**A REVIEW ON NANOCOMPUTING FOR POTENTIAL FUTURE SOLUTION**

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**I Introduction**

 Nowadays developing molecular-scale or nanoscale electrical gadgets for computing has become an assortment of challenges. How might they "look"? What operational guidelines would they follow? How can different gadgets be linked together? How will these computers be built after they have been designed? What are the outcomes from these gadgets? The present article answers some fundamental queries by reviewing the available literature on current investigations on the architecture of molecularly integrated electrical computers. The author endeavoured to convey a picture of the field's perspective developments considering present-day events. The concept and the responses to the preceding issues are offered in nonmathematical words for technically interested readers. This review article, nevertheless, relies on various previous, highly complex, and professional descriptions [1--5].

 Molecular-scale electrical gadgets are expected to have a side length of fewer about 100 nanometers. One nanometer (one billionth of a meter) is a linear distance equivalent to 10 atomic diameters. In contrast, the tiniest components on the present-day cutting-edge computer chips possess a length size of roughly 350 nanometers (0.35 microns) [6.7]. If a transistor could be manufactured with a minimum feature size of 1 nanometer (the dimension of the smallest feature on a device), nearly 10,000 of such "nanodevices" would fit into the same area as a modern transistor. In a nutshell, an electronic computer consisting of nanometer-scale components--referred to as a "nanocomputer"--could be several orders of magnitude faster than modern microcomputers.The arrangement and processing of data by computers that are far more compact are referred to as nanocomputing. Nanocomputers might benefit from conventional computers due to fast speed and low power consumption [8.9].Such characteristics could render nanocomputers both technically and economically appealing for a new set of uses [10]. This possibility has provided a tremendous incentive for investigation and advancement, resulting in substantial new developments at a faster pace.

 Such advancements are the outcome of the integration of technological progress in several sectors. Electronic nanodevices are achievable, according to mathematical and computer modelling [8]. These innovative technologies have been the topic of considerable discussion and inquiry in recent years. The latest developments in physics, material science, molecular biology, and electronics have generated tools and technologies with enough sensitiveness that prototype’s nanodevice fabrication. [10-14]. One way to make sense of the cutting-edge innovations emerging from the academic world is to understand the current developments in various fields are delineated in this chapter.

**II Nanoscale Quantum computing**

Quantum computing depends on quantum physics, which interacts with the physical world, which is uncertain and unpredictable. Quantum computing has the ability to tackle issues that traditional computer cannot. They employ unique quantum bits, often known as 'Qubits,' to store and manipulate information, in contrast to most classical computers, that are based on conventional computing which utilize binary bits 0 and 1 independently. 'Quantum Computers' are computers that use this sort of computation. It employs subatomic particles like as atoms, electrons, photons, and ions as bits, together with spin and state information. They may be superimposed to provide additional combinations. As a result, they may execute in parallel and use memory more effectively, making them more powerful.

In accordance with its quantum nature, the qubit's state transforms all at once when measured. It implies that someone never replicate information from qubits like is possible in modern computers since the copy and the original will be identical. This is known as "no cloning principle" [15]. Their control methods function as a computer's CPU as a computer's memory. It might be either 0 or 1, or both at the same time. They have both digital and analog natures, which gives the quantum computer its processing capacity. The qubit can be in either state (0 or 1) or in the superposed state of both states at the same time. These quantum states have a formulation known as Dirac notation.The states |0⟩ and |1⟩are two potential states for a qubit. The Dirac notation uses symbols such as | and ⟩. The distinction amongst bits and qubits is that a qubit can exist in states other than |0⟩ and |1⟩.

Quantum computation and quantum information offer a beneficial series of obstacles of varying complexity for people creating approaches to better manipulate single quantum systems, as well as promote the creation of new experimental approaches and provide guidance. The capacity to regulate single quantum systems, on the other hand, is required if we hope to exploit the potential of quantum mechanics for uses involving quantum computation and quantum information. Considering widespread interest, efforts to develop quantum information processing devices have had only little success to yet. The state of the art in quantum computation is represented by small quantum computers capable of performing thousands of operations on a few quantum bits (or qubits). Nanoelectronics and quantum computers can work together to improve security via quantum cryptography. Research prototypes for quantum cryptography - a method of communicating in secret across large distances - have been proven, and the developments are reaching the point that they might be beneficial in certain real-world applications [16]. Quantum computers can create and change quantum states, which makes it possible to make cryptographic systems that are indestructible by conventional computers. This could have adverse impacts on the protection of data and contact in nanoelectronic systems. However, developing strategies for large-scale quantum information processing relics a substantial problem for future physicists and technologists.

