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Moletronics

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Abstract— Moletronics or more precisely molecular electronics is the application of molecular building blocks for IC fabrication of electronic components. The main idea here is size reduction of the conventional silicon fabrications. This can well be sought as a potential to extend Moore's Law beyond the limits of ULSI semiconductor circuits. Though it spans over the disciplines of physics, chemistry and material science, the unifying feature is the molecular building blocks. Moletronics would not just help in size reduction of silicon chips but would also significantly increase processing speeds by almost 10 – 50 times than the conventional ULSI chips. Having known these advantages, this technology can be further extended in the field of "nano-robotics" wherein the main aspect is minimum size.

Index Terms— moletronics, vlsi, ulsi, molecular building blocks, fabrication, electronics

1 Introduction To Moletronics

The fabrications of semiconductor devices have so far been guided by the Moore's Law. From around 100 transistors on a single silicon chip to the very recent ULSI technique which allows over 91,000 transistors, semiconductor fabrication has come a long way. But the big question was "What after ULSI? Will Moore's Law cease?" The definite answer to this is Moletronics. "Moore's Law" is an observational theory which states that the number of transistors in any dense integrated circuit has approximately doubled over two years. For over four decades, this Law has proved to be accurate and also has been used by semiconductor industries as a planning and guiding tool.

2 Background of Moletronics

In 1940, Robert Muliken and Albert Szent-Gyorgy postulated the concept of charge transfer theory using molecules. In 1956, Arthur Von gave the idea about Molecular Engineering. Thus, the roots of moletronics can be traced back to the 1950s. Further, in 1974 Mark Ratner and Avi Aviram illustrated a theoretical molecular rectifier in their paper. Also, in the 1970s, the US Government's Defence Advanced Research Projects Agency (DARPA) organized a Moletronics Research Program, which had collaborations of Hewlett-Packard scientists and UCLA researchers. In 1988 Avi Aviram proposed about a single molecule field effect transistor. In the same year Forrest Carter described further the concept about a single molecule logic gate. C. Joachim and J.K Gimzewsky experimented the conductance of single molecule in IBM. In 1990 Mark Reed et al added few hundred molecules. In 2000 Shirakawa, Heeger and MacDiarmid won the Nobel Prize in physics for the development of highly conductive poly- acetylene. These discoveries have been the stepping stone for the development of moletronics. The conductive polymers can be used as "molecular wires". This will altogether alter the fabrication industry because a conventional silicon chip houses over 10-50 million switches over an as large as a postage stamp. Moletronics aims at redefining this powerful integration technology to density of over one million times than today's state-of-the-art IC fabrication.

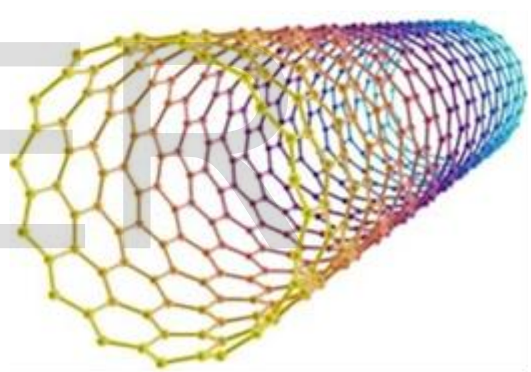

Fig 1.1 Carbon Nanotube

3 Moletronics (The Future Electronics)

A transistor is used as a switch in any IC fabricated silicon chip. This switch is at the heart of the silicon chip and thus determines the speed of the chip and eventually the computer/processor. It goes by the principle, "Smaller the switch, faster the process". Thus, all the fabrication techniques till today have the prime purpose to accommodate as many switches and also reduce their size. This simultaneously increased their speeds too. In moletronics, the above described transistor switches are made from molecules. This has a great advantage, as using an organic molecule reduces the size of the conventional switch to one-millionth size of a grain of sand and is 10 times faster than the traditional silicon-based switch. The organic molecule used was actually a thiol molecule, which is mixture of sulphur, carbon, and hydrogen. Several such thiol molecules were sandwiched between two gold plates to act as switches. These novel channels acted either insulators or conductors, as per the electric flow

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through them were generated. Further investigation in this field showed bafflingly results as the molecules could even amplify signals just like their conventional counterparts. This has further pushed the application of moletronics as logic gates. Conducting polymers such as polyacetylene, polypyrrole, and polyaniline have a linear-backbone and are the main classes of conducting polymers. These form the molecular building blocks in the field of moletronics. Poly (3-alkylthiophenes) is the archetypical materials for transistors. Along with these, the naturally available graphite too forms the raw material for moletronics. The Buckminster Fullerene or C-60 nanotubes are the final produce of graphite as an application in moletronics. While most of the conductive polymers have longed to find any large scale application, the nanostructured forms of these have provided a fresh look out to them.

