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Characterization of dot-specific and tunable effective $g$ factors in a GaAs/AlGaAs double quantum dot single-hole device

A. Padawer-Blatt and J. Ducatel
Emerging Technologies Division, National Research Council of Canada, Ottawa, Ontario, Canada K1A0R6 and Department of Physics and Astronomy, University of Waterloo, Waterloo, Ontario, Canada N2L 3G1

M. Korkusinski, A. Bogan, L. Gaudreau, P. Zawadzki, D. G. Austing, A. S. Sachrajda, and S. Studenikin
Emerging Technologies Division, National Research Council of Canada, Ottawa, Ontario, Canada K1A0R6

L. Tracy
Sandia National Laboratories, Albuquerque, New Mexico 87185, USA

J. Reno and T. Hargett
Center for Integrated Nanotechnologies, Sandia National Laboratories, Albuquerque, New Mexico 87185, USA

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Difference in $g$ factors in multidot structures can form the basis of dot-selective spin manipulation under global microwave irradiation. Employing electric dipole spin resonance facilitated by strong spin-orbit interaction (SOI), we observe differences in the extracted values of the single-hole effective $g$ factors of the constituent quantum dots of a GaAs/AlGaAs double quantum dot device at the level of $\sim 5\%–10\%$. We examine the continuous change in the hole $g$ factor with electrical detuning over a wide range of interdot tunnel couplings and for different out-of-plane magnetic fields. The observed tendency of the quantum dot effective $g$ factors to steadily increase on decreasing the interdot coupling or on increasing the magnetic field is attributed to the impact on the SOI of changing the dot confinement potential and heavy-hole light-hole mixing.

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Confined holes in semiconductor quantum dot systems are attracting a rapidly growing interest due to several appealing properties. The properties include: strong spin-orbit interaction (SOI) desirable for fast and convenient all-electric spin manipulation; highly anisotropic and tunable hole $g$ factors; and in group III–V semiconductors where interaction with the spins of the host material nuclei cannot be avoided, the coupling of the hole spins to the nuclei is significantly reduced compared to electron spins. See our recent topical review in Ref. [1] and references therein. The attraction of efficient control through strong SOI of spin qubits, particularly those featuring holes, and details of the mechanisms are discussed elsewhere [2–6]. In our recent work focusing on single holes confined in lateral quantum dots (QDs) in the GaAs/AlGaAs material platform, we have shown strong SOI introduces efficient spin-flip interdot tunneling channels [7], and leads to a strong voltage tunable spin-gap renormalization [8]. A consequence of both is an electrically tunable effective $g$ factor, $g_{\text{eff}}$, that is different from the familiar effective $g$ factor $g^*$ taken to be a constant determined solely by material properties. Taking advantage of the strong SOI offered by holes in semiconductors to couple electrically their spin and spatial motion through microwave (MW) signals applied to gates, the technique of electric-dipole spin resonance (EDSR) [9,10] is not only a powerful tool to gain insight into the physics underlying $g_{\text{eff}}$ but can also drive spin rotations efficiently [11–13]. See Ref. [1] for a comprehensive review of recent work on EDSR with holes in QD systems and in semiconductor materials other than the GaAs/AlGaAs system, along with an overview of the physics underlying the principal EDSR mechanisms exploiting SOI.

