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Direct observation of Plasmons in Graphene Quantum Dots with Scanning Near-Field Optical Microscopy

Surface Plasmon Polariton (SPP) in two-dimensional graphene has been applied to a wide range of fields such as photo-detectors [1, 2], bio-sensing [3], and optical communications [4]. In recent years, nanostructured graphene such as graphene nanoribbons and graphene quantum dots (GQDs) downsized in dimension attracts much attention as materials with novel SPP characteristics arising from nanostructures. Actually they have been studied by many spectroscopic techniques and these research opens the path for new functionalities [5]. These measurements, however, only show area-averaged optical response and nanoscale measurements have not been made due to diffraction limit. To explore and realize more SPP functionalities, understanding real-space characteristics in detail is indispensable.

To investigate such nanoscale spatial characteristics, a scattering scanning near-field optical microscopy (s-SNOM) provides a strong tool for accessing optical response of nanostructures. Mutual near-field interaction between highly-confined optical fields on an AFM tip and a sample provides high spatial resolution ~ 10 nm beyond the diffraction limit. Through the s-SNOM measurements, many nanoscale investigations have been reported including graphene [6]. In this work, we achieved to directly observe SPP in GQDs by using s-SNOM. Interestingly, the results indicate unique SPP frequency dependence derived from the nanostructure.

We synthesized epitaxial-GQDs with a diameter of ~40 nm on SiC substrate by a thermal decomposition method. For optical measurements, we utilized the s-SNOM equipped with a CO_2-gas laser at the wavenumber of 929.02 cm^{-1}. Figure 1 schematically illustrates the experimental setup. Figures 2 (a) and (b) display an AFM phase image and a near-field amplitude image, respectively. We succeeded in directly observing dot-like plasmon luminescence from the GQDs. Additionally, by utilizing monochromatic measurement (CO_2 gas laser) and nanoscale spectroscopy, we observed strong frequency dependence of SPP in GQDs, which is in strong contrast to 2D graphene on SiC.

Our findings indicate the geometric controllability of the SPP characteristics in nanostructured graphene, providing not only a deeper understanding of nanostructured graphene but also a new pathway to realize new functional SPP properties in a wide frequency range from terahertz and infrared regime.

References

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Figures

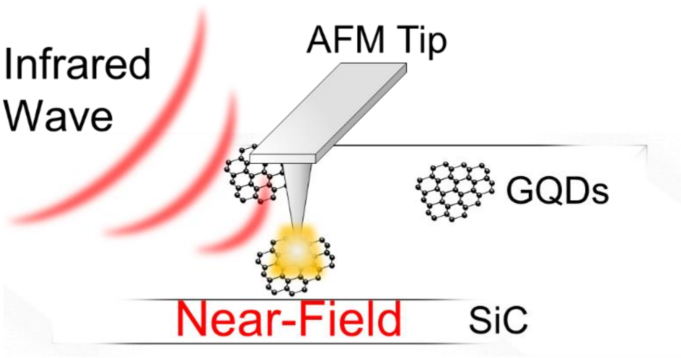

Figure 1: Schematic of the s-SNOM measurement

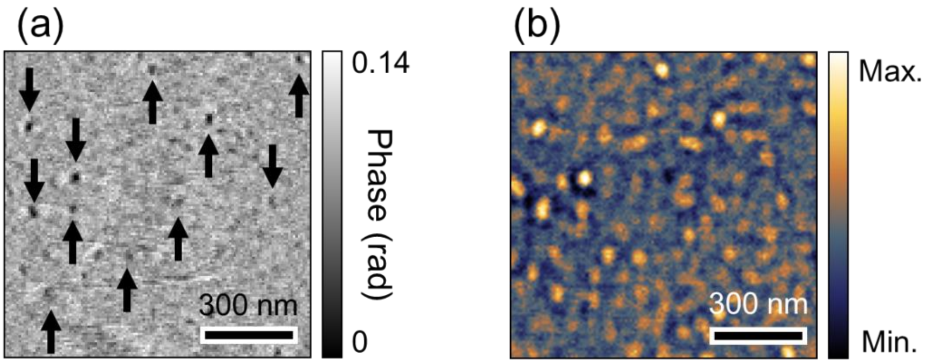

Figure 2: (a) AFM phase image. The black arrows indicate the GQDs with ~40 nm in a diameter. (b) Near-field amplitude image (929.02cm^{-1}) of the GQDs. The dot-like plasmonic luminescence is clearly visible.