The transferable nature of various resources in quantum physics is emphasized by quantum teleportation, which demonstrates that one shared EPR pair combined with two classical bits to exchange information is at least as valuable as one qubit of communication. Numerous ways for exchanging resources have been discovered as a result of quantum computing and quantum information, and several of those are based on quantum teleportation..

**III Nanocomputing quantum dots or spins**

 The nanocomputing is an area of developing and employing nanoscale devices and systems for computation and processing of information. The nanocomputing techniques induce the quantum effects phenomenon predominantly quantum dots and spins for information handling. These quantum dots are nanoscale semiconductor structures that reflect quantum mechanical anomalies. The semiconductors such as gallium arsenide or silicon significantly show these effects. The confinement of electrons within the quantum dot leads to distinct energy levels, analogous to the behavior of atoms. Quantum information may be encoded and processed by varying the charge and spin of electrons inside quantum dots [17].

Many researchers are indulged in exploring the quantum dots applications in quantum computing and quantum information processing. Now a day’s many techniques are evolved to alter the quantum dot's characteristics, such as tweaking its energy levels which enables to encode and manipulation of quantum state. These states can represent information in the form of qubits, the fundamental units of quantum information.

It is well-known that fundamental particles such as electrons exhibit the inherent spin angular momentum. The nanocomputing utilises these spin known as quantum bits or qubits, Information may be processed and stored by modifying and regulating the spin states of particles. The spin states can be manipulate and carry out necessary operations for quantum computing and information processing by using magnetic fields, electric fields, or laser pulses. Several quantum networks operate based on these spin and photon interfaces. These have the capacity to convert stationary quantum data, including the quantum state of an ion or a solid-state spin qubit, into long-range transportable light, or photons. However, a major challenge is to establish an interface that is efficient for simultaneously maintaining quantum information and converting it into light [18]. Opportunities for quantum computing and information processing lie in both quantum dots as well as spins. Spins make use of the intrinsic rotational momentum of particles, whereas quantum dots offer a platform for confining electrons and modifying their characteristics. Both the strategies are being thoroughly researched in the field of nanocomputing and hold promise for future technological advancements.

**IV Nanocomputing in Nanoscale Transistors**

Small particles of semiconductors known as quantum dots have quantum mechanical features. They may be employed in nanocomputing to build very small and effective machines. Single electron flow may be managed in quantum dot transistors resulting in very low power consumption and quick switching times. They are useful for industries demanding high-performance computation and low-power electronics because of these characteristics.

The fabrication of quantum dot transistors that function at the molecular level has been made possible via nanocomputing. In comparison to traditional transistors, particularly metal oxide semiconductor field effect transistors (MOSFET) with the incorporation of nanomaterials like carbon nanotubes or nanowires provides better performance, lower power consumption, and higher density. Figure 1 shows the fundamental physical picture of steady-state carrier transport in the nanoscale MOSFET. Additionally, nanoscale transistors integrate more components onto a single chip, increasing the processing capacity. These show unique features from ordinary transistors (MOSFET), where carriers are constrained in a direction normal to the channel and free to travel in two dimensions. Now a day it is feasible to create devices that limit carriers in two dimensions, allowing them to move only in one direction. This can be achieved by the nanowires (which use carbon nanotube and silicon) in the fabrication of field-effect transistors [19].