In Ref. [8], employing EDSR in conjunction with strong SOI in the GaAs valence band, we demonstrated the electrical tunability of the effective $g$ factor of a single-hole spin confined in a lateral GaAs/AlGaAs double quantum dot (DQD) device. In that work, we considered only the case of the strong interdot coupling regime (spin conserving tunneling matrix element $\sim 100 \mu$eV for a magnetic field approaching zero), and applied a model to fit the experimental data assuming the $g$ factors in both QDs are identical. Here, we extend our application of the EDSR technique for single holes to cover the impact of tuning the interdot coupling over a wide range down to the weak interdot coupling regime, and adapt our model to account for small differences in QD $g$ factors inevitably present. As discussed elsewhere, the holes confined in the DQD relevant to our discussion here for planar GaAs/AlGaAs structures are predominantly heavy hole in character [1,14]. As will become clear in the following discussion, we will take strong, intermediate, and weak interdot coupling, SC, IC, and WC, respectively, to be many tens, a couple tens, and a few microelectron volts.
Figure 1(a) shows a scanning electron micrograph of the lateral DQD device. Full details of the undoped GaAs/Al$_{0.5}$Ga$_{0.5}$As heterostructure and device fabrication are given in Refs. [7,8,14–17]. Holes are accumulated at the heterointerface by a global gate. Voltages $V_L$ and $V_R$, respectively, on the left (L) and right (R) plunger gates are used to tune the hole confining potentials in each QD, while voltage $V_C$ on the center (C) gate is used to adjust the interdot coupling. Current $I$ flows through the two coupled QDs when a source-drain bias $V_{SD}$ is applied. Measurements are performed in a dilution refrigerator and the effective hole temperature is $\sim 100$ mK. A magnetic (B$-$) field is applied out-of-plane. MWs are applied to the right plunger gate. The MW power $P$ quoted throughout this article is the nominal MW power at the MW source. The MW signal is attenuated by $-20$ dB at the 1-K stage and is further reduced by frequency-dependent loss in the coaxial lines [8]. As we report extensively elsewhere, verified by both transport and charge detection measurements, we are able to reach the single-hole regime [1,8,14].

We established in Ref. [8] that EDSR features arise on MW excitation in the vicinity of the single-hole high-bias transport triangle. Figure 1(b) depicts the origin of one of the EDSR features for the situation where, in the absence of MWs, one hole is trapped on the right QD (energy blockaded) and no current can flow. MW modulation at the appropriate frequency can promote the spin-down hole occupying the ground molecular state with weight largely on the right QD to the first excited state, spin-up also predominantly on the right QD, from where the hole can exit to the drain (D). The black arrow (asterisk) marks the EDSR signal for positive (negative) detuning $\varepsilon$. In subsequent measurements $V_L$ and $V_R$ are simultaneously scanned so as to sweep $\varepsilon$ and cut through the EDSR features outside of the bias triangle—see dashed arrow, for example. (c) Calculated eigenenergies as a function of detuning for model parameters $B = 2.0$ T, $t_F = 16.7 \mu$eV, $t_N = 13.0 \mu$eV, $g_L^* = 0.8$, and $g_R^* = 1.6$. GS, ES1, ES2, and ES3 correspond, respectively, to the ground and first three excited states. Black (red) identifies spin-down (spin-up). Green (blue) vertical lines identify examples of predominantly spin excitations in the left (right) QD. In the vicinity of the ES1-ES2 anticrossings the spin is hybrid spin-up and spin-down, and transitions from GS are hybrid spin-charge transitions. We stress that for illustration we have grossly exaggerated the difference in g factor between the two dots. The actual difference is typically 5%–10%. Note in (b) and (d), and henceforth in this article, for convenience, the positive direction of the energy axis corresponds to increasing hole energies.
excited molecular state, spin-up also weighted largely on the right QD, i.e., the right QD hole spin-down energy level is lower than the left QD hole spin-down energy level. These two features are approximately equidistant from and parallel to the base of the bias triangle (dotted line). Also, they are of comparable strength. Although the MW modulation is applied to the right plunger gate, both QDs see the MWs. Therefore conditional on the weight of the occupancy of the single hole trapped on the left or right QD, an excitation is possible in either QD if the MW frequency matches an energy gap between levels.