4 THE WORKING PRINCIPLE

The basic working principle of moletronics is the same as the conventional silicon fabricated chips. The main difference is in the workability of the two. While the conventional silicon chips have shown tremendous advancement throughout their development from the SSI to the latest ULSI, moletronics seems to the best bet when it comes to performance. Thus, moletronics uses molecular blocks as a substitute to the traditional silicon. Everything else remains more and the same in the integrated circuits. Also, to use them as a switch only one electron is sufficient to either turn ON or OFF these molecular transistors.

5 COMPONENTS

The main electronic component here is the molecular wire. This different concept than the use of conductive polymers. Molecular wires can be infused as conductive polymers, thereby enhancing their various mechano-electric properties. Molecular wires have a repeating structure which can be either organic or inorganic in nature. Their structure can be familiarized well with the study of the Human DNA. These can conduct electricity. These typically have non-linear current-voltage characteristics and do not behave like ohmic conductors. Their conductance follows the typical power law as a function of temperature or electric field, whichever is the greater, arising from their strong one-dimensional character. These are also called as “nanowires” which should be able to self-assemble to be used in moletronics. They should have the ability to connect to diverse metal surfaces such as gold which is extensively used in semiconductor fabrication industries to form the connection with the outside world. In addition to this, the connectors should have the recognitive ability. The next important component involves the concept of molecular logic gates. To start off with, molecular logic gate is a molecule that is capable of doing the logical operations as its bulk electronic counterpart. Its operations are based on one or more physical or chemical inputs and a single output. These molecular logic devices are also termed as “moleculators”. These have advanced so far that now these are capable of computing combinational and sequential logical operations. One breakthrough in this technology is the use of these components as memory storage devices. Molecular logic gates work with input signals based on chemical processes and with output signals based on spectroscopy. Compound A is a push-pull olefin with the top receptor containing four carboxylic acid anion groups (and non-disclosed counter cations) capable of binding to calcium. The bottom part is a quinolone molecule which is a receptor for hydrogen ions. The logic gate operates as follows. Without any chemical input of Ca2+ or H+, the chromophore shows a maximum absorbance in UV/VIS spectroscopy at 390 nm. When calcium is introduced a blue shift takes place and the absorbance at 390 nm decreases. Likewise addition of protons causes a red shift and when both cations are in the water the net result is absorption at the original 390 nm. This system represents a XNOR logic gate in absorption and a XOR logic gate in transmittance.

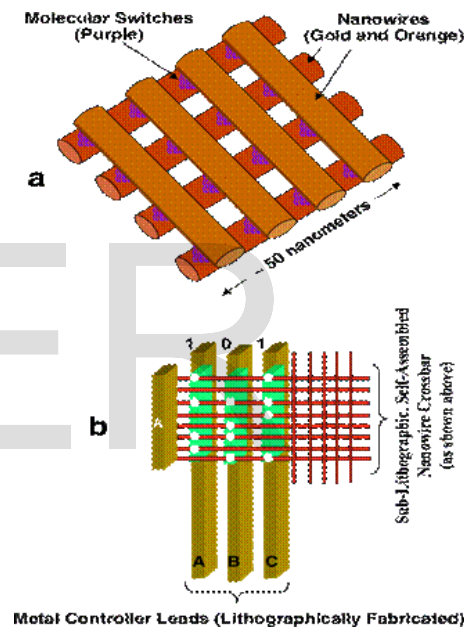

Fig 3.1 Molecular-scale crossbar circuit architecture [1]

In compound B the bottom section now contains a tertiary amino group also capable of binding to protons. In this system fluorescence only takes place when both cations available. The presence of both cations hinders photo induced electron transfer (PET) allowing compound B to fluoresce. In the absence of both or either ion, fluorescence is quenched by PET, which involves an electron transfer from either the nitrogen atom or the oxygen atoms, or both to the anthracenyl group. When both receptors are bound to calcium ions and protons respectively, both PET channels are shut off. The overall result of Compound B is AND logic, since an output of “1” (fluorescence) occurs only when both Ca2+ and H+ are present in solution, that is, have values as “1”. With both systems run in parallel and with monitoring of transmittance for system A and fluorescence for system B the result is a half-adder capable of reproducing the equation 1+1=2.

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A full adder system based on fluorescein is able to compute 1+1+1=3.

6 Molecular Sequential Logic

Molecular sequential logic is exemplified by D. Margulies et al., were they demonstrate a molecular keypad lock resembling the processing capabilities of an electronic security device which is equivalent to incorporates several interconnected AND logic gates in parallel. The molecule mimics an electronic keypad of an automated teller machine (ATM). The output signals are dependent not only on the combination of inputs but also on the correct order of inputs: in other words the correct password must be entered. The molecule was designed using pyrene and fluorescein fluorophores connected by a siderophore, which binds to Fe (III), and the acidic of the solution changes the fluorescence properties of the fluorescein fluorophore.

