A QUANTUM-DOT CELLULAR AUTOMATA SHIFT REGISTER

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Quantum-dot Cellular Automata (QCA) is a computational paradigm [1] where the position of single electrons within cells, composed of coupled quantum dots, is used to encode and process binary information. In the past few years the basic QCA devices were experimentally tested and good agreement with theoretical predictions was demonstrated [2]. In the early asynchronous devices, pipelining was not possible due to lack of control over electron switching and power gain was not possible since the only source of energy was the input signal. To overcome these obstacles clocked control over the QCA circuitry was proposed [3,4]. In clocked QCAs, energy is supplied to the cells by the clock lines, rather than by inputs alone. As a result, in contrast to the edge driven cellular architectures, power gain, reduced power dissipation and pipelining can be achieved in clocked QCA systems. Recently, a functional clocked cell [5] and a QCA latch [6] were fabricated and tested.

Here we present a more advanced device in the family of clocked QCA systems - a two cell shift register. The device consists of two capacitively coupled QCA latches L_1 and L_2 (Fig. 1). The QCA latch [6] consists of three micron-sized aluminum islands, or dots (D_1-D_3 for L_1, and D_4-D_6 for L_2), separated by tunnel junctions. Both L_1 and L_2 are leadless, i.e. they are not connected to any external charge reservoirs. Multiple tunnel junctions are used between dots to increase the charge retention time of the latches. Two single-electron electrometers measure the state of the shift register (E_1 reads the state of L_1, and E_2 reads the state of L_2). The layout of the device is shown in Fig. 2.

Figure 3 demonstrates the operation of the device. To operate the shift register, a differential input signal V_{IN} is applied to the inputs V_{IN}^+ and V_{IN}^- at t_1 (Fig. 3 A). L_1 and L_2 remain in the neutral state until the first clock is applied (t_2 in Fig. 3 B). When the clock CLK_1 is applied to L_1 (t_2 in Fig. 3 C), an electron is switched and locked in the direction defined by the input signal. Once L_1 is set (i.e. an electron is locked on one of the end dots), input signal is removed (t_3 in Fig. 3 A) and the state of L_1 does not change. When the second clock CLK_2 is applied to L_2 (t_4 in Fig. 3 D), it switches in the direction defined by the state of the first latch (t_4 in Fig.3 E). The state of L_2 remains unchanged when CLK_1 is removed and L_1 turns off (t_5 in Fig. 3 B & C), as long as CLK_2 is applied (t_6 in Fig. 3 E). As can be seen in Fig. 3 for the input signal of reversed polarity, the switching direction is reversed. An interesting feature of this design is that the propagation of the information can be reversed by changing clocking sequence and input gates, so the QCA shift register is a logically reversible device [7].

The current prototype operates at a temperature of 70 mK. However, future generations of the QCA devices based on new technologies are expected to work at liquid nitrogen (metal nanocluster QCA) and room temperatures (molecular QCA).

[1] C.S. Lent, P.D. Tougaw, W. Porod, and G.H. Bernstein, Nanotechnology 4, p. 49, 1993.

[2] A .O. Orlov, I.Amlani, G.H.Bernstein, C.S.Lent, and G.L.Snider, Science, **277**, 928 (1997); I. Amlani, A.O. Orlov, G.Toth, C. S. Lent, G. H. Bernstein, and G. L. Snider, Science (284), 289 (1999)

[3] C. S. Lent and P. D. Tougaw, Proceedings of the IEEE. 85, 541 (1997).

[4] G. Toth, C. S. Lent, J.Appl.Phys. 85, 2977 (1999).

[5] A.O. Orlov, I.Amlani, R. K. Kummamuru, R. Ramasubramaniam, G. Toth, C. S. Lent, G. H. Bernstein, and G. L. Snider, Appl. Phys. Lett, 77(2), pp. 295-297 (2000).

[6] A.O. Orlov, R. K. Kummamuru, R. Ramasubramaniam, G. Toth, C. S. Lent, G. H. Bernstein, and G. L. Snider, Appl. Phys. Lett, 78(11),pp. 1625-1627 (2001).

[7] A. N. Korotkov, K. K. Likharev, J.Appl.Phys. 84, 6114 (1998).

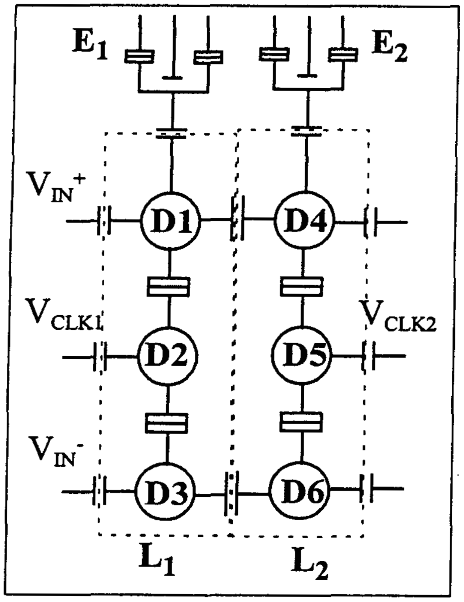

Figure 1. Schematic Diagram of a QCA shift register.

