Optik 127 (2016) 4246–4249

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

A novel quantum dot cellular automata for 4-bit code converters

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ARTICLE INFO

Article history:
Received 9 September 2015
Accepted 28 December 2015

Keywords:
Quantum-dot cellular automata
Binary to gray and gray to binary code converters
QCAD tool

ABSTRACT

Quantum-dot cellular automata is a promising successor of CMOS technology. QCA proposed by Lent et al. is an emerging technology that offers an innovative approach for computing at nano-scale by monitoring the position of a single electron. This technology allows the implementation of logic devices using quantum dots instead of transistors, diodes. QCA technology has large potential in terms of high space density and power, possible to achieve miniaturization of circuits and high speed processing. The paper provides an efficient design and layout of code converters based on quantum-dot cellular automata using QCADesigner tool. In this paper a number of new results on binary to gray and gray to binary code converters and detailed simulation using QCAD designer tool is presented. We have performed a comparative study of proposed design with recent previous designs and proved that proposed design is efficient in terms of complexity, cell count, area usage and clocking.

1. Introduction

Quantum Dot cellular Automata (QCA) is a new and emerging computing paradigm. The basic element of QCA is a quantum cell [1]. QCA is visualized as a coupled dot system with four quantum dots at the corners of a square structure. Two free electrons are confined to any of two quantum dots [2]. Quantum dots are nanostructures created from standard semiconductive materials such as Si/SiO_2 [3]. QCA accomplishes the logic operations and the data flow occur in the circuit by means of columbic interaction of the electrons of neighboring cells [4].

QCA structures are designed as an array of quantum cells [5]. QCA uses polarization effect rather than conventional charge flow or current for the transmission of digital information. Thus a quantum cell is responsible for the transfer of information throughout the circuit. The basic primitives used in QCA are three input majority gates, wire and an inverter [6].

2. QCA designer

QCA circuit designers require an accurate and rapid simulation and design layout tool to determine the functionality of QCA circuits. QCADesigner tool gives the ability to quickly layout a QCA design by providing an extensive set of CAD tools [7]. As well, several simulation engines facilitate rapid and accurate simulation. It is the first publicly available design and simulation tool for QCA. QCA designer tool was developed at the ATIPS Laboratory, at the University of Calgary. QCADesigner currently supports three different simulation engines, and many of the CAD features required for complex circuit design.

3. QCA architecture

3.1. Basics of QCA

The basic element of QCA is a quantum cell. The fundamental primitives are majority gate, inverter and wire. Each QCA cell each has four quantum dots and two free electrons. The locations of the electrons determine the binary states. These two arrangements are denoted as cell polarization $P=+1$ and $P=-1$. By using cell polarization $P=+1$ to represent logic “1” and $P=-1$ to represent logic “0”. Binary information is encoded in the charge configuration of the QCA cell [6] (Fig. 1).

3.2. QCA cell

A quantum-dot cellular automata (QCA) is a square nanostructure of electron wells having free electrons. Each cell has four quantum dots. The four dots are located in the four corners. The cell can be charged with two free electrons. By using proper clocking mechanism, the electrons tunnel to proper location during the

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http://dx.doi.org/10.1016/j.ijleo.2015.12.119

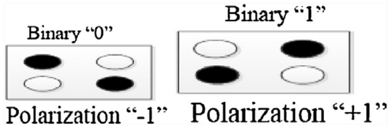

Fig. 1. QCA cell polarization.

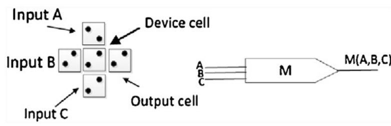

Fig. 2. Majority gate.

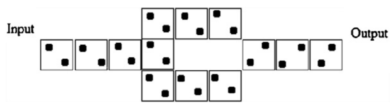

Fig. 3. Inverter.

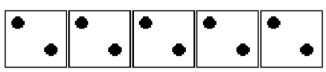

Fig. 4. QCA wire.

clock transition [3]. The arrangement below gives the realization of majority gate using QCA.

