Quantum Dot Cellular Automata-The Endowment for Modern computing

H.UMAMAHESVARI¹, D.AJITHA², V.SUMALATHA³

¹Department of Science and Humanities, Sreenivasa Institute of Technology and management Studies, Chittoor,Andhrapradesh, India
² Department of Electronics and Communication, Sreenivasa Institute of Technology and management Studies, Chittoor,Andhrapradesh, India
³ Associate Professor, Dept of ECE, J.N.T.U.C.E.Ananthapur, Andhrapradesh, India
¹umamaheswarilhema@gmail.com, ²ajithavijay1@gmail.com, ³sumaatp@yahoo.com

ABSTRACT

Quantum-dot cellular automata (QCA) is an efficient technology to create computing devices. QCA is a suitable candidate for the next generation of digital systems. A quantum-dot cellular automaton (QCA) is a new nanotechnology that can help us to reach low-power consumption, high device density, and high clock frequency. QCA size is smaller than CMOS it can, even be implemented in molecule or atom size. QCA power consumption is extremely lower than CMOS because there are not any current in the circuit and output capacity. The two important gates in QCA are three-input majority gate and inverter. This paper explains about the origin, construction and implantation of logical gates by using QCA, the energy gain in QCA and its future applications.

Key words: Quantum dot cellular Automata, power gain, device density, Quantum dots

1. INTRODUCTION

In recent years the development of integrated circuits has been essentially based on scaling down that is, increasing the element density on the wafer. Scaling down of CMOS circuits, however, has its limits. Above a certain element density various physical phenomena, including quantum effects, conspire to make transistor operation difficult if not impossible. If a new technology is to be created for devices of nanometer scale, new design principles are necessary. One promising approach is to move to a transistor-less cellular architecture based on interacting quantum dots, Quantum-dot Cellular Automata. Quantum Dot Cellular Automata (sometimes referred to simply as quantum cellular automata, or QCA) are proposed models of quantum computation, which have been devised in analogy to conventional models of cellular automata introduced by von Neumann. Quantum-dot cellular automata (QCA) is an alternative approach to binary computing which may be more suited for nano-scale electronics than conventional transistors and current switches.

2. MOLECULAR QUANTUM DOT CELLULAR AUTOMATA

Modern computing has achieved phenomenal success based on the use of binary numbers encoded as on or off states of current switches. However, scaling current switches down to the molecular level presents a host of problems, including complications arising from charge quantization, and high levels of power dissipation [1]. An alternative approach, quantum-dot cellular automata (QCA) [2]–[6] retains the use of binary digits but represents the digits with the electronic charge configuration of a cell rather than states of current switches. This eliminates the need to use molecules as current switches and allows them to assume the more natural role of structured charge containers. For this scheme, charge quantization is an advantage because we are interested in the positions of individual electrons. It also has been shown that power dissipation in QCA can be reduced to a tolerable level, while true power gain is possible [7].

2.1. What are quantum dots?

- In order to implement a system that encodes information in the form of electron position it becomes necessary to construct a vessel in which an electron can be trapped and "counted" as there or not there.
- A quantum dot does just this by establishing a region of low potential surrounded by a ring of high potential. Such rings are able to trap electrons of sufficiently low energies/temperature and are sometimes called potential wells.
- A quantum dot is a nanometer sized structure that is capable of trapping electrons in three dimensions.
- Quantum dots are made by creating an island of conductive material surrounded by insulating material. Electrons that enter the quantum dot will be confined because of the high potential required to escape.
2.2. Why are Quantum Dots important?
Quantum dots will become the backbone of future microelectronic and photonic devices, it is due to their unique properties due to quantum confinement of electrons in 3-dimensions this results in interesting electronic and optical properties

2.3. How Quantum dot cellular Automata works?
In the QCA approach, devices are composed of cells, each of which contains a small number of quantum dots. A dot, in this case, is simply a region in which charge is localized. Fig. 1(a) illustrates a schematic four-dot QCA cell. This cell has two extra mobile electrons (or holes), which tend to minimize their mutual Coulomb interaction by occupying opposite corners of the cell. The cell therefore has two degenerate ground states, which we associate with a binary “0” and “1”.

Computation requires interactions among bits or, in this case, among cells. If a second cell is placed near the first, the electro- static interaction between the cells removes the degeneracy and determines the ground state of the first cell. A key feature necessary for QCA operation is that the interaction between cells is nonlinear. The cells should “click” into essentially completely aligned configuration (“1” or “0” as appropriate) with even a small perturbation from a neighboring cell. It is also noteworthy that the interaction between cells involves no current flow from one cell to another.

QCA devices are constructed by arranging cells near each other an appropriate layout. Arranging cells in a line, as in Fig. 1(b), results in a QCA wire, which transmits binary information from one end to the other. The natural logic gate is the three-input majority gate shown in Fig. 1(c). Three input lines converge at a device cell, whose state is determined by the state of the majority of the inputs. Building from these, more complex circuits, such as adders [4] and even simple microprocessors [5] have been designed.

3. QUANTUM-DOT CELLULAR AUTOMATA AS LINE AND MAJORITY LOGIC GATE
Advances in the microelectronic industry depend upon the ever-shrinking size of transistors. For more than 30 years, this trend has followed Moore’s law, which predicts that the number of devices integrated on a chip will double every 18 months. Computing in the QCA paradigm can be viewed as computing with the ground state of the system. A computational problem is mapped onto an array of cells by the layout of the cells, where the goal...
is to make the ground state configuration of electrons represent the solution to the posed problem. Then computation becomes a task of applying a set of inputs, and then letting it relax into a new ground state. For each set of inputs a unique system ground state exists that represents the solution for those inputs.

