Ultrastrong remote interaction between terahertz magnetoplasmons and electrons in a quantum point contact mediated by a split-ring resonator

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Plasmons are collective excitations of free electrons coupled to electromagnetic (EM) fields and can squeeze EM fields into a space much smaller than their diffraction limits, resulting in the ultrastrong light-matter coupling [1]. Since the localized EM field has a large spatial variation, the light-matter interaction acquires a spatially nonlocal nature [2]. Such a nonlocality of plasmons appears between an E-field and matter excitation, and, microscopically, matter excitation can be induced by an E-field at a spatially different region. However, since observation of individual matter excitations in collective electron systems is very challenging, the spatially nonlocal excitations have never been observed directly.

In this work, we have experimentally shown the spatial nonlocality of the light-matter interaction between the localized magnetoplasmon (MP) and the second harmonic of the cyclotron resonance (2CR) in a high-mobility GaAs two-dimensional electron system. We fabricated a quantum point contact (QPC) next to the gap of the split-ring resonator (SRR) (Fig. 1(a)). We measured a THz-induced current change (photocurrent) through the QPC as a function of the frequency, *f*, of the incident THz EM wave and a perpendicular magnetic field, *B*. The QPC photocurrent spectrum exhibits a large anti-crossing between the MP excitation and the 2CR (see black arrows in Fig. 1(b)). Our analysis shows that the electron effective masses of these electron excitations are significantly different, indicating that the localized MP is excited in the gap region of the THz-SRR, while the 2CR are excited in the vicinity of the QPC. This difference in the locations of the excitations directly shows the nonlocality of the light-matter interaction. Furthermore, interestingly, we have found that their coupling strength is significantly enhanced as the confinement strength of the nearby QPC increases and eventually enters the ultrastrong coupling regime, despite the nonlocal nature of interaction and the higher order optical transition. The controllability of the MP-2CR coupling strength can be qualitatively understood by the nonlocal light-matter interaction induced by a spatially inhomogeneous THz *E*-field created by the MP near the QPC.

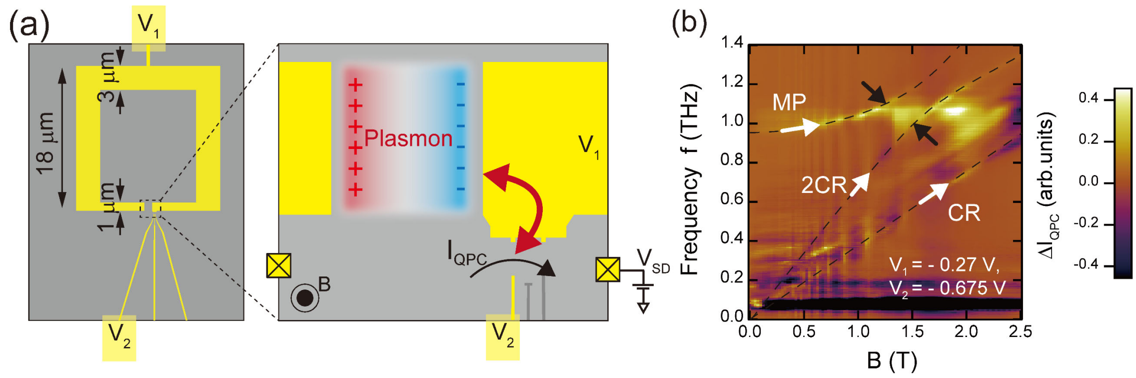

Fig.1. (a) Geometry of the QPC-SRR sample fabricated on the GaAs high mobility wafer. The QPC is formed between the SRR and the leftmost split gate. Black crosses represent Ohmic contacts to the 2D electrons. (b) Color-coded map of the THz-induced QPC photocurrent spectrum. An anti-crossing signal between the MP and the 2CR is indicated by black arrows.

References

[1] A. F. Kochum et al., Nature Reviews Physics 1, 19 (2019).

[2] Antoine Reserbat-Plantey et al., ACS Photonics 8, 85 (2021).