QCA cells A, B and C are input cells, and M is the output cell that is polarized according to the polarization of the majority of the three input cells. In this example, since two input QCA cells are polarized to +1, the output cell is also polarized to +1. QCA cells can also be used to construct wires. When an input is applied to the left input cell, the binary information propagates from the left to the right. When all cells in a wire settle down to their ground states, they have the same polarization (Figs. 2–4).

There are two types of crossovers i.e. overlapping of wires. Coplanar crossover uses single layer but involves usage of two cell types termed regular and rotated, the multilayer crossover involves more than one layer of cells. Here we use both coplanar and multilayer crossover for wire crossings since we can effectively cross signals over another layer and the extra layers can be used as active components of the circuit.

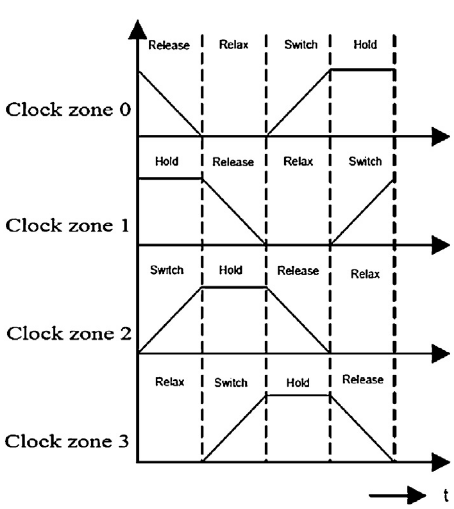

Fig. 5. QCA clock zones and QCA clock with four phases.

3.3. QCA clock system

The QCA circuits require a clock, not only to synchronize and control information flow but also to provide the power to run the circuit since there is no external source for powering the quantum cells. In QCA, clocking can be accomplished by controlling the

Fig. 6. Layouts of AND gate and OR gate.

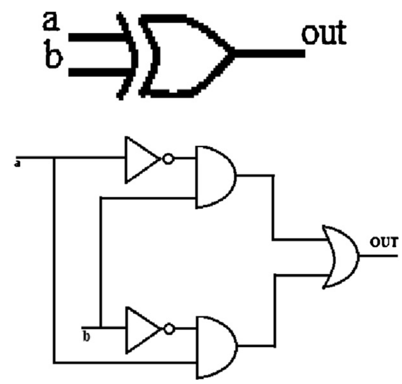

Fig. 7. XOR gate graphical symbol and implementation.

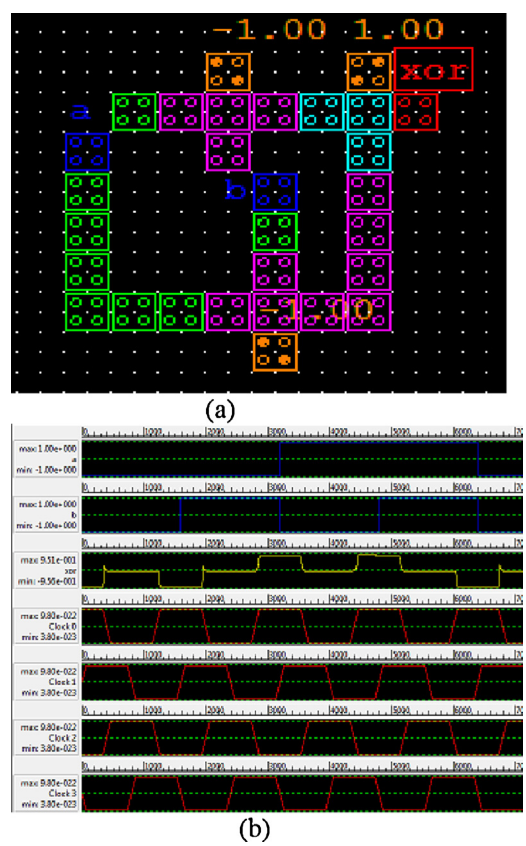

Fig. 8. (a) QCA layout of XOR gate and (b) simulation result.