Supplemental Material to 'Fast spin-orbit qubit in an indium antimonide nanowire'

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DOUBLE DOT OCCUPATION

Figure S1 displays a stability diagram mapping out the current through the quantum dot as a function of the voltages V_2 and V_4 on the two plunger gates. The large addition energies and their odd-even structure indicates that we have reached the few-electron regime. The last visible bias triangles exhibited spin-blockade in the expected positions, further confirming that we have reached the few-electron regime. However, due to the absence of a charge sensor in our device, it is impossible to determine the absolute number of electrons in our dots. Thus, there may be more electrons in the dot for which the charge transitions are not visible (the increased current in the top left of the diagram indicates this is actually likely for one of the dots). We assume, however, that these electrons are paired and can further be ignored. In the labeling of the charge transitions we account for this uncertainty in the electron number by including terms of $2m$ and $2n$ respectively, where m and n are small integers. The first visible triangle is then the $(2m,2n+1)\rightarrow(2m+1,2n)$ transition.

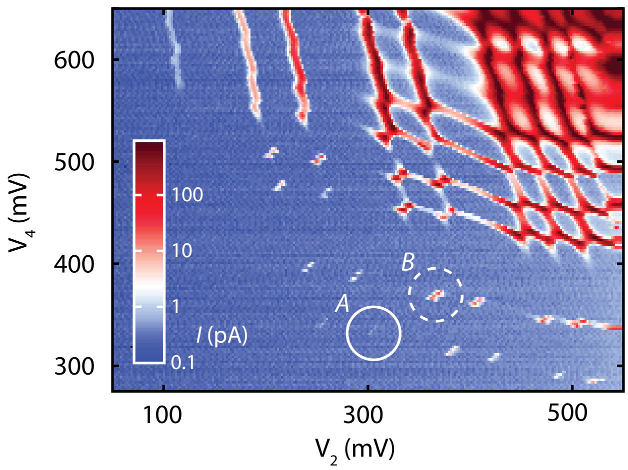

FIG. S1. Stability diagram of our double quantum dot at small positive bias. Circles indicate charge transitions at which data presented in the main paper has been obtained. Transition A (solid circle) indicates the $(2m+1,2n+1)\rightarrow(2m,2n+2)$ transition used for figures 1–3 and transition B (dashed circle) is $(2m+1,2n+3)\rightarrow(2m+2,2n+2)$ used for figure 4).

RABI OSCILLATIONS

In the main text Rabi oscillations have been presented at frequencies up to 104 MHz. Higher Rabi frequencies could be achieved at higher microwave power, at the expense of reduced (i.e. faster decaying) visibility of the oscillations, likely due to photon assisted tunneling. In figure S2 we present data displaying this behavior. The higher Rabi frequency of 117 ± 1 MHz only shows half the number of oscillations compared to the data presented in the main text.

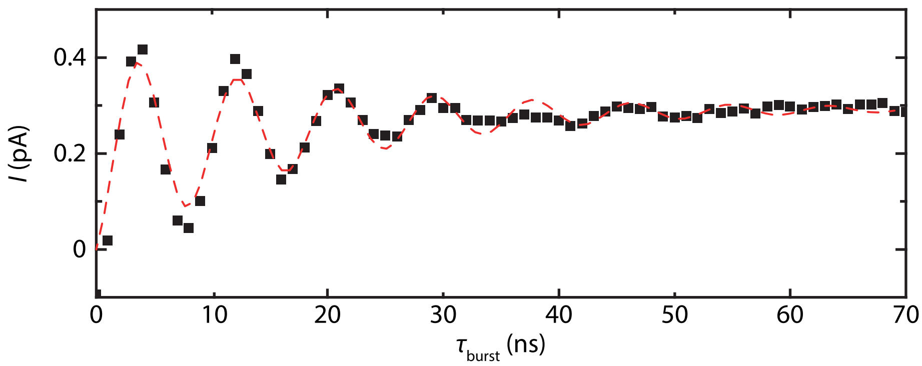

FIG. S2. Rabi oscillations obtained at the same settings as those presented in the main paper, except for a larger microwave source power of 18 dBm. Dashed line is a fit to a simple exponentially decaying sinusoidal oscillation from which a Rabi frequency of 117 ± 1 MHz is extracted.

