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New Approach to Decreasing the Number of Quantum Dot Cells in QCA Inverter

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Abstract

A new method for decreasing the number of Quantum Dot Cells in Quantum Dot Cellular Automata (QCA) circuits is presented. The proposed method is based on physical modeling between electrons. Correctness of presented method is proved using some physical proofs. Our method is useful for QCA circuits with many inverter gates. It should be noted that in order to achieve more stability, the potential energy of QCA electrons reach the minimum level. The proposed approach can be used for designing any QCA arithmetic circuit.

Keywords: Quantum- dot cellular automata (QCA), Nanoelectronic circuits, Inverter.

1. INTRODUCTION

Quantum-dot Cellular Automata (QCA) has revolutionized nano-level computing technologies [1]. Logical states of zero or one can be represented by two stable configuration of a pair electrons, which can occupy four dots diagonally. Circuits those using such devices, does not require traditional interconnections and have extremely low power dissipation. The QCA cells, as well as circuits utilizing these cells, have been fully fabricated and tested by many researchers [2-4]. The basic Boolean primitive in QCA is the majority gate. Hence, construction of efficient QCA circuits using the majority gates has attracted many researchers [5-13]. Besides, another important component in constructing QCA circuits is inverter, because any QCA circuit can be efficiently built using only majority gates and inverters. Hence, efficient constructing inverter in QCA is of great interest.

In this paper, we present a new approach for decreasing the number of QCA cells in a QCA inverter gate. The presented method is based on physical relations. The reduction in cell counts of a QCA inverter results simple construction of QCA circuits and reduction the QCA circuit complexity.

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2. MATERIALS AND METHODS

2.1 Background

A QCA cell shown in Fig. 1 (a) where four quantum dots positioned at the corner of a square and two electrons that can move to any quantum dot within the cell through electron tunneling [14]. Due to Columbic interactions, only two configurations of the electron pair exist those are stable. Assigning a polarization P of -1 and +1 to distinguish between these two configurations leads to a binary logic system. Any QCA circuit can efficiently be built using the only majority gates and inverters. As shown in Fig. 1 (b), the majority function implemented using an ordinary QCA gate is as follows: Assume the inputs are A, B

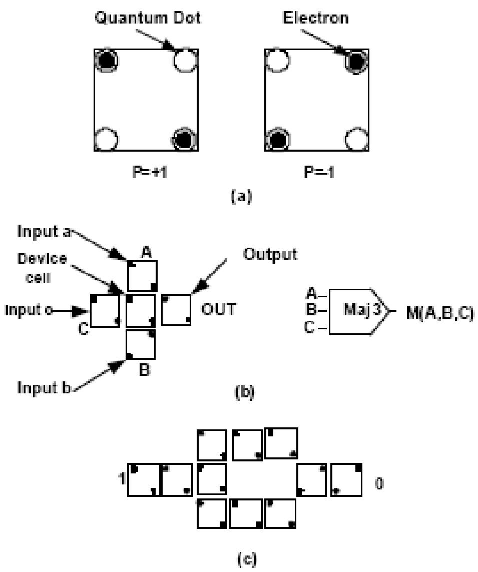


Fig. 1. (a) Basic QCA cell and binary encoding, (b) A QCA majority gate (c) A QCA inverter.

and C, then the logic function of a majority gate is,

M (A, B, C) =AB+BC+AC (1)

Each QCA majority gate as illustrated in Fig. 1 (b) requires only five QCA cells and also every QCA inverter gate can be implemented by 11 quantum cells (see Fig. 1 (c)). As it was mentioned before, the majority gate constitutes complete gate beside an inverter. Therefore by reducing the number of inverter cells, particularly in complicated QCA circuits, the size of circuit decreases drastically, so we need less hardware, which in addition to economization of costs, leads to less complexity.

For basic calculation, we assume a simple model of standard inverter (see Fig. 2) and then generalize it. For this purpose, at first we calculate the forces bring by all the electrons available in cell (2). As already mentioned, the electrons of cell (2) can be only located at diameter position [13]. Consequently we calculate the resultant of the forces and moment of forces in two situations of (1) and (2) which have been shown in Fig. 2. In all figures, a rectangle shows a QCA cell and the circles inside indicate the corresponding electrons inside that cell. The circles contain numbers that show the electron number and are used for calculating the force on the electrons of