**Figure 1** Essential physical picture of steady-state carrier transport in the nanoscale MOSFET

The nanowire FETs uses nanowires as the channel for conduction of current. They have the potential applications, especially in nanoelectronics and nanocomputing as they provide special qualities and benefits over conventional planar MOSFETs. Inorganic semiconductors like silicon, germanium, or compound semiconductors like gallium arsenide are often used to create small structure nanowires. There size varies from a range tens to hundreds of nanometers in length, and diameters in nanometer scale. The Nanowire FETs also have a three-dimensional structure. The gate electrode encircles the nanowire, which acts as a conduit between the source and drain regions. Usage of nanowire in FETs provides reduction in transistor size. The nanoscale diameter of the nanowire explicates the greater electrostatic control of the channel leading to better gate control and less short-channel effects. These nanowires may provide greater sensitivity for sensing applications and enable more device integration on a chip because of their enormous surface area relative to volume. The tailoring properties of nanowire's diameter, doping level, and material composition customizes the characteristics of nanowire FETs [15.16]. This adaptability enhances the device's efficiency to be optimized for certain applications. The nanowire FETs may function in a variety of ways, such as field-effect transistors (FETs), in which the channel current is controlled by the gate voltage, or tunneling FETs (TFETs), in which current is conducted by a carrier tunneling across a barrier.

Multiple investigations demonstrate that due to the influence of carrier backscattering, the average carrier velocity at the source of nanowire MOSFETs is lower than the thermal injection velocity. For steady-state current, the backscattering that occurs within a critical distance, from the channel's entrance. The length of this critical region is roughly the distance over which the potential plummet by the average kinetic energy of the injected carriers. Backscattering within the critical region is related (through the mean-free-path) to the low-field, near-equilibrium mobility of inversion layer carriers. Deeper channel backscattering carriers are more likely to emerge from the drain and add to the DC drain current. (Scattering along the channel affects the device transit time, although the transit time in a nanoscale) Strong velocity overshoot arises and carrier transport is complicated deep in the channel. Velocity overshoot reduces the carrier density close to the drain, resulting in an indirect impact on the self-consistent electric field and the drain current. The smaller gadgets size will influence more indirect effect [20].



Figure 2: The geometry of a coaxial gate nanowire MOSFET

Nanowire MOSFETs have certain unique properties that set them apart from conventional MOSFETs with 2D channels. Illustration includes a drain conductance that is unaffected by the gate voltage and, in the quantum capacitance limit a transconductance that is identical to the drain conductance. The quantum capacitance owing to low state density and high-k gate dielectrics plays a significant factor in carbon nanotube FETs. Although there are still many unreciprocated concerns and problems, our comprehension of science and the technical aspects enhance the performance of nanowire FETs.

Nanowire FETs have explored itself in many applications including sensors, low-power electronics, high-performance logic circuits, as well as possible usage in quantum computing. In recent year’s investigation of new nanowire materials, enhancement in their functionality, and novel production methods to incorporate these nanowire FETs into useful systems and devices are explored. It is essential to analyze the how scattering phenomena in these devices. According to symmetry considerations, mean free pathways of several hundred nanometers are conceivable at low biases with reduced backscattering. However, at high biases, optical phonon emission reduces the current in a long nanotube to around 25 A [15]. On other hand, molecular transistors, also acts as switch and amplify electrical impulses at the molecular level. These nanowire CNTFETs also shows the possible application in digital circuits. Owing to direct bandgap, these carbon nanotubes can be used as electrically pumped optical emitters. The exceptional transport properties of CNTFETs act high-frequency transistors. It's also intriguing that single electron transistors are produced at normal temperature utilizing nanowires. These nanowires can also be used as sensitive sensors for bio-medical applications. It's difficult to tell where this will all go, but as we investigate these possibilities, we will undoubtedly learn more about the physics and electronics of microscopic electrical devices.

**V Nanowire Based Memory Devices**

Nanocomputing has also led to the development of nanoscale memory devices that can store and retrieve information at the atomic level. Nanoscale memory devices refer to a class of memory storage devices that operate at the nanoscale level, typically with feature sizes on the order of nanometers (10-9meters). Tiny nanowires are often fabricated from silicon or another semiconductor material. The fabrication of memory devices involves the tailoring the electrical properties of the nanowires.



**Figure 3** Application of nanowire based memory

These devices offer the potential for high-density data storage, fast access times, and low power consumption.