MANIPULATION FIDELITY

The nuclear magnetic field changes the intended rotation axis for qubit operations, thereby affecting the fidelity of these rotations. To estimate this fidelity requires knowledge of the spin-orbit driving field B_{SO}, as well as the strength of the fluctuating nuclear field B_N. The effective field driving the rotations can be determined from the Rabi frequency through $B_{SO} = 2hf_R/(g\mu_B)$. We estimate the RMS value of the nuclear field fluctuations, B_N, from the width of the EDSR peak. More commonly, this is done with the hyperfine peak at $B = 0$ [1–3]. However, it has been previously observed that hyperfine peak widths can vary greatly between different InSb nanowire devices [4], despite similar dot sizes. We therefore make an upper estimate for B_N based on the width of the EDSR peak, which is also broadened by the nuclear field fluctuations at low driving power [5].

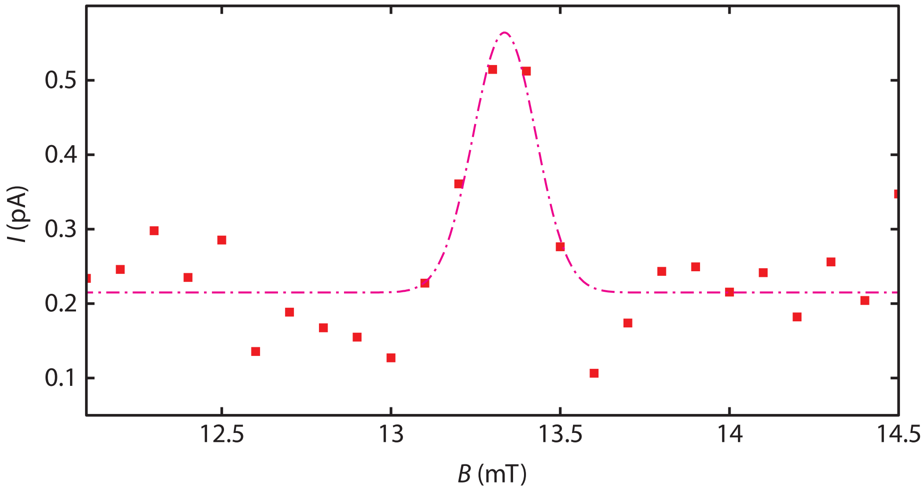

FIG. S3. Solid points: data from an EDSR peak obtained at 7.9 GHz driving frequency. Dashed line is a Gaussian fit to the data.

Figure S3 shows an EDSR peak, which has been fitted to a Gaussian curve. The standard deviation of this curve gives the strength of the nuclear field fluctuations in the z-direction. From it we determine the total nuclear field fluctuations $B_N = \sqrt{3}B_{N,z} = 0.16 \pm 0.02$ mT. Following the procedure explained in [6] this leads to a manipulation fidelity of 81 ± 6 % for the Rabi oscillations at 104 MHz.

We note that the absence of a double frequency component in the Rabi oscillations indicates that only one of the qubits is rotated. This cannot be caused by different nuclear fields in the two dots, as B_N is relatively small. This suggests that the second qubit is undriven because of a differing g-factor from the first dot and/or a decreased coupling of the microwave driving field to this dot.

INDIVIDUAL ADDRESSING OF THE QUBITS

In figure S4 we present the magnetic field dependence data of the two EDSR peaks already shown in the main paper. The resonance frequency varies linearly with field for both resonances, from which the g-factors of 48 and 36 can be determined. A very faint feature may be discerned in the lower right corner of this graph. As it has half the slope of the strongest ($g = 48$) resonance, we attribute it to a multi-photon process. The bright band that is visible parallel to the hyperfine peak is not caused by the microwave signal, as it is also present without applying microwaves, though it is unclear what its exact origin is.

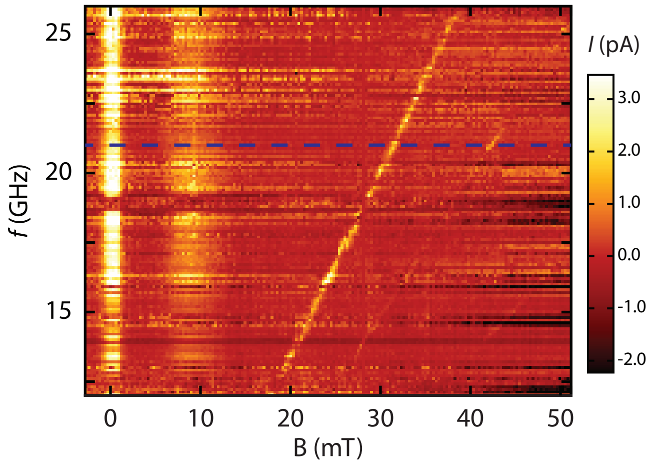

FIG. S4. Magnetic field dependence of the EDSR signals from the two dots. The dashed blue line indicates the position of the trace presented in the main paper. (A vertical linecut has been subtracted to suppress resonances at constant frequency.)

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