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Direct observation of infrared electroluminescence of high mobility graphene field-effect transistors

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Abstract. In this presentation we will discuss our efforts based on high sensitivity infrared microscopy and spectroscopy to unravel the origin of super-incandescent emission of high-mobility graphene transistors.

Key-words

Electroluminescence, radiative cooling, near-field spectroscopy

Introduction

Electroluminescence is a non-thermal radiative process in which a material emits electromagnetic radiation as a response to an electrical current passing through it. If the recombination of electrons and holes giving rise to electroluminescence, can easily be achieved in semi-conductors thanks to their band structure, it is precluded in metals since the electron gas rapidly relaxes to a thermal state. However, we have recently observed that high-quality electrically doped graphene field-effect transistors encapsulated in hexagonal boron nitride (hBN) exhibits a specific behaviour under high bias: the power it emits exceeds the expected one for incandescence.

High-mobility graphene field-effect transistors (HGFETs) under large bias

Figure 1 shows a schematic representation of an HGFET. The encapsulation of the graphene layer in hBN leads to an enhancement of its flatness, resulting in large electron mobility in the graphene up to $\sim 150\,000\text{ cm}^2\cdot\text{V}^{-1}\cdot\text{s}^{-1}$. The drain and source electrodes allow to apply a longitudinal electric field in the channel of the transistor, whereas the gold backgate permits to tune the electron density in graphene based on capacitor effect.

Electroluminescence of graphene

We first demonstrate with infrared imaging that the emission exists only in the transistor region. Raman thermometry is then used to rule out the possibility of incandescent emission from optical phonons of graphene. Finally,

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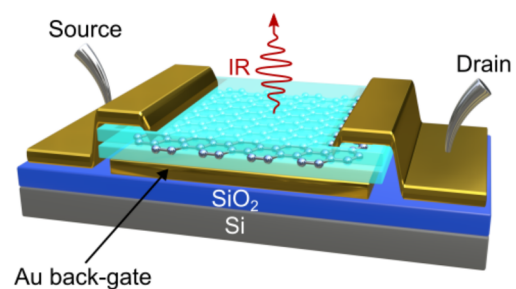


Figure 1. High-mobility field effect graphene transistor. Graphene encapsulated in hBN (light blue) is deposited onto a gold backgate. Drain and source are made of gold electrodes and allow to bias the graphene layer.

we use our recently developed infrared spatial modulation spectroscopy method [1–3] to show that the spectra of the emission exhibit the spectral signature of hyperbolic phonon polaritons of hBN, excited by the electroluminescence in graphene. The amplitude of this feature is such that it largely exceeds that of incandescent emission from hBN.



Figure 2. Microscope image of a field effect graphene transistor from [4]. The transistor channel, in between two gold electrodes, is partially covered in small gold disks that are essential for near-field infrared spectroscopy.

Figure 2 is a microscope image of an HGFET channel between two gold electrodes. Small gold disks are deposited over the encapsulated graphene region and play the role of scatterers of the near-field to the far-field. This feature is essential to achieve spectroscopy of the near-field modes of hyperbolic phonon polaritons of hBN.

Conduction mechanism and interpretation

The achievement of electroluminescent graphene is closely related to interband Zener-Klein tunneling, which is a conduction mechanism involving interband transitions in which electron-hole pairs are formed under an intense electric field, producing a strongly non-equilibrium electronic distribution. In such condition, an efficient cooling mechanism of the electron gas occurs through the excitation of hyperbolic phonon polaritons in hBN as recently observed by some of us in high mobility field-effect graphene transistors [5, 6].

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