**A Phase Change Memory (PCM)**

Phase-change memories (PCM) utilize the materials that may switch between amorphous and crystalline forms in response to electrical pulses. Each of the phases stands for a value in the binary data system (0 or 1). PCM has quick read/write times, long battery life, and is non-volatile. PCM offers fast read/write speeds, high endurance, non-volatility having capacity to store and retrieve data. PCM relies on the ability of these materials to switch between amorphous (disordered) and crystalline (ordered) phases, which represent the binary states of 0 and 1 in digital data storage [19-21].

1. **Material Composition**: PCM typically employs chalcogenide-based alloys, such as Ge2Sb2Te5 (GST), which exhibit reversible phase change behavior. These materials can exist in amorphous and crystalline states with distinct electrical properties.
2. **Phase Change Process:** To store information in PCM, an electrical current or voltage is provided to a small section of the PCM cell called a "phase change element" or "memory cell." This triggers a phase change in the material between its amorphous and crystalline phases due to the increase in temperature. The data value is represented by whether the cell becomes amorphous or crystalline, depending on the timing of the heating and chilling operations (Figure 4).
3. **Read and Write Operations**: PCM allows for both read and write operations. During a read operation, a lower voltage is applied to the cell, and the resistance of the material is measured. The resistance value corresponds to the phase (amorphous or crystalline) and thus determines the stored data. During a write operation, a higher voltage is applied to induce the phase change, switching the cell between states.
4. **Non-volatility:** PCM is non-volatile, meaning it retains data even when power is removed. The stored data remains intact in the amorphous or crystalline phase until explicitly rewritten.



**Figure 4:** A typical PCM

PCM explores several advantages over other memory technologies:

1. Fast Read/Write Speeds: PCM has fast access times, allowing for quick data retrieval and storage operations.
2. High Endurance: PCM can withstand a large number of read and write cycles without degradation, making it suitable for applications that require frequent data updates.
3. High Density: PCM has the potential for high-density data storage, as its memory cells can be densely packed on a chip.
4. Low Power Consumption: PCM operates at low power levels, consuming less energy compared to some other memory technologies.

PCM has attracted significant attention in the field of memory research and development due to its unique characteristics. It holds promise for use in various applications, including mobile devices, embedded systems, solid-state drives (SSDs), and other data storage applications. However, it's important to note that PCM technology is still evolving, and further advancements are being made to optimize its performance and reliability.

**B Magnetic Random Access Memory (MRAM):**

MRAM utilizes the magnetic properties of materials to store information. It relies on the orientation of magnetic domains within a storage element, such as a magnetic tunnel junction (MTJ). MRAM offers non-volatility, high endurance, and fast read/write operations. Magnetic Random Access Memory (MRAM) is a type of non-volatile memory that utilizes the magnetic properties of materials to store and retrieve data. MRAM combines the benefits of both conventional random access memory (RAM) and magnetic storage, offering fast access times, high endurance, and non-volatility [21-23]. Here are the key features and working principles of MRAM:

1. Magnetic Tunnel Junction (MTJ): The fundamental building block of MRAM is the magnetic tunnel junction, which consists of two magnetic layers separated by a thin insulating layer. The magnetic layers have different orientations, typically referred to as "pinned" and "free" layers.
2. Magnetic States: The orientation of the magnetic layers in the MTJ represents the binary data values. The relative alignment of the magnetization in the pinned and free layers determines the resistance of the tunnel junction, which can be detected as either a high or low resistance state. These states correspond to the binary values of 0 and 1.
3. Read Operation: During a read operation, a small voltage is applied across the MTJ, and the resistance is measured. The resistance value indicates the magnetic state of the MTJ and represents the stored data.
4. Write Operation: MRAM allows for both read and write operations. During a write operation, a strong external magnetic field is applied to change the orientation of the free layer's magnetization. This alters the magnetic state of the MTJ and allows data to be written.
5. Non-volatility: MRAM is non-volatile, meaning it retains data even when power is removed. The information stored in the magnetic orientations of the MTJ remains intact until explicitly rewritten.

MRAM offers several advantages over other memory technologies:

1. Fast Access Times: MRAM provides fast read and write speeds, comparable to conventional RAM technologies, allowing for quick data retrieval and storage operations.
2. Non-volatility: As a non-volatile memory, MRAM does not require power to maintain stored data, making it suitable for applications that demand instant-on and power-failure resilience.
3. High Endurance: MRAM can endure a large number of read and write cycles without degradation, providing longevity and reliability.
4. Low Power Consumption: MRAM operates at low power levels, consuming less energy compared to certain other memory technologies.

