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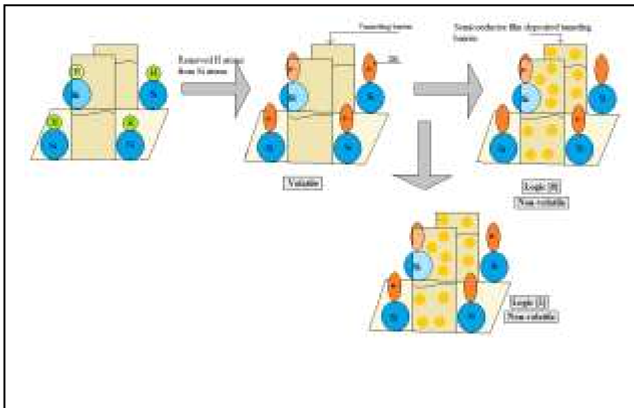
Non-volatile device architecture using quantum dot cellular automata

Soudip Sinha Roy[1]
Theoretical Physicist
Director at Physics Tomorrow
soudipsinharoy@{gmail.com;physicist.net}
Tel.: +91 8327656228

Anusua Chakraborty[2]
RBU Kolkata
Anusuachakraborty2016@gmail.com

Abstract

Non volatile device is proposed in this article based on quantum dot cellular automata architecture, which will be efficiently useful as a binary qubit system. In standards, todays theoretical researches are going on the volatile QCA gates, which are efficient well in performance towards the rapid binary data computation. However, what if it can store some data for a while. ? Therefore, a novel methodology has been proposed theoretically towards the non-volatility of the QCA cells. As expected that this gate would be able to exhibit the non-volatility.



Non-volatile nanostructure architecture for QCA.

Special issue.

Keys: *quantum dot; non-volatile memory; resistive memory; nano-crystal device; nanolectronics.*

1 Introduction

In the present technology, the quantum computing has been playing an emergent role for overcoming certain major complications and the fundamental limitations of the traditional semiconductor devices, for instance, MOSFET, MESFET, MODFET, TTL, ECL, RTL, DTL etc. In those devices, the major problems are the consistency of the dopant impurity due to certain external impacts like temperature variation, hall effect, strong external magnetic field etc. that imposes the semiconductor materials to exhibit some unacceptable behavior during the operation. This causes a high discrepancy in device performance. Although the power utilization of those devices is proportionally higher, that truly does not match with the actual expectation. Nowadays there are various instances for binary information computing in nanoelectronics, like the electron island devices, for example, Single-Electron Transistor, electron spin-based qubit devices etc.

In this research, a novel type of non-volatile binary qubit system is proposed, with the controllable electron tunneling island, fig. 1. In present days quantum-dot cellular automata is a nanoscale information computing technology which is leading the quantum computing with a broad dimension. This device is an electron tunneling based device, consisting of the lighting speed of operation 50 PHz [1] and the power dissipation is also limited to some fraction of mili watts. The main thought is to implement an electron island based qubit system that can store the binary bit in terms of charge for a longer period.

2 Motivation of the work in detail

The below figure illustrates a quantum cell which consists of four quantum dots placed cornerwise of a square cell. Inside the qudots four electrons are bounded by the dangling bond (DB) and separated from other qudots by a tunneling barrier. The tunneling barrier is simply an energy gap between two energy states of the electron. The fig. 1, shows the depolarized state of the quantum cell, but once the cell is polarized either by positive or negative polarization, the electrons receive enough energy and tunnels the barrier and obtain a stationary position in another qudot until the polarization is removed. So as per the fig. 1,2, initially the electron is polarized with or more than the threshold potential and which enforced the electron to get ejected from the existing qudot and settled at another qudot. Afterwards, just after the removal of the applied potential, the electron again reverted its position and this is called superposition state. This superposition state is like that only when the electron cloud is distributed throughout the available qudot energy states while there has no applied electric field. This is a dynamic logic operation in a volatile manner. Because after the removal of the driven polarization (electric field) the electrons become depolarized, that is not useful to store any logical bit.

