Nonlinear Landau fan diagram in graphene by cavity vacuum field

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Abstract

Recent studies on cavity-coupled 2D electron gas systems in the ultra-strong coupling regime have shown strong modifications of quantum-Hall transport at fixed charge density (n), including Shubnikov-de Haas oscillations and quantum Hall effect [1-2]. In this study, by designing a terahertz cavity strongly coupled to graphene (Figs. 1A and 1B), we experimentally demonstrate that the cavity vacuum fluctuations significantly alter the quantum Hall transport, producing a nonlinear Landau fan diagram (Fig. 1C). By utilizing the high tunability of graphene via a gate voltage (V_g) that varies both the charge density and the type (electron and hole), we find that minima in longitudinal resistance (R_{xx}) and the corresponding quantized Hall resistances no longer occur at constant filling factors ($\nu = nh/eB$) but shift to lower n at higher magnetic field (B) and ν. This suggests that virtual photons in the resonator may mediate transitions between the Landau levels. Our work paves the way for exploring cavity quantum electrodynamics in highly tunable and experimentally accessible atomically thin 2D crystals.

References

[1] F. Appugliese, J. Enkner, G. L. Paravicini-Bagliani *et al.*, Science, 6584 (2022) 1030
[2] G. L. Paravicini-Bagliani, F. Appugliese, E. Richter *et al.*, Nature Physics, 15 (2019) 186
[3] A. F. Kockum, A. Miranowicz, S. D. Liberato *et al.*, Nature Reviews Physics, 1 (2019) 19
[4] F. J. Garcia-Vidal, C. Ciuti, T. W. Ebbesen, Science, 6551 (2021) eabd0336

Figures

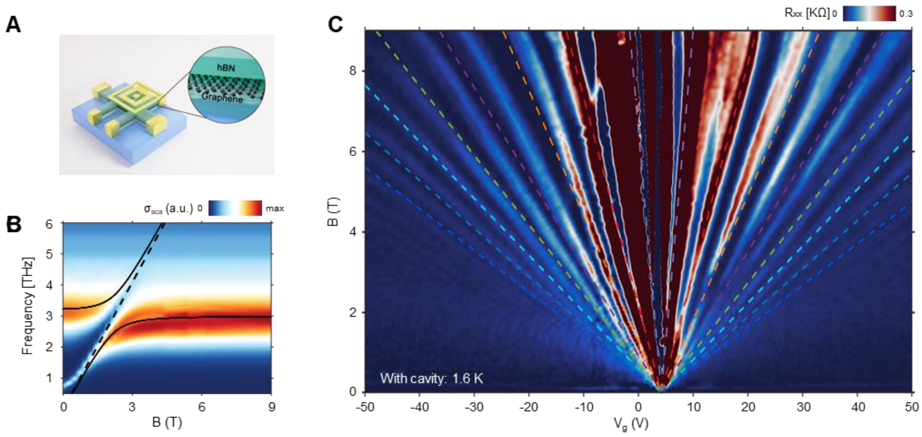

Figure 1: (A) Schematic of sample with a cavity. (**B**) The transmission colour map. (**C**) Nonlinear Landau fan-diagram in cavity-coupled graphene. The dashed lines, corresponding to a set of filling factors (ν = ±2, ±6, ±10......), are plot by aligning with zero-minima in R_{xx} at small magnetic field B.