MRAM has found applications in various fields, including automotive electronics, industrial automation, aerospace systems, and mobile devices. It is particularly advantageous in scenarios where the combination of high speed, non-volatility, and endurance is required. Ongoing research and development aim to further improve the performance, density, and scalability of MRAM for broader application possibilities.

**C Atomic-scale Memory (ASM)**

Atomic-scale memory refers to a class of memory devices that operate at the atomic scale, where individual atoms or molecules are used to represent and store data. In order to store more information in less space, these memories take use of the peculiar characteristics and manipulability of individual atoms [24-26]. The key aspects and concepts related to atomic-scale memory are discussed below,

1. Atomic Manipulation: Atomic-scale memory relies on the ability to manipulate individual atoms or molecules to encode and retrieve data. Techniques such as scanning tunneling microscopy (STM) or atomic force microscopy (AFM) are used to position and control atoms with high precision.
2. Bit Storage: Individual atoms or molecules can be used to represent bits of information, with different states corresponding to binary values (e.g., 0 and 1). The manipulation and positioning of atoms determine the stored data.
3. Stability and Endurance: Atomic-scale memory technologies aim to achieve stability and endurance by ensuring that the encoded information remains intact over time and through multiple read and write operations.
4. Quantum Effects: At the atomic scale, quantum effects become prominent. These effects can be harnessed to enable novel memory functionalities, such as quantum superposition and entanglement, which may lead to new computing paradigms.
5. Research and Development: Atomic-scale memory is an emerging field of research, and various approaches are being explored. For example, researchers are investigating using atoms or molecules on surfaces, nanostructures, or defects in materials to create stable and controllable memory elements.

However, it is important to note that atomic-scale memory is still in the early stages of development, and many technical challenges need to be addressed before practical implementations can be realized. However, intriguing possibilities for the future of memory devices are provided by current research and breakthroughs in nanotechnology and atomic manipulation methods. It's important to note that nanoscale memory devices are a hotspot for innovation in the IT world. Upcoming electronic gadgets may be far smaller and more powerful because to the possible storage revolution brought forth by these devices.

**VI Future of nanocomputing**

The future of nanocomputing holds immense potential and is likely to bring about significant advancements in various aspects of computing. Apart from the formentioned topics some key aspects that may shape the future of nanocomputing:

1. Increased Computing Power: Nanocomputing has the potential to enable more powerful and efficient computing systems. Through the use of nanoscale components, such as nanowires, nanotubes, or quantum dots, it may be possible to create high-performance processors and memory systems with enhanced speed and computational capabilities.
2. Energy Efficiency: Nanocomputing has the potential to significantly improve energy efficiency in computing systems. By leveraging nanoscale components and designs, it may be possible to reduce power consumption, minimize heat dissipation, and enhance overall energy efficiency, addressing the growing demand for sustainable computing solutions.
3. Novel Architectures and Paradigms: Nanocomputing opens up possibilities for exploring new computing architectures and paradigms. For example, emerging technologies like neuromorphic computing, which mimics the brain's neural structure, and quantum computing, which leverages quantum phenomena, could revolutionize how computations are performed and expand the range of problems that can be solved.
4. Integration with Other Technologies: Nanocomputing is likely to intersect and integrate with other emerging technologies, such as nanoelectronics, nanophotonics, and nanosensors. This convergence can lead to advancements in areas such as nanoscale sensing, communication, and interdisciplinary applications like nanomedicine and nanorobotics.
5. Nanofabrication Techniques: Nanocomputing will rely heavily on the continued development of nanofabrication methods including improved lithography, self-assembly, and atomic manipulation. The development of nanocomputing devices and systems is facilitated by these methods of accurate manufacture and assembly of tiny components.

It's worth noting that nanocomputing is still a very new discipline, with a long way to go before it's ready for general use. However, nanocomputing's potential lies in its ability to revolutionize the computing industry by paving the way for quicker, more efficient, and more competent systems that can propel developments in a wide range of sectors.

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