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Deep strong coupling in a circuit QED system (3) - data and analysis -[1] FUMIKI YOSHIHARA, TOMOKO FUSE, KOUICHI SEMBA, National Institute of Information and Communications Technology, Koganei, Tokyo, Japan, SAHEL ASHHAB, Qatar Environment and Energy Research Institute, Hamad Bin Khalifa University, Qatar Foundation, Doha, Qatar — We have experimentally achieved deep-strong coupling between a superconducting flux qubit and a superconducting LC circuit, where the coupling energy, $\hbar g$, exceeds both the transition energy of the flux qubit, $\hbar\omega_{\rm q}$, and the resonant energy of the LC circuit, $\hbar\omega_{\rm r}$. At the optimal flux bias of the flux qubit, the qubit-resonator system is described by the Rabi model, which is one of the simplest quantum models of atom-cavity systems. The Hamiltonian of the Rabi model can be written as $\mathcal{H}_{\rm Rabi} = -\frac{\hbar}{2}\omega_{\rm q}\sigma_z + \hbar\omega_{\rm r}(a^\dagger a + \frac{1}{2}) + \hbar g\sigma_x(a + a^\dagger)$, where $\sigma_{x(z)}$ is a Pauli matrix and $a(a^\dagger)$ is an annihilation (creation) operator. In this presentation, we will show the spectroscopy data of qubit-resonator systems in the deep-strong-coupling regime. Transition frequencies calculated from $\mathcal{H}_{\rm Rabi}$ fit the measured data well. We have also observed that $\hbar\omega_{\rm q}$ is largely suppressed due to the Lamb shift caused by the deep-strong coupling to the resonator. In this regime, the ground state is predicted to be an entangled state of the qubit's persistent-current states and the resonator's coherent states.

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