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RESEARCH HIGHLIGHT

Whispering-gallery mode quantum resonators in graphene

Suyong Jung

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Recently, a research group from the Center for Nanoscale Science and Technology at the National Institute of Standards and Technology (NIST), and the Massachusetts Institute of Technology in the United States has demonstrated a new type of quantum electro-optic phenomenon, whispering-gallery mode resonators.[1] The resonators are generated by a scanning tunneling microscope (STM) in proximity to graphene devices (Figure 1). On the basis of the quantum effect of electron tunneling, STM is a powerful technique to investigate the local electronic properties of both metallic and semiconducting systems with atomic resolution. Graphene, the most acclaimed material of the last decade, has enabled new horizons for STM research. The graphene surface can be directly probed by the scanning tip, whereas remaining chemically stable and clean even exposure to ambient air for days. Charged carriers in graphene can be readily tuned from holes to electrons using an external gate electrode. Furthermore, the charge carriers in graphene, often called Dirac particles, behave like electromagnetic waves, setting the stage for graphene to realize quantum electro-optic phenomena such as Veselago lensing[2] and Klein tunneling.[3]

To realize the whispering-gallery mode resonators, the NIST-led research group has utilized high-quality graphene devices. The peculiar wave-like nature of Dirac particles is disguised by residual disorders that limit the movement of Dirac particles, consequently scrambling the quantum mechanical information. Thus, minimizing disorder is critically important to explore graphene's quantum-mechanical properties. To address this issue, NIST researchers prepared devices by placing graphene layer on top of hexagonal boron nitride crystals by dry-transfer method, which is known for producing the best-quality samples.[4]

The charge density of graphene devices can be controlled not only by the back gate but also by any external electric field. The researchers used the electric field from the STM tip, created by the work-function difference between the tip and graphene, and by the tunneling bias, to independently control the local charge density under the tip.[5] This local gating produced circular *p*–*n* junction whose shape and size can be manipulated by the tip and the back gate potentials. Inside circular *p*–*n* junctions, quantum mechanical properties of Dirac particles have the major role. Once electrons tunnel to the center of the *p*–*n* junction, the reflection and refraction of Dirac particles at the junction boundary are governed by the Klein scattering. The relative strength of different quantum mechanical states in the resonators depends on their angular momenta; states with high momenta display strong confinement resembling classical whispering-gallery modes, whereas others leak out of the resonators.

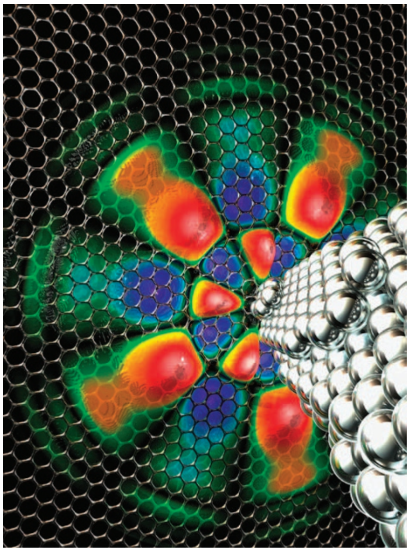

Figure 1 Whispering-galley mode resonators in a single-layer graphene device. The STM tip creates and controls a circular shape *p*–*n* junction in graphene, and Dirac particles bounce back and forth at the *p*–*n* junction boundary to form the electro-optic resonator. Image is prepared by Jon Wyrick, CNST/NIST.

At this stage, the NIST-led group has demonstrated that they can control all the relevant experimental knobs and techniques, from low-temperature STM to high-quality graphene device fabrication, with an unprecedented precision and tunability. This brings up high expectations that more exciting quantum phenomena will be found soon.

CONFLICT OF INTEREST

The author declares no conflict of interest.

Center for Quantum Measurement Science, Division of Convergence Technology, Korea Research Institute of Standards and Science, Daejeon, Korea
E-mail: syjung@kriss.re.kr

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