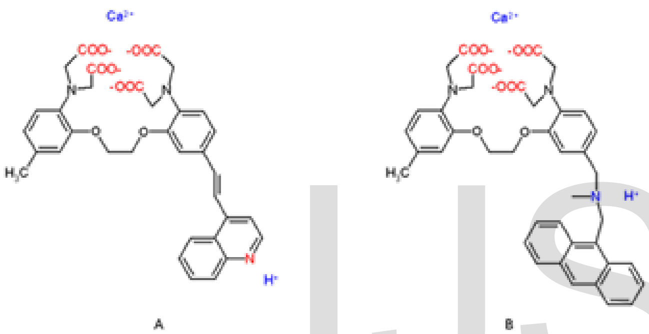

Fig 6.1 Molecular Logic Gates [2]

7 Advantages and Disadvantages

One can consider moletronics as the safest bet after ULSI in order to break the limits of Moore's Law. This is also true in most of the cases. As seen till now moletronics will surely redefine the future scope of not only the semiconductor fabrication industry but also the field of electronics. All this can be foretold from the numerous benefits that moletronics has to offer. The primary advantage is the size reduction of the electronic chips. So far ULSI is the only technology that has the least size. Moletronics will help in reducing this size to the size of a grain of sand. Also, molecules can be stacked three dimensionally, thus, increasing the overall efficiency of the transistor and in turn the whole system. Another important aspect of moletronics is its cost efficiency. Moletronics uses single spin coating or self-assembly of the molecules in the designing techniques. Low temperature manufacturing is also another feather in the cap of moletronics. The molecules do not require high temperature for their assembly. Stereo chemical properties also add to the unique electronic properties of the molecules. This is also important in providing a synthetic flexibility to the molecules in terms of their physical, chemical and optical properties. Although moletronics may seem as the best technology after the ULSI but it has some strong roadblocks that have to be dodged before actually using it in the practical applications. The major disadvantage is that the molecules cannot be directly connected to the electrodes. The molecules have to be integrated with silicon; this can seriously affect the efficiency of the chip. It is not possible to determine the resistivity or conductivity of a single molecule. It is impossible to directly characterize a single molecule. Another roadblock faced by moletronics is the interconnection at the molecular scale. Research is still going on to find out the best possible method to carry out the interconnection. The important aspect in moletronics has to be the measurement of the molecule. And again this is another hurdle that is difficult to cross. Some of these measurement techniques require very low temperatures for their operation and this is energy-consuming. Fabrication has to be controlled with specified tolerance. Experimentally these devices cannot be verified. Their error determination is almost impossible since they are integrated at a very small scale.

CONCLUSION

Moletronics is nowadays seen as the next step in the world of microelectronics. It can assuredly change the way chip-fabrication works in this present era. With a vision to go beyond the scope of Moore's law, moletronics has paved a way for the future of the microelectronics industry. But there are still some issues that need to be taken into consideration so as to practically implement this technology. Mass production of moletronic chips is only possible after we have sorted these issues. It has tremendous potential to rightly achieve another milestone in the fabrication industry. Use of organic polymers also ensures lesser generation of carbon emissions. With this technology, Nano-robotics & DNA Computing can be easily materialized. With this view, we can conclude that moletronics is a safe and efficient future technology in chip-fabrication after ULSI.

FUTURE SCOPE

Moletronics has a very great scope in the field of semiconductor fabrication as well as Nano electronics. Its applications span over the various disciplines like physics, chemistry and bio medicals to name a few. Scientists are particularly interested in the application of moletronics in Nano robotics. Nano robotics may necessarily use moletronics to use "molecular processors" as the central processing unit (CPU). Nano robotics is seen as the next big thing in the field of bio medical. Along with their obvious application in the fabrication industry, they have numerous baffling applications. All this thanks to their miniaturization plus points.

What's more astonishing is that researchers around the world are trying moletronics in the field of quantum computing. All this sums up a great logic; the Human DNA can store great amounts of information or "data" in a sufficiently small area. Moletronics too offers the same application. Hence, the future computers could have the "Double Helix" as the main computing unit. Quantum computing is gathering as much importance as any other new technology. One can definitely think of Quantum computing as the future of computing.
Another important research that scientists world-wide are carrying out is the interfacing of VLSI and moletronics on a single chip. This can surely sort out some of the disadvantages of moletronics. If done practically, the interfacing would also mean that the recent technologies like VLSI and ULSI would gain "immortality". Thus we can safely say that moletronics is truly the "Future Electronics".

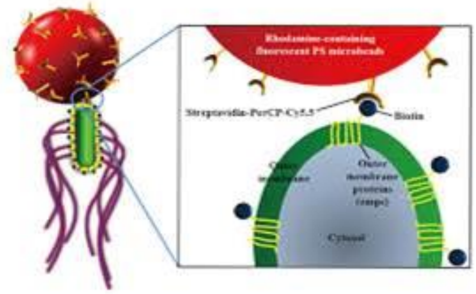

Fig. 9.1 Nano Robotics

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