In Refs. [1,8] it was assumed in the modeling of the EDSR data taken in the strong interdot coupling regime that the $g$ factors of the two QDs are equal. The schematic in Fig. 1(b) is also drawn for this situation. The key finding of our work here is that the EDSR technique is sufficiently sensitive to detect small differences in the dot $g$ factors. For illustration of what we can expect when the $g$ factors of the two QDs are not equal consider the following. Figure 1(d) shows the calculated eigenenergies of the ground state (GS) and the first three excited states (ES1, ES2, ES3) as a function of detuning for model parameters $B = 2.0$ T, $t_N = 16.7$ $\mu$eV, $t_F = 13.0$ $\mu$eV, $g_L^* = 1.33$, and $g_R^* = 1.39$. These values are comparable to the effective $g$ factors of the left and right QDs in our experiment. The high activation energy barrier also results in a small $g$ factor for the right QD, while the left QD is significantly more spin-polarized. This is consistent with our experimental data, where the right QD shows a lower $g$ factor than the left QD. The inset in Fig. 1(d) shows the calculated hole occupations for the ground state and the first three excited states as a function of detuning. The inset shows that the ground state is a nearly pure $S_z = -1$ state, while the first excited state is a nearly pure $S_z = 0$ state. The second and third excited states are also nearly pure $S_z = 0$ and $S_z = -1$ states, respectively. This is consistent with our experimental data, where we observe a strong signal for the ground state and a weak signal for the first excited state.

Figure 1(c) shows an example of a single-hole high-bias transport triangle for a weak interdot coupling condition (WC1: see discussion later regarding coupling conditions and the labeling thereof) at $B = 1.8$ T with MWs applied at frequency $f = 35.3$ GHz and power $P = -12$ dBm (see also Supplemental Fig. S1 which includes charge boundaries and hole occupation numbers [18]). Here $V_{SD} = -0.5$ mV: negative bias polarity corresponds to holes flowing from left to right in panel (b). Two resonant transition lines located outside the bias triangle are clearly identified. The black arrow points to the EDSR signal for positive detuning $\varepsilon$: hole initially trapped on the right QD [case depicted in Fig. 1(b)], i.e., the right QD hole spin-down energy level is lower than the left QD hole spin-down energy level. The asterisk marks the EDSR signal for negative detuning $\varepsilon$ [8]: hole initially trapped on the left QD, i.e., the left QD hole spin-down energy level is lower than the right QD hole spin-down energy level. These two features are approximately equidistant from and parallel...
right QD. We have straightforwardly modified the model described in Refs. [1,8] to account for different Zeeman splitting energies in the left and right QDs. Henceforth we refer to this model as the two–g-factor model. For the lowest energy excitation corresponding to the GS → ES1 transition, we expect

\[ g^\sigma_L(g^\sigma_R) \]

that at large negative (positive) detuning the transition tends to an energy, independent of detuning, reflecting the value of \( g^\sigma_L \) (\( g^\sigma_R \)). See green (blue) vertical lines near \(-300 \mu\text{eV}\) (\(+300 \mu\text{eV}\)) in detuning showing an excitation in the left (right) QD that is principally spinlike in character. For detuning in the range of \(-135 \mu\text{eV}\) to \(+135 \mu\text{eV}\) the GS → ES1 transition becomes strongly detuning dependent and is chargelike in character. The minimum energy reflects the strength of spin-conserving tunneling. For the next higher energy excitation corresponding to the GS → ES2 transition, we expect that at large negative and positive detuning the detuning is linear in detuning, and is chargelike in character. The dependence for detuning in the range of \(-135 \mu\text{eV}\) to \(+135 \mu\text{eV}\) is quite different. For detuning between \(-135 \mu\text{eV}\) and \(-45 \mu\text{eV}\) (\(+45 \mu\text{eV}\) and \(+135 \mu\text{eV}\)) the excitation energy is nearly constant reflecting the value of \( g^\sigma_L \) (\( g^\sigma_R \)) in detuning showing excitations in the left (right) QD that are spinlike in character. A smooth evolution in the excitation energy occurs for detuning between \(-45 \mu\text{eV}\) and \(+45 \mu\text{eV}\). This steplike change in the GS → ES2 transition at small detuning between two excitation energies reflective of a difference in \( g^\sigma_L \) and \( g^\sigma_R \) is expected to become more pronounced as the interdot coupling strength is progressively reduced (see Fig. 3 and discussion later). We note that for clear illustration here we have grossly exaggerated the difference in \( g \) factor between the two QDs. As we will soon demonstrate, in actuality, the difference between the two QD \( g \) factors is much smaller, at the level of 5%–10%. We note that in our model zero detuning corresponds to the crossing of the lowest energy single-hole levels in the left and right QDs at zero \( B \) field and in the absence of tunnel coupling. Consequently, for our choice of very different left and right QD \( g \) factors, the maximum in

