Ultrastrong Light-Matter Coupling in a High-*Q* Terahertz Cavity

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Strong resonant light-matter coupling in a cavity setting is an essential ingredient in fundamental cavity quantum electrodynamics (QED) studies as well as in cavity-QED-based quantum information processing. In particular, a variety of solid-state cavity QED systems have recently been examined, not only for the purpose of developing scalable quantum technologies, but also for exploring novel many-body effects inherent to condensed matter. For example, collective $N^{1/2}$-fold enhancement of light-matter coupling in an N-body system, combined with colossal dipole moments available in solids, compared to traditional atomic systems, is promising for entering uncharted regimes of ultrastrong light-matter coupling. Nonintuitive quantum phenomena can occur in such regimes, including a squeezed vacuum state, the Dicke superradiant phase transition, the breakdown of the Purcell effect, and quantum vacuum radiation induced by the dynamic Casimir effect. However, creating a system that combines a long electronic coherence time, a large dipole moment, and a high cavity quality (Q) factor has been a challenging goal.

This talk will describe our recent observation of collective ultrastrong light-matter coupling in an ultrahigh-mobility two-dimensional electron gas (2DEG) in a high-Q terahertz photonic-crystal cavity in a quantizing magnetic field, demonstrating a cooperativity of ~360 [1]. The electron cyclotron resonance (CR) peak exhibited splitting into the lower and upper polariton branches with a magnitude that is proportional to the square-root of the 2DEG density, a hallmark of collective vacuum Rabi splitting. Remarkably, the influence of this large splitting can be seen even in a frequency region where the detuning is larger than the resonance frequency itself. Furthermore, a small but definite blue shift was observed for the polariton frequencies due to the normally negligible A^2 term in the light-matter interaction Hamiltonian. Finally, the high-Q cavity suppressed the superradiant decay of coherent CR, which resulted in an unprecedentedly narrow intrinsic CR linewidth of 5.6 GHz at 2 K. These results open up a variety of new possibilities to combine the traditional disciplines of many-body condensed matter physics and cavity-based quantum optics.

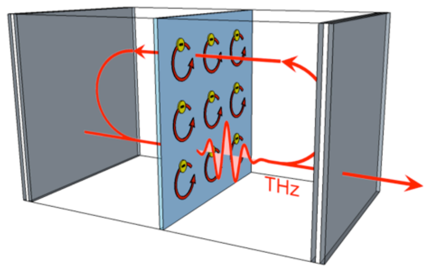

Fig.1. 2D electrons coupled with THz cavity photons.

[1] Q. Zhang, M. Lou, X. Li, J. L. Reno, W. Pan, J. D. Watson, M. J. Manfra, and J. Kono, "Collective Non-perturbative Coupling of 2D Electrons with High-Quality-Factor Terahertz Cavity Photons," *Nature Physics* **12**, 1005 (2016).