Comment on "Vacuum Rabi Splitting in a Semiconductor Circuit QED System"

In this Comment, we challenge the main claims made by Toida *et al.* [1] and demonstrate that their results do not provide direct evidence of vacuum Rabi splitting or vacuum Rabi oscillations. In contrast to statements made by Toida *et al.*, the two sharp parallel structures in Fig. 3(b) of [1] are not indicative of a coherent quantum mechanical interaction. Instead, as shown in previous work [2,3], they are a result of the resonant interaction between the double quantum dot (DQD) and the resonator at detunings $\pm\epsilon$ corresponding to a crossing of the bare DQD transition frequency and the bare resonator frequency. More importantly, a clear anticrossing, allowing for a claim of the observation of strong coherent interaction of the vacuum-Rabi-type, is not observed. Surprisingly, the frequency range of the data displayed in Fig. 4(a) of [1] is narrower than the suggested interaction rate $2g/(2\pi) = 40(60)$ MHz, which does not even in principle allow the resolution of the vacuum Rabi mode splitting in their data. Instead, the data in Fig. 4(b) of [1], reproduced here in Fig. 1(b), show a small frequency shift of less than 2 MHz due to the dispersive interaction between the DQD and the resonator.

The key signature of strong coherent coupling of the vacuum Rabi type is the observation of a resonant mode-splitting with a pair of clearly identifiable distinct modes separated in frequency by $2g/(2\pi)$ [4,5]. The linewidth of these *two distinct modes* on resonance is $\Gamma = \gamma + \kappa/2$, with the resonator energy decay rate κ and the DQD decoherence rate $\gamma = \gamma_1/2 + \gamma_\phi$ determined by its energy decay γ_1 and pure dephasing rates γ_ϕ [6]. From their measurements Toida *et al.* correctly determine $\kappa/(2\pi) = 8$ MHz. However, the authors extract the linewidth of the data shown in Fig. 4(a) of [1] and claim that the maximum observed value represents an accurate measure of Γ on resonance. This is incorrect, as the above expression for Γ requires a resolved spectral measurement of the two vacuum Rabi modes to be applicable [5]. Toida *et al.* mistakenly solve the expression of Γ for the DQD decoherence rate finding a too small estimate of $\gamma/(2\pi) = 12(25)$ MHz [1] resulting in their unjustified claim of having observed the strong coupling limit with $g > \kappa, \gamma$.

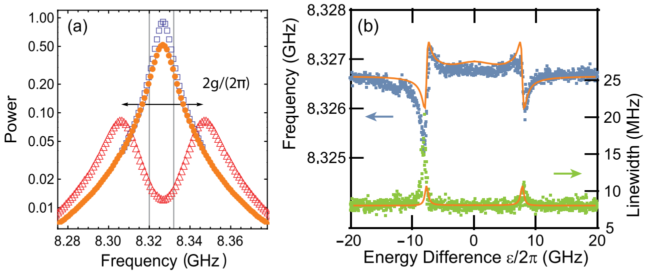

FIG. 1 (color online). (a) Simulation of transmitted power as a function of drive frequency with the DQD on resonance with the resonator for $(\gamma_1, \gamma_\phi, \gamma)/(2\pi) = (8, 8, 12)$ MHz (red open triangles) and (200, 200, 300) MHz (orange solid dots) and $\kappa = 8$ MHz as indicated by the spectrum calculated with the DQD far detuned from the cavity (blue open squares). (b) Comparison of Fig. 4(b) of [1] with our master equation simulation (solid orange lines) using the parameters of [1] but decoherence rates $\gamma_1/(2\pi) = \gamma_\phi/(2\pi) = 200$ MHz. The asymmetry in the data is due to a change in the decoherence rate with ϵ.

To confirm our claims, we have solved the system's master equation (see Ref. [2]) to determine the expected transmission spectrum in the low photon number limit with the wrongly estimated parameters of [1] finding a clearly resolved vacuum Rabi mode splitting, see red open triangles in Fig. 1(a). However, the authors of [1] do not present this essential data in their work. In addition, numerical calculations of the frequency shifts and linewidths presented in Figs. 4(b),(c) of [1] are in good agreement with the data by Toida *et al.* only when assuming more than 10 times larger values of $\gamma/2\pi = 300$ MHz with $\gamma_1/(2\pi) = \gamma_\phi/(2\pi) = 200$ MHz than claimed in [1], see Fig. 1(b). With these parameters the vacuum Rabi mode splitting is not resolvable, see Fig. 1(a). As a result, using γ extracted from our analysis, the number of Rabi flops $n_{\mathrm{Rabi}} = 0.07 \ll 1$, the critical photon number $n_0 = 112 \gg 1$, and the critical atom number $N_0 = 12 \gg 1$ all lead to the conclusion that the strong coupling regime is *not* reached in [1].

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[6] We note that the expression for Γ stated in Ref. [1] is incorrect.