the GS energy in Fig. 1(d) is noticeably shifted to negative detuning at finite \( B \) field. For smaller realistic differences in the \( g \) factor this maximum, also marking the onset of transport at the base of the bias triangle, occurs at \( \varepsilon \approx 0 \).

Figure 2(a) shows the frequency dependence of the measured EDSR signal as a function of detuning for an intermediate interdot coupling condition (IC1) at \( B = 2 \text{T} \) and \( V_{SD} = +1 \text{mV} \). Two branches corresponding to the GS → ES1 and GS → ES2 MW transitions are clear. The sweep in detuning is generated by simultaneously changing \( V_L \) and \( V_R \) in such a way as to cut through the EDSR features outside of the bias triangle [see dashed arrow, for example, in the case of bias triangle for the SC condition in Fig. 1(c)]. From such data we can extract the position of the EDSR peaks. Since we are interested in the EDSR peak position and not the EDSR peak height, details of the tunneling rates for the barriers to the source and drains contacts are not important here [19].

Figures 2(b)–2(d) show the extracted peak position as a function of detuning for strong (SC), intermediate (IC1), and weak (WC1) coupling conditions at \( 2 \text{T} \). For the SC case, only the GS → ES1 transition is recorded, whereas for the IC1 and WC1 cases, the GS → ES2 transition is additionally observed. The upper bound for the MW frequency we can apply is 50 GHz limited by the MW source. To track the EDSR over a wide range of frequency, because MW losses in the coaxial lines grow with increasing MW frequency, the data is often captured in blocks for which the MW power is progressively stepped up to compensate. The data blocks are then stitched together. The magnitude and sign of the applied bias voltage also determines the accessible detuning range. For sufficiently large bias, the single-hole transport triangle will merge with the adjoining transport triangle. Also there tends to be more extractable data points at negative (positive) detuning for an applied positive (negative) bias voltage. In the three panels, the dashed lines are fits to the EDSR peaks according to the two–g-factor model. The fitted values for \( g^\sigma_L \) and \( g^\sigma_R \) are also given. Although we can calibrate the energy scale on the detuning axes from details of the DQD trans-
port characteristics on changing $V_d$ and $V_g$, since the onset of transport along the base of the transport triangle is not generally sharp, it is not always straightforward to determine zero detuning precisely, even for the case of $g_L^* = g_R^*$, hence we have manually shifted the detuning axis scales in the Fig. 2 panels by small amounts so that the minimum in frequency for the GS $\rightarrow$ ES1 transition is set to be $\varepsilon = 0$: this applies, too, for the data shown in Fig. 3. We note here that the data shown in both Figs. 2 and 3, and the determination of coupling parameters, for example, as discussed below, does not rely solely on EDSR where the transition is predominantly spinlike, but also on photon-assisted tunneling when the transition is predominantly chargelike: See Ref. [8] for further discussion.