The mapping of a combinational logic problem onto a QCA system can be accomplished by finding arrangements of QCA cells that implement the basic logic functions AND, OR, and NOT. An inverter, or NOT, is shown in Fig. 2(a).

![Fig. 2(a). A QCA Inverter](image)

In this inverter the input is first split into two lines of cells then brought back together at a cell that is displaced by 45° from the two lines, as shown. The 45° placement of the cell produces a polarization that is opposite to that in the two lines, as required in an inverter. AND and OR gates are implemented using the topology shown in Fig. 2(b), called a majority gate. In this gate the three inputs “vote” on the polarization of the central cell, and the majority wins.

![Fig. 2(b). The Programmable QCA AND and OR Gate](image)

The polarization of the central cell is then propagated as the output. One of the inputs can be used as a programming input to select the AND or OR function. If the programming input is a logic 1 then the gate is an OR, but if a 0 then the gate is an AND. Thus, with majority gates and inverters it is possible to implement all combinational logic functions. Memory can also be implemented using QCA cells, making general purpose computing possible.

4. POWER GAIN AND DISSIPATION IN QUANTUM-DOT CELLULAR AUTOMATA

Any successful approach to nanoscale electronics must address the important questions related to energy gain and dissipation.
Do the devices exhibit power gain? In all practical electronic circuits, dissipation of signal power occurs through irreversible loss processes. For an electronic architecture to be viable, it must have a mechanism for restoring signal power. In conventional electronic devices, power lines and transistors are used to achieve power gain and logic level restoration. While there are conventional logic schemes, such as those based on pass transistors that do not provide power gain, signal degradation occurs along the circuit path and gain stages are required to ensure signal integrity. In the area of molecular electronics, power gain is particularly important since most proposed molecular devices lack power gain and will require the introduction of gain stages [7].

Quantum-dot cellular automata known as QCA [8,9] is a device architecture that uses changes in quantum dot arrays and can provide power gain and miniaturize digital logic circuits to the molecular level, well beyond what can be achieved using field effect transistors. In recent years, several QCA devices such as a QCA cell, majority gate, leadless cell, and a latch, have been fabricated and tested [10-15]. The power gain in a QCA device [16] demonstrated through a single latch in a QCA shift register is

\[
\text{Energy gain} = \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{W_{\text{out}}/T}{W_{\text{in}}/T}
\]

To calculate this, we measure the work done on the latch by its predecessor \((W_{\text{in}})\) and the work done by the latch on its successor \((W_{\text{out}})\) in one clock cycle.

\[W = \int V\, dQ = \int \frac{dQ}{C} \frac{dV}{dt} = \int \frac{dQ}{C} \Delta t\]

where \(V(t)\) is the voltage applied to the lead and \(Q(t)\) is charge on the capacitor coupling the dot to the voltage lead. There are four paths for energy transfer in a QCA latch, the input signal, the output signal, the clock signal, and irreversible power dissipation. The work done on the latch by its neighboring latches or vice versa constitutes energy flow due to the input and output signals. While the input and output signals are determined by the latches in the shift register, the clock is an external signal that can be used as an energy source or sink for the latch.

CONCLUSION

In computers of the future, transistors may be replaced by assemblies of quantum dots called "Quantum-dot Cellular Automata" (QCA). Current transistor-based IC fabrication technology faces many trivial issues such as those of excess power dissipation, expensive fabrication and short channel effects at very low device size. Quantum-dot cellular automata (QCA)-based digital electronics on the other hand provide scope for further development in the future by shrinking the device size. Current QCA logic circuits are based on logic synthesis using Inverters and (three or five input) Majority Gates. By taking full advantage of the unique features of this technology, we are able to create complete circuits on a single layer of QCA. Such devices are expected to function with ultra low power consumption and very high operating speeds.

REFERENCES

The first author Dr. H. Umamahesvari, Associate Professor in SITAMS, Chittoor is having 14 Years of teaching and 6 years of research experience. She completed her M.Sc, M.Phil in Pondicherry University and Awarded “Gold medal” for her research in “Molecular Interactions in Dielectrics with Various solvents” in the year 1999 and completed Ph.D in Mother Teresa University, Kodaikanal in the Year 2009. She published 12 International papers in reputed Journals like Science direct and presented six papers in the International conference and 9 papers in National conferences on Quantum Computing. She applied for a DST project on “Study of important Cancerous drugs by FT-IR and Raman studies with Quantum computing methods”. Her interest is implementing the quantum computing methods in nanofield.

The second author D. Ajitha Assistant Professor, ECE Dept in SITAMS, Chittoor is having 7 Years of teaching experience. She completed her Bachelor of Technology degree from JNTUCEA, JNTU, Hyd in 2007 & M.Tech in VLSI System Design from SITAMS, Chittoor. She is currently pursuing the Ph.D (part-time) Degree from the Dept of E.C.E, JNTUA, Anantapur under the guidance of Dr. Dr. K.V. Ramaiah, Associate Professor, ECE Dept, Y S R Engineering College of Yogi Vemana University, Proddatur & Dr. V. Sumalatha, Associate Professor, Dept of ECE, J.N.T.U.C.E.A, Ananthapur. Her interest is implementing the Digital logic circuits in nanofield.