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To cite this version:
Sylvain Hermelin, Seigo Takada, M. Yamamoto, Seigo Tarucha, Andreas D. Wieck, et al.. Fast end efficient single electron transfer between distant quantum dots. Journal of Applied Physics, American Institute of Physics, 2013, 113, pp.136508. <hal-00997028>

HAL Id: hal-00997028
https://hal.archives-ouvertes.fr/hal-00997028
Submitted on 27 May 2014

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Citation: J. Appl. Phys. 113, 136508 (2013); doi: 10.1063/1.4795528
View online: http://dx.doi.org/10.1063/1.4795528
View Table of Contents: http://jap.aip.org/resource/1/JAPIAU/v113/i13
Published by the American Institute of Physics.

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Fast and efficient single electron transfer between distant quantum dots

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(Received 1 October 2012; accepted 3 January 2013; published online 29 March 2013)

Lateral quantum dots are a promising system for quantum information processing devices. The required basic manipulations of a single electron spin have indeed been demonstrated. However, a stringent requirement is the ability to transfer quantum information from place to place within one sample. In this work, we explore and demonstrate the possibility to transfer a single electron between two distant quantum dots in a fast and reliable manner. © 2013 American Institute of Physics. [http://dx.doi.org/10.1063/1.4795528]

I. INTRODUCTION

Lateral quantum dots have seen tremendous improvements over the past years and allow to manipulate a single electron or its spin quantum coherently.1–5 In addition, double dots—i.e., two dots lithographed close to each other—offer the possibility to make two electrons interact with each other in a controlled manner. These tools can hence be seen as new building blocks for electronic devices based on single electrons, whether in classical manner or for a quantum computer. However, in both cases, a major ingredient is missing in the previous list: the possibility to transfer the information, that is the transfer of a single electron from one quantum dot towards another distant one in keeping the electron isolated in the structure. In the following, we show that this missing ingredient has been realised thanks to surface-acoustic-wave assisted transport. In the context of quantum computing, displaced electrons can play the role of photons in superconducting systems, and is com-
will then need to push the electrons higher in energy if we want them to be able to reach the 1D-channel (see Fig. 2).

Figure 2 shows QPC traces resulting from a gate sequence that loads one electron (in the \( n = 1 \) region of the dot’s stability diagram, Fig. 1, A) and then pushes it high in energy into a metastable position\(^{13}\) (into the \( n = 0 \) region, Fig. 1, B). We can clearly see two levels for the QPC trace: The dot is loaded with 0 or 1 electron. If loaded with one electron on arrival at the metastable point, it leaves the dot after a stochastic time. If averaged, we recover an exponential decay towards 0 electron with a characteristic time around 600 ms, characteristic of the tunneling back to the reservoir. The same experiment can be repeated, but now a burst of acoustic wave is generated 100 ms after the dot is set in the metastable position. The results indicate (data not shown here) that the electron gets out of the quantum dot with a high probability. In order to check that the electron is indeed transported through the 1D-channel and is not simply kicked back into the reservoir,\(^{13}\) we will set up the second quantum dot to try and catch the electron.

The reception quantum dot is thus polarized deep in the metastable region (point D in Figure 1). This configuration allows to get a high and thick barrier between the reservoir and the dot: the electron will indeed be pushed by the SAW, we hence need this barrier high enough to block it. Once the electron is caught, the dot is polarized at point C to empty it and reset the experiment. The overall sequence is hence as follows: (1) the injection dot is loaded, (2) the reception dot is emptied and set in reception position, (3) the injection dot is set in the metastable position, (4) the charge states are checked for 50 ms, (5) a burst of SAW is generated, and (6) the (new) charge states are measured for 50 ms. The resulting single shot traces observed experimentally are presented in Figure 3. Statistics are accumulated for 10 001 repetitions in different loading situations in the source dot. This analysis allows to completely characterize the transfer process and shows that it is indeed the electron that is loaded in the injection dot that actually arrives in the reception dot with a high efficiency: 95% for the injection and 92% for the reception.\(^{14}\) This high efficiency and reliability have been confirmed in a simultaneous work by McNeil and co-authors.\(^{15}\)

**IV. NANOSECOND TRIGGERED ELECTRON TRANSFER**

An important parameter for the use of this system in a quantum computer resides in the ability to trigger every...
operation faster than the coherence time of a single electron spin. If spin echo sequences can raise this time up to 200 μs, the “bare” coherence time is typically around 10 ns.\textsuperscript{2,16–18} We thus need to trigger the transfer on this timescale. However, the experiments already presented here used a SAW burst of 65 ns, which is the limit imposed by the bandwidth of the IDT. The idea to get triggering at the nanosecond timescale is first to bury the electron deeper in the emission dot so that the SAW excitation is not enough to inject the electron into the moving quantum dots. Second, the addition of a voltage pulse on gate c (see Figure 1) during 1 ns allows to bring back the electron in a situation where it is more sensitive to SAW excitation and allows to turn back on the injection probability (while conserving the good transfer efficiency). The corresponding transfer probabilities are presented in Figure 4, where the delay between the generation of the SAW burst and the ns-gate is varied.

This shows that the injection can indeed be triggered within 1 ns and the limit to go lower should only be technological (a faster pulse generator with the same amplitude should allow the same result on faster time scales).

V. CONCLUSION

In conclusion, we have demonstrated a fast and efficient transfer method for a single electron between two distant quantum dots. Further investigations on the spin of the transported electrons are to be realized to fully characterize the abilities of this system.