As the interdot coupling ($t_N$) is reduced from strong coupling to weak coupling several trends are immediately clear in Figs. 2(b)–2(d). First, the zero-detuning minimum frequency for the GS $\rightarrow$ ES1 transitions decreases. The minimum frequency generally reflects direct the strength of the spin-conserving tunneling. Values for $t_N$ determined from the fits for SC, IC1, and WC1 data sets, respectively, at 2 T are 63, 28, and 6 $\mu$eV—the error in these values is at the $\pm 1$ $\mu$eV level. For IC1 and WC1 cases, the minimum frequency is essentially given by $\sim 2t_N$. Our classification of strength of interdot coupling now becomes clear. We generally declare strong, intermediate, and weak interdot coupling, respectively, to be many tens, a couple tens, and a few microelectron volts (see also discussion related to Fig. 4). Second, the anticrossing gap between GS $\rightarrow$ ES1 and GS $\rightarrow$ ES2 branches at finite detuning is larger for the IC case than the WC1 case. The anticrossing gap here arises from spin-flip tunneling facilitated by the strong spin-orbit interaction and is quantified by the spin-flip tunneling matrix element $t_F$. For the SC case, the GS $\rightarrow$ ES2 branch is out of range for this set of data, but the comparatively weak curvature in the GS $\rightarrow$ ES1 branch at finite detuning as the frequency starts to flatten points to a significant spin-flip contribution. Values of $t_F$ determined from the fits for SC, IC1, and WC1 data sets, respectively, at 2 T are 41, 16, and 6 $\mu$eV. As discussed in Refs. [1,7,8] $t_F$ is comparable in value to $t_N$ and dependent to a degree on $t_N$ so the decrease in $t_F$ with reduced interdot coupling is expected. Third, the range over which the effective g factor $g_{eff}$ associated with the GS $\rightarrow$ ES1 branch can be tuned by changing the detuning at fixed B field, here 2 T, clearly grows as the tunnel coupling weakens (the right axis scale in each panel directly gives $g_{eff}$). This broad tunability in $g_{eff}$ with static electric fields is attractive for potential qubit manipulations with global MW illumination: See Refs. [1,8] for extended commentary. Lastly, not only do the fits reveal that $g_L^*$ and $g_R^*$ are different at the level of 5%–10% with $g_L^* < g_R^*$, which is useful for local manipulations, but both $g_L^*$ and $g_R^*$ steadily increase as the interdot coupling decreases—for the sequence shown the change in the $g$ factor is 15%–20%.

The small difference in the QD $g$ factors is not unexpected. Statistical variations in dot $g$ factors in multidot devices of magnitude 1%–10% due to microscopic differences in the dot environment, for example, due to variation in the local confinement from disorder, are documented [20–23]. We note these works applied the EDSR technique to GaAs/AIGAAs heterostructure QD circuits confining single electrons. See also Refs. [12,24] featuring Ge/SiGe heterostructure QD circuits confining multiple holes whereby the difference in hole $g$ factors between the QDs is ascribed to different QD sizes and hole occupancies, i.e., orbital effects. We comment further on the steady increase in $g_L^*$ and $g_R^*$ on decreasing the interdot coupling later when we discuss Fig. 4(b).

