A Systematic Scrutiny of Electronic Products from DNA Electronics: An Application to Nanotechnology

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Abstract: **It is incredible to imagine the usefulness of biomedical science in the field of electronics. DNA electronics, which is one of the most attractive applications of bionanotechnology is making its way in nanotechnology like a wild uncontrollable fire. DNA is regarded as a sturdy tool in the application of electrical transport with the support of semiconductor devices. With the aid of electronic properties exhibited by semiconductors, electron transfer exhibited by both N and P types semiconductors through donating and accepting electrons result to electrical transport that enables the production of electronic devices from nanomolecules. The process leads to nanoelectronics that are discussed in this paper. On the other hand, DNA molecules also showcase electronic coupling, which is identical to semiconductors. This paper examines DNA electronics with the light of current innovative research in bionanotechnology. Different DNA electronic applications are highlighted in addition to some of the products and devices that are bi-products DNA of electronics. The paper demonstrates the effectualness of DNA in bionanotechnology and its assimilation in electronic engineering. The article expatiates on the usefulness of DNA as a resourceful tool for the production of electronic devices.**

Keywords: **Bionanotechnology, Nanotechnology, Nanodevices, Nanomaterials, Electron Transfer, DNA Electronics, Electronic Engineering.**

I. INTRODUCTION

Nanotechnology is one of the most attractive fields in engineering, and a 21st century research pulling branch of engineering that embraces biology, chemistry, and physics [3-5]. Figure 1 shows major applications of bionanotechnolgy as a specialisation in nanotechnology.

The adequacies of DNA in nanotechnology in the design of electric circuits eradicate the barrier that silicon-based electronics could face in the near future. This application in electronics emanates substantial ideas in nanoelectronics, which is discussed in this paper as DNA electronics. Genetic information reveals that DNA is meant to code for functional proteins from the perspective of biology. This article centres on DNA electronics as an application in bionanotechnology that synthesizes biomedical sciences and electronics.

Genetic engineering has redemptive power in human health because DNA electronics have produced several nanomachines for the usefulness of the health industry. Crick and Watson are eminent scientists who won the Nobel Prize and the first to discover the structure of DNA in 1962 [1]. The concept of the capability of DNA was first discovered at that time, but the limited factor was how to use it as an electric conductor for measuring electric current through DNA. Not until 1974 when supplemental knowledge on how to use organic molecules to model electronic components brought up earlier proposal, which was implemented that year. Ever since its first implementation, DNA has been an enthralling research field that justifies that DNA can conduct electrical current, and that organic molecules can be used to design electronic components such as the Integrated Circuits (ICs) , which is much applicable in many of the electronic products and devices.

The rest of the paper is organised as follows: Section 2 discusses the literature review on DNA, while Section 3 highlights some types of DNA applicable in nanotechnology. Section 4 produces information about the application of DNA electronics; Finally, Section 5 concludes the paper.