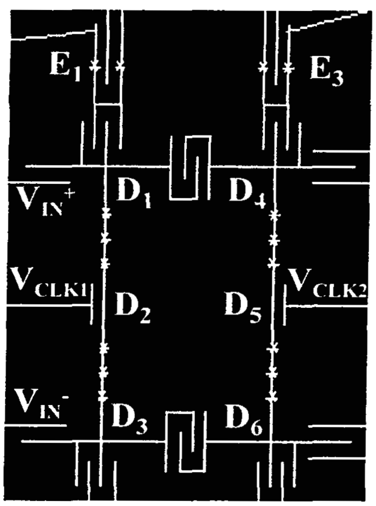

Figure 2. Layout of the device. Lines represent aluminum islands and leads and '*'s represent tunnel junctions.

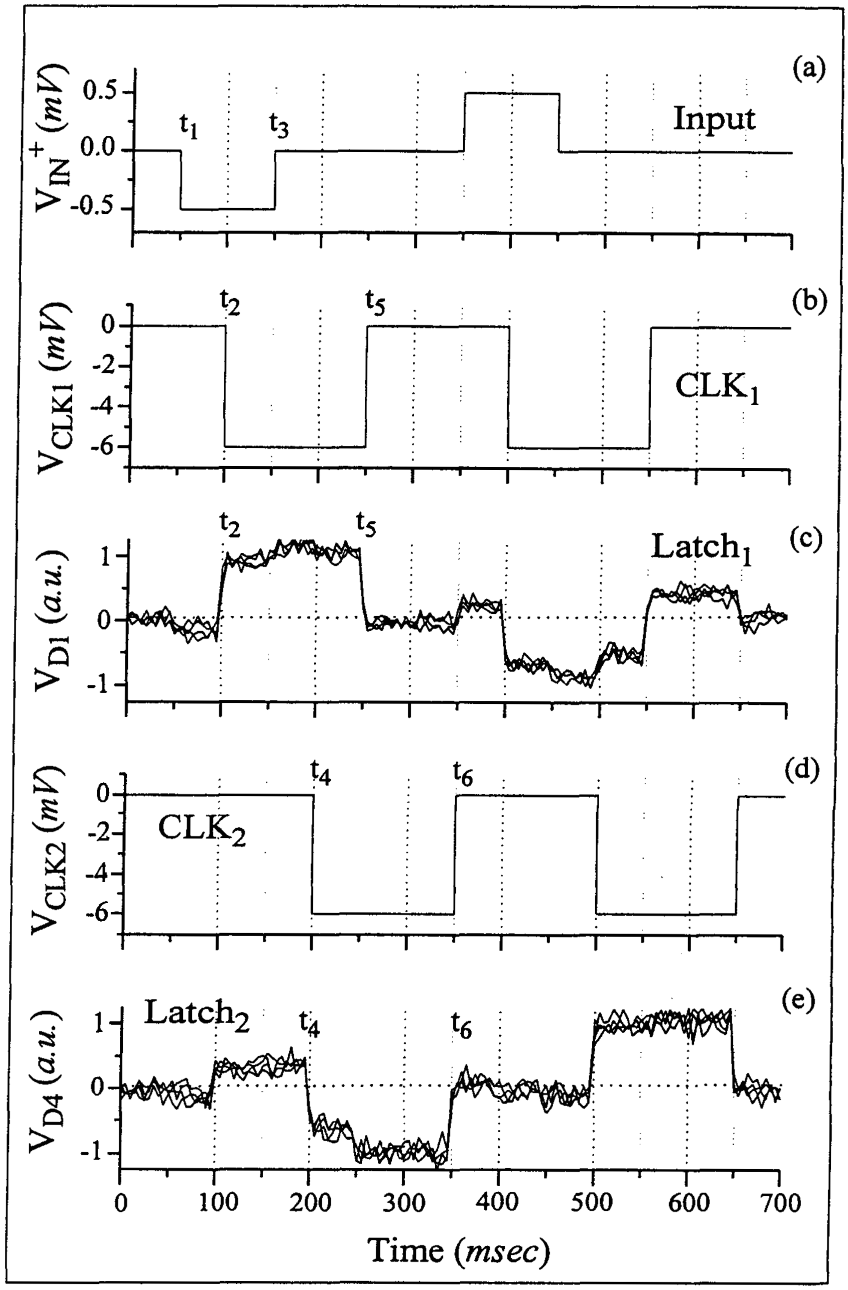

Figure 3. Operation of a shift register (a) Differential input signal ($V_{IN}^{+} = -V_{IN}^{-}$) (b) Clock signal applied to latch L_1 (c) Potential on dot D_1 in arbitrary units (d) Clock signal applied to latch L_2 (e) Potential on dot D_4 in arbitrary units