Also becoming apparent in the WC1 data in Fig. 2(d) is the near flat dependence of the GS $\rightarrow$ ES2 transition frequency for detuning in the range from $-150$ to $150 \mu$eV other than a small “step” near zero detuning reflecting the change in $g_{eff}$ from 1.33 to 1.39. The steplike behavior here is a signature of differing $g$ factors in the two QDs, consistent with our discussion above in connection to the calculated eigenenergy plot for model parameters in Fig. 1(d), and should become more apparent at weaker interdot coupling when the anticrossing gap between GS $\rightarrow$ ES1 and GS $\rightarrow$ ES2 branches is diminished. Figure 3 emphasises the trend. Here we plot the frequency dependence of the extracted EDSR peak position as a function of detuning for three interdot coupling conditions: (a) IC2; (b)
WC1; and (c) WC2. Of these three coupling conditions, IC2 (WC2) is the strongest (weakest). Note the coupling for IC2 is slightly less than that for IC1: \( t_0 \) for IC1 (IC2) at 2 T (1.8 T) is \( 28 \, \mu eV \) \( (24 \, \mu eV) \). For Figs. 3(a) and 3(b), fits to the data according to the two–\( g \)-factor model are included. For Fig. 3(c), a fit to the data with the two–\( g \)-factor model could not be reliably obtained due to a combination of insufficient data points below 25 GHz, especially near the frequency minimum in the GS → ES1 transition at zero detuning, and insufficient data resolution in the vicinity of the now small anticrossing gaps between GS → ES1 and GS → ES2 branches at finite detuning in the limit of very weak interdot coupling. The fitted [estimated] values for \( g_L^* \) and \( g_R^* \) in (a) and (b) [(c)] are also indicated. On inspection of the three data sets, clearly on decreasing the interdot coupling, as discussed above, the \( g_L^* \) and \( g_R^* \) increase, and the anticrossing gap between GS → ES1 and GS → ES2 branches shrinks leading to a sharper step near \( \varepsilon = 0 \).

Lastly, we provide in Fig. 4 a compilation of the tunneling elements \( t_N \) and \( t_F \) [Fig. 4(a)], and the left QD \( g \) factor \( g_L^* \) [Fig. 4(b)]. These parameters are extracted from the two–\( g \)-factor model for strong (SC), intermediate (IC1), and weak (WC1) interdot coupling conditions as a function of magnetic field. Regarding the tunneling elements we make the following three observations. First, the motivation for our classification of strong, intermediate, and weak interdot coupling, respectively, as many tens, a couple tens, and a few microelectron volts, particularly evident at low B field (\(<1 \, T\)), is clear. For all the coupling conditions considered in this article, the ordering from strongest to weakest coupling is SC, IC1, IC2, WC1, and WC2. Second, as comprehensively discussed in Refs. [1,7,8] \( t_N \) and \( t_F \) are of comparable magnitude, and the general decrease in their values with increasing B field reflects the decreasing overlap between the left QD and the right QD orbitals driven by diamagnetic squeezing of the cyclotron orbits. Interestingly, the B-field dependence of \( t_N \) and \( t_F \) for the case of SC notably deviate strongly from each other with increasing B field, whereas those in the case of IC1 and WC1 track each other closely. The reason for this difference is currently not understood. Third, the values of \( t_N \) and \( t_F \) for SC, here obtained from the two–\( g \)-factor model, are a little different but quite comparable to those reported in Ref. [8] determined with a model assuming the \( g \) factors in the two QDs are identical. Regarding the \( g \) factors, as exemplified here by \( g_L^* \) (the trends are similar for \( g_R^* \); see Supplemental Fig. S2 [18]), we make the following comments.

