Supporting Information
for
Radio-frequency detected fast charge sensing in undoped silicon quantum dots

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Supporting Information is provided on single-spin readout by energy selective tunneling and single-spin control.

1. Single-spin readout by energy selective tunneling

In the main text, we discuss the performance of singlet-triplet readout. Spin-to-charge conversion by the energy selective tunneling[1,2] is another scheme for single-spin readout widely used in spin qubit experiments and therefore we discuss the performance of this scheme in terms of SNR. Figure S1 shows a typical real time trace of charge sensor signal for spin detection measured near the boundary between (0,1) and (1,1) charge states (shown by M in Figure S2(a)). When the spin state is up, a blip is observed in the time trace associated with electron tunneling events between the left QD and the adjacent reservoir. Normally, the signal of this scheme, the difference of charge sensor signal between (0,1) and (1,1) states, is greater than that of the singlet-triplet readout (Figure 3(c)). In fact, we observe the signal level and therefore the SNR [the noise level is almost unchanged] are enhanced by a factor of 2.5 compared to that of the singlet-triplet readout.

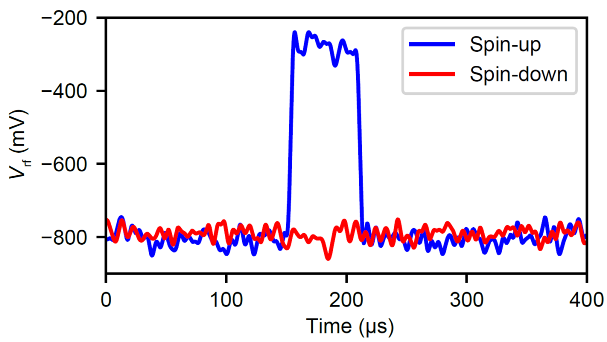

Figure S1. Real time traces of charge sensor signal for spin detection. The blue (red) trace shows a typical signal in the case of spin-up (spin-down). The device and measurement setup are the same as those used in Figure 3. The sensor signal is low-pass filtered at a cut-off frequency of 100 kHz.

2. Single-spin control

In this section, we demonstrate the compatibility of our small accumulation gate device with a high performance of spin qubit operation. This is done in a different gate voltage condition from that used in Figure 3 with a relatively small inter-dot tunnel coupling, where spin initialization by slow adiabatic passage becomes inefficient[3,4]. In order to initialize and measure the single-spin state, we instead use spin-dependent electron tunneling between the left QD and the adjacent reservoir (see Figures S2(a), (b) and S1). The device has a micro-magnet on top of the accumulation gate for electric dipole spin resonance (EDSR) manipulation of an electron spin[5,6]. The DQD is controllable and stable enough to perform a single qubit rotation experiment. Indeed, we observe a clear Rabi oscillation by applying a microwave (MW) burst to the gate electrode C as shown in Figure S2(c). From this result, we confirm that the small accumulation gate design is compatible with a high-fidelity spin qubit operation.

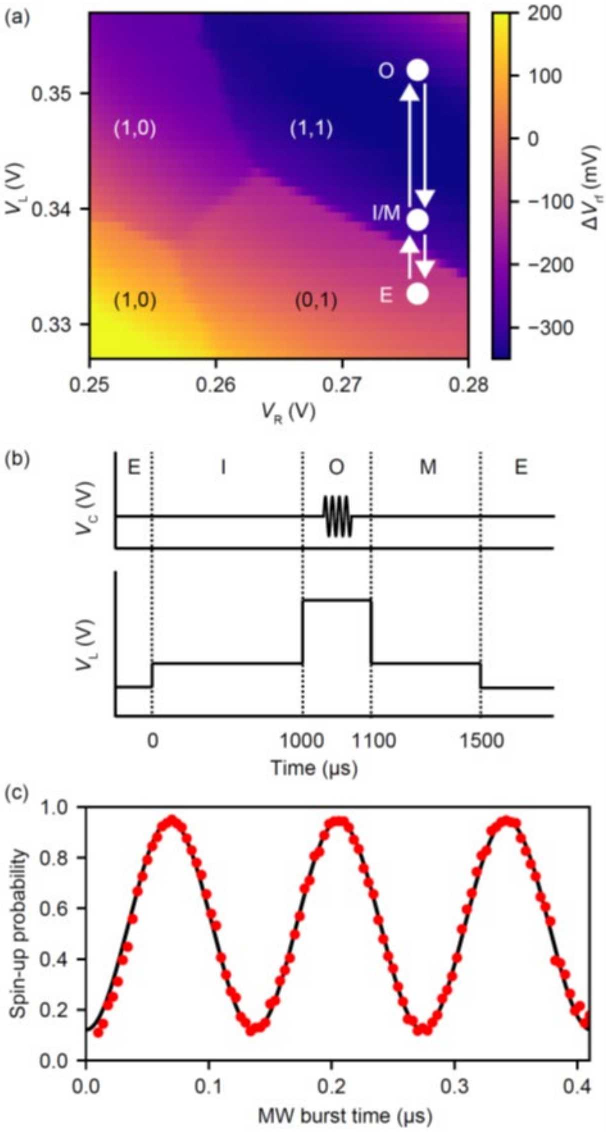

Figure S2. Rabi oscillation of a single-spin in the left QD by EDSR. (a) Stability diagram showing gate voltage conditions where evacuation (E), initialization (I), operation (O) and measurement (M) are performed. (b) Schematic of the voltage pulse shape. (c) Rabi oscillation measured at the external magnetic field of 0.54 T and the MW frequency of 16.514 GHz. From a sine curve fit, we obtain a Rabi frequency of 7.3 MHz.

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