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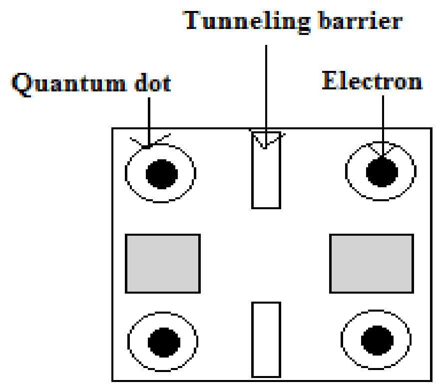

Figure 1 | Typical view of the QCA cell.

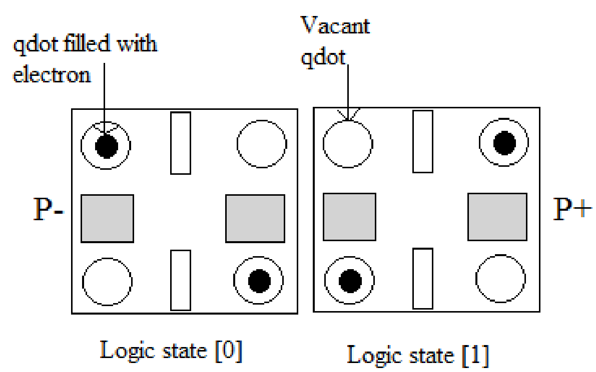

Figure 2 | States of the logic for QCA

To overcome all limitations of the volatility of the QCA cells, it is necessary to have some rectification overcome all limitations of the volatility of the QCA cells, it is necessary to have some rectification is the device architecture.

It is very much well known that the interstitial doping is possible up to 0.5 Angstrom by using a high-resolution Scanning Tunneling Microscope. So thereby, when the energy gap between two Si atoms will be doped by the p-type ion then it will be possible to create a deep trap state in between two qubits, fig. Y. When the electron will be polarized then it will be driven towards another vacant qubit. During this transition, state inside the deep trap state the electron will get stacked. Now this state of the electron can be stated as high or low binary logic.

One Si atom acts as a single quantum dot, and one Si atom has around 26-27 DB on its surface. When the STM tip will scan the hydrogenated surface of the Si thin film (0.5 nm) then it will dope with the p-type material and as well, it will remove the electrons to generate the DBs.

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In certain previews of QCA logic gate designing it is shown that this device can operate at a maximum 50 PHz of frequency [1], which asserts that this device has the lightning speed of operation. Implementing a few cells sequentially the nonvolatile qubit device can be created successfully, fig 3.

3 Implementation methodology of the non-volatile device

On a mono-dispersed Si thin film (0.50nm) the hydrogen will be doped (hydrogenation) with the maximum accuracy, that will provide a uniform hydrogenated lattice to attain the uniform property at each and every location in the lattice. In the next step, the four H atoms to be removed by STM that will result four dangling bonds associated with each Si atom. Then the electron will be implanted inside the DBs that will act as a trapped in the energy state (shallow trap). Only under the influence of suitable electric field (polarization) the electrons will become tunnable by absorbing the external applied energy. The stable electrons inside the DBs just after tunneling will make either right handed or left handed orientation as per the binary logic state, fig.2. This is expected to be the nonvolatile qubit system.