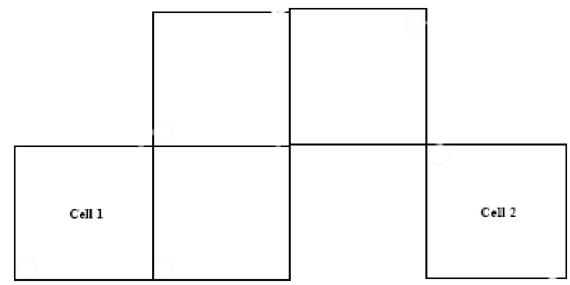


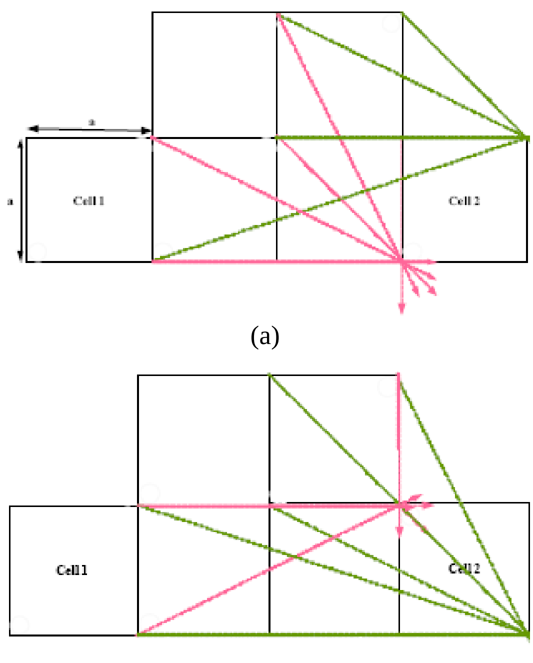
Fig. 2. Simple model of a QCA inverter.

cell 2. Arrays also show the forces on the electrons of cell 2. For all calculations, the following postulates are assumed:

- The forces bring from cell (1) are deniable against other forces.
- The force which is bringing by the electrons of cell (2) can be deniable.
- Electrons are set at the corner points of quadrangular.
- All the cells are similar with the length of a (a = 18 nm) which are set close to each other without any space.

It is worth mentioning that the angle between vectors has been calculated by Pythagoras' theorem in right angle trapezoids. The force that two electric charges put on each other is calculated from Eq. (2) where F is force, k is fixed colon, q_1 is the first electric charge, q_2 is the 2nd electric charge and r is the distance of two electric charges from each other. By putting the amounts of k, q and a, we obtain Eq. (3) where F_T is the resultant of forces that are calculated from Eq. (4) in which in addition to forces; we need the angle between two vectors. Moment of forces is obtained from Eq. (5). In this way, the relationship is between F (force), R (moment arm) and j (the angle between force vector and moment arm). Moment of forces can be internal or external according to right hand law. In this paper for simplicity purpose, we have considered the internal moment negative and the external moment positive [15].

$$F = \frac{kq_1q_2}{r^2} \quad (2)$$



(a)

(b)

Fig. 3 (a): Forces on the electrons of cell 2 in state1, (b) Forces on the electrons of cell 2 in state2.

$$\frac{kq^2}{r^2} = A = cte \qquad (3)$$

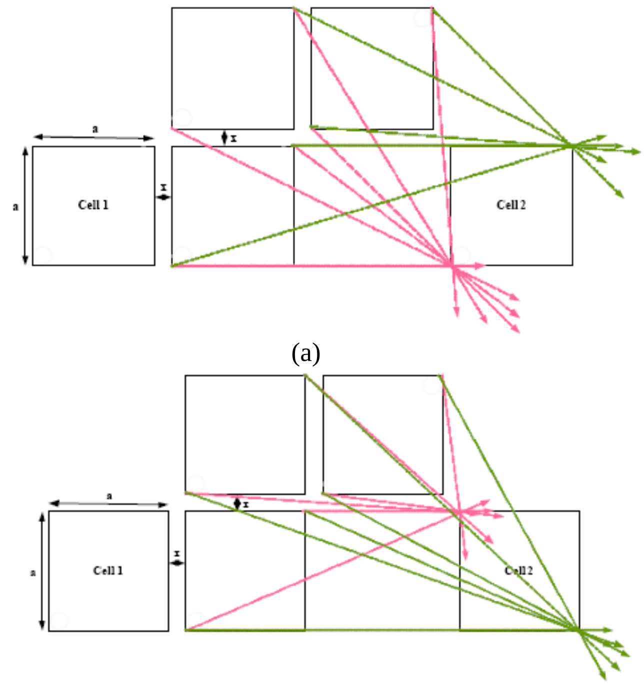
$$F_T = \sqrt{F_1^2 + F_2^2 + 2F_1F_2} \qquad (4)$$

$$\tau = 12.73 \quad (nm) \qquad (5)$$

In all figures, F_i is the force entered by electron i to the favorite electron in cell 2 and r_i is the distance of these two electrons which is calculated according to Eq. (2). $F_{i'}$ is the total of F_i and F_j forces. F_τ is the total resultant of forces entered to the considered electron in cell 2.

