



Fast electrical modulation of erbium emitter decay rates using graphene

Strong and rapidly tunable interaction between emitters and graphene.

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Crystals doped with rare-earth ions, such as erbium (Er^{3+}), play an important role for existing and future technologies. For example, erbium-doped fibers are crucial for optical communications systems carrying information as optical signals over long distances. Rare-earth ions furthermore have several properties that make them highly promising and quantum technologies, such as long lifetimes and long decoherence times. Indeed, systems based on rare-earth ions are gaining increasing attention for serving, for example, as quantum bits and quantum memories.

Scientists at ICFO (Spain), CNRS (France) and ICN2 (Spain) have now made several breakthroughs regarding novel quantum and plasmonic applications based on nanoscale rare-earth-ion systems. In particular, they have managed to create erbium emitter layers of nanoscale thickness (~ 10 nm) with emission properties that are similar to those of bulk

emitter materials. Owing to the very small layer thickness, the emitters can efficiently interact with their environment. By exploiting this property, the researchers have created nanophotonic devices where the environment of the nanolayer of emitters is formed by electrically tunable monolayer graphene. These hybrid erbium-graphene devices allow for extremely strong emitter-environment interactions via dipole-dipole coupling. This interaction is so strong that for a large fraction of the erbium emitters the decay is enhanced by a factor of more than 1000. This means that more than 99.9% of the energy flows from excited emitters to graphene.

Besides providing a platform for very strong emitter-environment interactions, the hybrid devices allow for tuning the Fermi energy of graphene in a dynamical fashion using a small electrical voltage. As a result, the interaction strength can be controlled with a high modulation frequency - up to 300 kHz. Remarkably, this is more than three orders of magnitude faster than the natural decay rate of excited erbium ions. Furthermore, the energy flow pathway can be controlled with this high modulation frequency, where excited ions lead to mainly electron-hole pair creation or to plasmon launching in graphene. Thus, the device allows for temporal control of plasmon launching, as well as creating controlled waveforms, with applications in plasmonic and quantum technologies.

The results have been recently published in Nature Communications under the study *Fast electrical modulation of strong near-field interactions between erbium emitters and graphene*. The work was carried out within the framework of the Horizon2020 FET open project *NanOQTech* (2016-2019) that aimed to establish nanoscale rare-earth systems as a novel material platform for various technological applications.