable monolayer of graphene [1]. This system thus combines the optical addressability of erbium ions with high-speed, all-electrical modulation of the strong near-field interactions between the emitters and graphene. Modulation is made possible via both a *p*-doped silicon backgate and a polymer electrolyte topgate. In this hybrid erbium-graphene system, we observe a significant fraction of erbium ions with a decay rate that is enhanced by a factor 1,000 and higher due to strong dipole-dipole interaction with graphene. This indicates that extremely efficient emitter-graphene interaction occurs: 99.9% of the energy of these excited erbium emitters flows to graphene. The energy that is transferred from excited erbium emitters to graphene leads to either electron-hole pair generation or plasmon launching in graphene, depending on the Fermi energy of graphene [2]. By rapidly modulating the gate voltage of only a few Volt, we modulate the energy flow path, and thereby the emitter-graphene interaction strength. Interestingly, we demonstrate modulation with a frequency up to 300 kHz, many orders of magnitude faster than the natural decay rate of erbium ions of ~100 Hz. This constitutes an enabling platform for integrated quantum technologies, for example opening routes to quantum entanglement generation by collective plasmon emission or photon emission with controlled waveform.

In the second hybrid material platform, we combine monolayer graphene with a metallic grating. Exploiting the grating-induced field enhancement, this hybrid grating-graphene metamaterial leads to a strongly increased optical nonlinearity in the terahertz range [3], which was already very large for bare graphene [4]. We find an unprecedently large third order (sheet) susceptibility in the terahertz range of tens of ESU, equivalent to $>10^{-8}$ m^2/V^2. Moreover, we observe terahertz (THz) third-harmonic generation with a field conversion efficiency above 1%, and 9^{th} harmonic generation, both with a very moderate field strength of tens of kV/cm. This is remarkable, since nonlinear optics typically requires field strengths in the MV/cm range, thus enabling much lower power consumption. This hybrid grating-graphene metamaterial system is thus highly promising for on-chip nonlinear signal processing in the THz.

REFERENCES

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