Wire-Crossing Technique on Quantum-Dot Cellular Automata

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Abstract. A wire-crossing is very important technique in quantum-dot cellular automata (QCA) design. The typical wire-crossing techniques have many problems such as additional tasks and noise. In this paper, we use the characteristic of a QCA clock cycle which composed of four different clock phase such as locking, locked, relaxing and relaxed in order to achieve an efficient wire-crossing. We control the clock phase between two wires so that they do not have any interference to each other. As a result of it, we can design and construct a slim, regular and noiseless architecture.

Keywords: Wire-crossing; Quantum-Dot cellular Automata (QCA); Clock Phase; QCA Designer

1 Introduction

A quantum-dot cellular automata (QCA) is the computing with cellular automata composed of arrays of quantum devices. A QCA cell is a nano-scale device capable of encoding information by two-electron configuration. The basic QCA concept was introduced by Tougaw and Lent in 1993[1, 2].

Wire-crossing is very important in QCA-based design, and many techniques have been proposed in order to design an efficient wire-crossing, such as coplanar-based [2-5] and the multilayer-based [6-8] techniques, recently. In the meantime, the wire-crossing techniques using the control of clock phase have been also proposed in [3,9,10]. In order to design the wire-crossing using the mentioned techniques, additional tasks should be demanded, such as translation or rotation of QCA cells, control of clock phase, addition of layer and so on. Therefore their techniques demand additional time or area complexity.

A QCA cell typically consists of four quantum dots placed at the four corners of a square as shown in Fig. 1(a). QCA devices are designed by carefully selecting the placement of QCA cells and the timing with which their tunneling barriers are raised and lowered. The tunneling barriers are typically modulated through four separate phases: locking, locked, relaxing, and relaxed as shown in Fig.1(b). The tunneling
barriers are raised in locking state while tunneling is restricted by high barriers, limiting electron movement in locked state. However, tunneling barriers are lowered in relaxing state while tunneling barriers are held very low, allowing nearly free electron movement within a cell in relaxed state [10].

In this paper, a wire-crossing technique using the difference of clock phase is proposed. For the efficient data transmission, we control the clock phase on the intersection cell between two wires.

![QCA basic concepts and structures: (a) standard and 45 degree rotated QCA cells, (b) four distinct QCA clock phases (locking, locked, relaxing and relaxed)](image)

Fig. 1. QCA basic concepts and structures: (a) standard and 45 degree rotated QCA cells, (b) four distinct QCA clock phases (locking, locked, relaxing and relaxed)

2 The Previous Wire-Crossing

There exist two representative wire-crossing techniques: a coplanar-based and a multilayer-based. A coplanar-based wire-crossing technique was proposed by Touegaw and Lent [4]. Fig. 2(a) shows a simple geometry of the coplanar-based wire-crossing technique. In this example, the vertical (i.e., A) and horizontal (i.e., B) wires are transmitting the value ‘1’ and ‘0’, respectively.

To implement this wire-crossing, the cells of horizontal wire are rotated by 45 degree. If the length of the vertical wire after an intersection cell is sufficient (that is, the length of the wire is more than or equal to 3), a transmitting value does not affect from the other wire. Also, the horizontal wire should be composed of odd number cells because the property of the rotated cells has an inverter chain that the polarization alternates direction between each adjacent cells.

45 degree rotated cells induce the additional space between cells. It significantly decreases the energy separation between the ground state and the first excited state, which degrades the performance of such a device in terms of maximum operating temperature, resistance to entropy, and minimum switching time [10].

In the meantime, the multilayer-based wire-crossing technique uses a crossover bridge method. This technique is similar to coplanar-based technique in the perspective of the floor plan because it looks like appearance of two wires crossing. In fact, it consists of the stereoscopic structure as shown in Fig. 2(b).

Fig. 2(b) shows a simple geometry of the multilayer-based wire crossing technique. In this example, the wire B is using a crossover bridge. The structure of this technique can be more miniaturized and generalized than coplanar-based technique because it
does not need to rotate cells. Although this technique has some advantages, the noise problem between intersection cells in crossover area is existed [6]. There are also several things to consider for design and simulation processes in QCA Designer such as the number of layers, crossover and vertical cells [5].

![Typical QCA wire-crossing techniques](image1)

**Fig. 2** Typical QCA wire-crossing techniques: (a) Geometry example of coplanar-based QCA wire-crossing and (b) Geometry example of multilayer-based QCA wire-crossing.

![Data transmission](image2)

**Fig. 3** Data transmission (a) The principle of data propagation between two clock regions. (b) The relationships according to the 180 degree different clock regions (the clock region 3 is “relaxed” phase, while the clock region 1 is “locked” phase).

### 3 The Proposed Wire-Crossing

The typical wire-crossing techniques have some problems as mentioned in the previous Section 2. The common problems of those techniques are the occurrence of noise and the additional tasks of the QCA cell array.

In order to design the wire-crossing using the difference of QCA clock phase, we consider the concept of QCA clock phase. For two adjacent clock regions in the current clock phase, the data can be received or transmitted as shown in Fig. 3(a). For
example, the data of present clock region is received by the previous clock region, if the previous and present clock regions are locked and locking phases, respectively.

But, the data transmission for two non-adjacent clock regions does not work. Each non-adjacent clock region (or clock phase) does not affect the opposite clock region. The proposed wire-crossing is based on the difference of 180 degree between two non-adjacent clock regions. Moreover, the additional tasks which are the rotation, translation of QCA cells, and the consideration of the number of sub-layers are not necessary.

The geometry of the proposed QCA wire-crossing using the difference of clock phase is shown in Fig. 4. A and B wires are transmitting a specific value, respectively without any interference. Each wire-crossing has 180 degree different clock phase such as a clock 0 and 2 pair or a clock 1 and 3 pair. As shown in Fig. 4, the intersection cell can be belong to any one of two wires (vertical or horizontal line), and there is no interference each other.

4 Design and Simulation

In this section, we have designed and simulated a XOR logic gate based on the proposed wire-crossing using QCA Designer [5].

The simple XOR gate has been designed using the proposed wire-crossing technique without any additional tasks and a burdensome noise as shown in Fig.5(a). This simulation result in Fig.5(b) shows that the proposed wire-crossing does not affect surrounding QCA cells, and we obtained the accurate output values with high polarization.

Fig. 4 Geometry examples of the proposed QCA wire-crossing using the difference of clock phase: (a) an example of the wire-crossing using clock 0 and 2, (b) an example of the wire-crossing using clock 1 and 3.
5 Conclusions

In this paper, we proposed a wire-crossing technique using the difference of clock phase. We have shown that a XOR gate is simply designed and simulated by controlling the clock phase without any other additional tasks and considerations. Thus we expect that our technique can reduce not only the execution time but the number of cells and noise occurrence.

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