The propensity for the \( g^* \) to increase with the B field for a given coupling condition in Fig. 4(b), as well as for \( g^* \) to steadily increase on decreasing the interdot coupling at a given B field as seen in Figs. 2 and 4, we attribute to a tuning of the microscopic nature of the hole states, and specifically to the reduction of the admixture of the light-hole sub-bands. The degree of heavy-hole–light-hole mixing is sensitive to the energy separation between the sub-bands as well as to the magnitude of the momentum matrix element describing the sub-band mixing [3,5,25,26]. As the B field and the gate voltages are tuned, the degree of mixing is impacted by changes in the dot confinement potential, both in the shape and the strength, brought about by the change in voltage \( V_C \) on the center gate aimed at reducing the interdot coupling, and increase in the B field leading to the diamagnetic squeezing of orbitals. Both effects strengthen the hole confinement and change the symmetry of the hole wave functions. The alteration of the spin-orbit interaction by change of dot confinement has been reported for electrons [27,28] and for holes [24]. See also Refs. [25,26,29] for discussion of the influence of the size, shape, and geometry of a self-assembled dot, tailored, for example, through the growth process [30], on the hole wave functions and subsequently hole mixing. As discussed in Refs. [1,14], for the GaAs/AlGaAs heterointerface employed, heavy holes are strongly localized laterally by the potential imposed by the voltages applied to the gates, whereas the light-hole states are essentially delocalized in-plane. Further localization by reducing the interdot coupling or diamagnetically squeezing the QD orbitals tend to raise the energy of the heavy-hole (measured from the valence band edge) but not the light-hole states leading to a further reduction of the already weak heavy-hole–light-hole mixing [3,5]. The net effect is the \( g \) factor of the lowest energy sub-band should increase, as observed, as the sub-band becomes more heavy-hole-like. We emphasise that the \( g^* \) values shown in Fig. 4(b) and Fig. S2 [18] were determined in the asymptotic limit at large detuning as illustrated in Fig. 3 so are not impacted directly by \( t_N \) and \( t_F \), i.e., at large detuning essentially the individual dots are probed rather than the coupled double dot.

In itself, the decrease of the interdot couplings with the B field [Fig. 4(a)] is not the direct driver for the increase of \( g^* \) factors with the B field [Fig. 4(b) and Fig. S2], rather it is the impact of heavy-hole–light-hole mixing.

In itself, the decrease of the interdot couplings with the B field [Fig. 4(a)] is not the direct cause of the increase \( g^* \) with the B field [Fig. 4(b) and Fig. S2], rather it is the impact of the heavy-hole–light-hole mixing. We emphasise that all DQD gate voltages are changed in the process of tuning between the WC1-IC1-SC coupling regimes which affects both the tunneling matrix elements and the QD confining potentials (shape and strength).

In summary, utilizing the EDSR tool in the single-hole regime, we found the hole effective \( g \) factors for the two QDs of a GaAs/AlGaAs DQD device differ by \( \sim 5\%–10\% \). Additionally we demonstrated the hole \( g \) factor can be varied over a wide range dependent not only on the electrical detuning, but also the interdot tunnel coupling, and the out-of-plane B field. This tunability attests to the importance of the strong SOI in a two-dimensional system further influenced by change in the hole confinement, and mixing between heavy-hole and light-hole sub-bands. As an alternative to on-chip micromagnets [31], constituent QDs in multidot structures with different \( g \) factors furnish dot-selective spin manipulations. Additionally electrical adjustment of the detuning to change the hole \( g \) factor continuously and smoothly in a controlled manner to a desired value while the system is subject to global MW irradiation is convenient, and provides circuit functionality to switch between spinlike and spin-charge-hybrid excitation regimes. The former (latter) regime is good when, for example, long spin relaxation and dephasing times for qubit operations are (coupling to a MW cavity for long-range qubit-qubit coupling is) required. These potential functionalities
featuring holes are more extensively discussed in our work in Refs. [1,8]; see also Refs. [32–38]. The means to control the hole $g$ factor described in this article add to those described in our earlier work whereby the heavy-hole $g$ factor can be set to nearly zero by applying an external $B$ field in-plane as opposed to out-of-plane [14,39]. Hole effective $g$ factors that are electrically tunable through SOI are also reported in Refs. [12,24] for planar Ge/SiGe QD circuits in the multihole regime. In Ref. [24], although individual QD $g$ factors are not determined directly, a $\sim50\%$ change in the difference in the hole effective $g$ factors of two coupled QDs forming a singlet-triplet qubit on adjustment of the interdot coupling is demonstrated.

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[18] See Supplemental Material at http://link.aps.org/supplemental/10.1103/PhysRevB.105.195305. for figures showing Fig. 1(c) plotted over a wider gate voltage range with the charge boundaries and hole occupation numbers included, and $g_h$ as a function of magnetic field for SC and WC1 interdot coupling conditions.