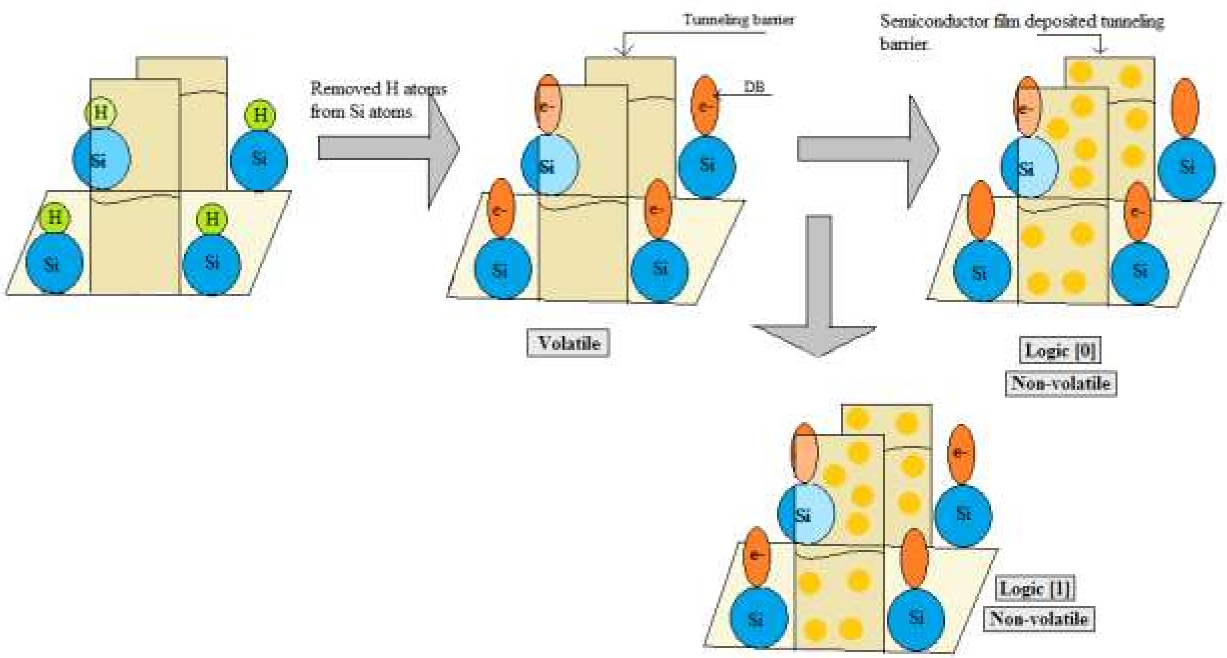

Figure 3 | Proposed architecture for the non-volatile quantum dot cellular automata based device.

This interstitial doping inside the lattice of the quantum dot will also improvise restriction against the thermal ejection of the electrons from the dangling bonds. As the external temperature, increases the electrons get the kinetic energy that enforces it outwards to form the lattice somewhat towards the surface potential region. However, if, an electron is trapped under a deep trap then the probability of the electron ejection becomes equivalently less.

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3. Conclusion

This research wants to insert a new aspect of exploration on the QCA research field by incorporating the novel architecture of the non-volatile quantum island device. Using four-dot qubit the volatility of the traditional devices could be overcome towards the non-volatility. This theory completely imposes onto the theoretical architecture however; the next publication will contain the complete fabrication process. Therefore, at this point, we conclude this proposal by indicating our future publication on the fabrication of the non-volatile quantum-dot cellular automata device.

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References

[1] S. S. Roy, "Generalized Quantum Tunneling Effect and Ultimate Equations for Switching Time and Cell to Cell Power Dissipation Approximation in QCA Devices", doi: 10.13140/RG.2.2.23039.71849

[2] Fushan Li, et.al. , "Nonvolatile Memory Effects of ZnO Nanoparticles Embedded in an Amorphous Carbon Layer", Japanese Journal of Applied Physics 49 (2010) 070209.

[3] Biswanath Mukherjee and Moumita Mukherjee, "Nonvolatile memory device based on Ag nanoparticle: Characteristics improvement" Applied Physics Letters 94, 173510 (2009); doi: 10.1063/1.3127233.

[4] Soudip sinha roy, "Fabrication of Non-volatile Charge Storage Memory Device by Novel doped ZnO nanoparticles with 4.79 eV bandgap", Physics Tomorrow Letters, 20(12): 01-01

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