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 \( \kappa \) and the DQD decoherence rate \( \gamma = \gamma_1/2 + \gamma_\phi \) determined by its energy decay \( \gamma_1 \) and pure dephasing rates \( \gamma_\phi \) [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 \( \Gamma \) on resonance. This is incorrect, as the above expression for \( \Gamma \) requires a resolved spectral measurement of the two vacuum Rabi modes to be applicable [5]. Toida et al. mistakenly solve the expression of \( \Gamma \) 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 \( g > \kappa, \gamma \).

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 \( \gamma_1/(2\pi) = 300 \) 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 \( \gamma \) extracted from our analysis, the number of Rabi flops \( n_{\text{Rabi}} = 0.07 \ll 1 \), the critical photon number \( n_{\text{th}} = 112 \gg 1 \), 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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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 \( \epsilon \).

[6] We note that the expression for \( \Gamma \) stated in Ref. [1] is incorrect.