2.2 Method of Proving

At first, the force entering by all electrons on e_1 and e_2 in cell 2 are obtained from Eq. (2). Then the resultant of force/s are calculated two by two from Eq. (4) and finally the total resultant of forces and its angel is obtained with positive direction of x axis. After that, the moment of forces is obtained according to right hand law (based on



(a)

(b)

Fig. 4. (a): Forces on the electrons of cell 2 in state1, (b) Forces on the electrons of cell 2 in state2.

Eq. 5). Comparison between the moment of forces in state 1 and state 2 in every figures show the state electrons where they are more stable (see Fig. 3).

The following parameters are used for Fig. 3(a):

$F_T = 3.55A = 25.24 * 10^{-13} \quad (N)$

$\tau_1 = -295.6 * 10^{-13}$

For Fig. 3 (b):

$F_T = 0.85A = 6.04 * 10^{-13} \quad (N)$

$\tau_2 = 3.07 * 10^{-13}$

$\tau_t = -292.53 * 10^{-13}$

Based on the above mentioned calculations, since the moment of forces is great in state 2; the electrons set in state 1 are more stable. This state acts as a wire and is not favorable for us. In order to make an inverter logic gate, we modify Fig. 3 as follows by using the above structure (see Fig. 4). As it is seen in Fig. 4, the cells have space *x* (*x= 2 nm*) with each other.

The following parameters are used for Fig. 4 (a):

$\tau_1 = -13.49 * 10^{-13}$

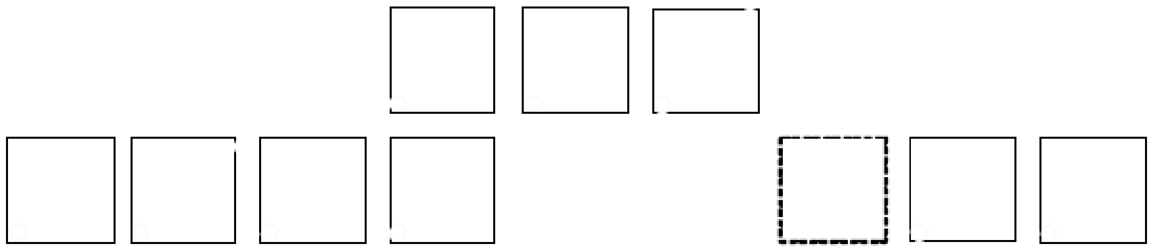


Fig. 5. A QCA inverter.

$\tau_2 = 10.31*10^{-13}$

$\tau_t = -3.18*10^{-13}$

The following parameters are used for Fig. 4(b):

$\tau_1 = 70.39*10^{-13}$

$\tau_2 = -10^{-14}$

$\tau_t = 70.39*10^{-13}$

All the functions, which have been performed till now, can be generalized for the standard inverter and finally the number of standard inverter cells which is 13 or less decreases to 9 or less cells (Fig. 5). So, we can decrease the number of cells of all QCA circuits, because as already mentioned, the inverter and majority function form a complete gate together.

In this paper, we tried to use some formulae and physical proofs to remarkably reduce the number of standard QCA inverter cells. Regarding the fact that majority gate forms a complete gate beside the inverter, therefore by reducing the number of inverter cells we can improve making QCA logical gates and minimize the size of these gates in attempting to reduce the complexity of circuits. This is of particular importance in big and sophisticated circuits.

3. CONCLUSION

Every QCA circuit can be built only using majority and inverter gates. Hence, constructing each of these gates in a more efficient form can be valuable. This study proposes a novel method for decreasing the number of Quantum Dot Cell in QCA circuits based on a new technique for reducing the number of QCA cells in an inverter gate. The proposed method is based on physical relations. Through physical and mathematical calculation, the proposed method is completely correct. This method can be useful in decreasing the complexity of QCA design as it works toward removing some cells in a QCA inverter gate, without any effect on the inverter functionality.

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