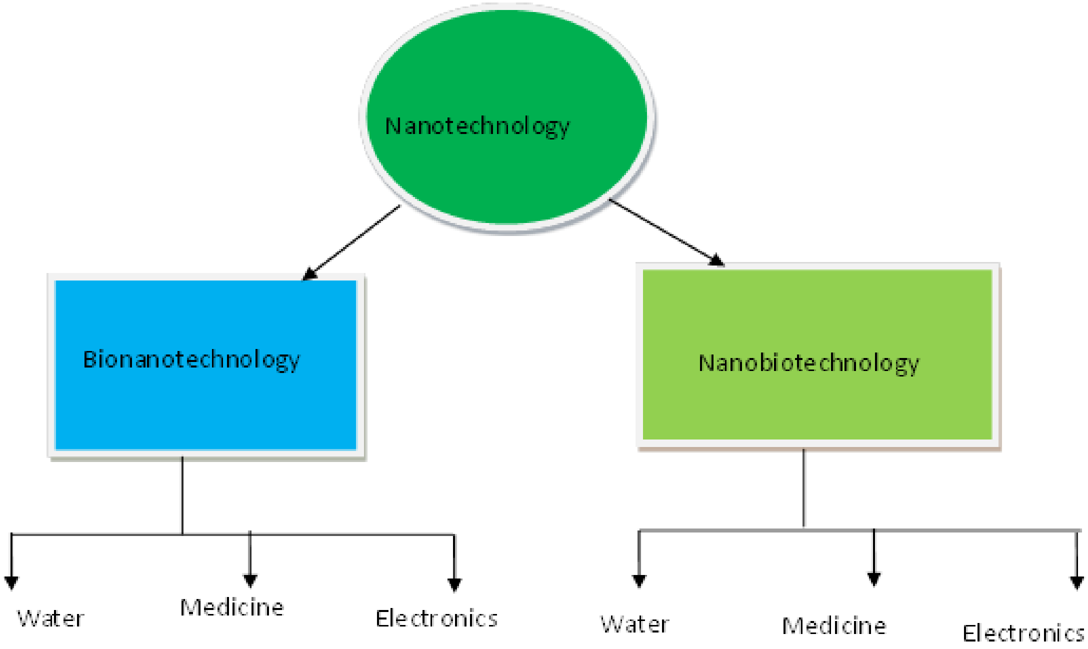

Figure 1. Branch of Nanotechnology and applications.

II. LITERATURE REVIEW

This section elucidates in details the background of DNA and also appraises literature on findings in DNA electronics. There is high progression on the level of research interest in DNA electronics in the past decades because of its efficacy in nanomedicine. T The relevance of DNA to human health cannot be correlated, and hence it is appraised as the blueprint of life according to genetic studies [17, 19]. The literature expands on some of the pertinence of DNA with electronics.

A. Background of DNA:

DNA is a powerful subject that bespeaks the role of some science and engineering fields and their homogenization in the theme of DNA. Genetically, DNA is the carrier of genetic information, found in all living things. With the prospects in nanomedicine, the chemists and physicists were aspired to explore the use of electronic properties in DNA resulting in DNA electronics. Presently, DNA is not limited to only genetic information [16], but have so much wields in electronics, in that it performs as an insulator, molecular wire, and producer of electronics devices. Amazingly, many people would not know that florescent is a bi-product of DNA [11, 13]. This is as a result of the structure of DNA and DNA molecules, discussed in later section. The M-DNA is also a complicated [9] type which possess unusual conductive characteristics; it is also handled later in this paper.

DNA molecules produce several structures known as nanostructures [33], which can be refined and use for applications in photonic and magnetic rays. The two types of structural DNA and M-DNA are discussed in section 3. DNA also produces structure-switching, as a result of the DNA molecules [29, 30]. These characteristics help in the fabrication of nanomachine devices. There is also DNA strand that is composed of sugar and a base, while the DNA double strand is relevant for conductivity [10, 14, 18]. The DNA double bond formed in strand results to a tunnel junction, it also result to the **pi** bond used in electron dissipation. DNA strand allows design on a nanometre length scale [28], while DNA supramolecular chemistry for self-assembly of DNA nanostructures [20]. In addition, DNA architecture exists in two and three dimensions [27]. These dimensions are for control of motion when applied in nanomechanical components.

Information computation is another sector where DNA system is applicable; this is because DNA-based system can integrate long-range transport and information processing [26]. The operation is based on the synthetic molecular motors. It is an important application in computer networks for sorting and dissimilation of information. Section IV explains more on DNA molecules and structure and its usefulness in semiconductors.

B. Literature review:

In [24], a researcher Fraser Stoddart executed the application of Brownian motion known in Physics with his knowledge of nanomaterial to develop and design materials for DNA. He first started the development of this device in 1991 using an axle. Fraser, a chemist applied chemical boding to a ring to create molecular shuttle. In 1994, he modified the design such that the axle would have two separate binding sites. He made the shuttle to operate as a reversible switch by changing the acidity of the liquid, which in turn forces the ring to hop one angle to the other. The switch that was proposed could be used as a sensor in the near future, and also for cargo delivery of drug molecules. Interestingly, the bond can be linked to the two strands of DNA. Also, a nano-logical device from DNA molecules was proposed [7]. In this article, the principle of chemical bonding was applied to coat DNA strands with metal. This proposal was based on the theoretical prediction that chemical bonds have the ability to act as tunnel junctions in the Coulombs blockade regime. The proposed device was intended to operate in the nano-meter (nm) scale as its metric system and to operate at room temperature. Authors concluded that complicated network can be engendered by substituting the proposed device with self-assembly property.

Consequently, due to the prospects in bionanotechnology, authors in [6] emphasised on the progressive trend of research interest in electrical transport through mesoscopic conductors. This subject deals with nanomaterials with electronics. The paper unveiled that focus on nanomaterials is said to have been drifting from the artificial structures to the natural nm size. A 4 nm Pt electrode was proposed, which should be able to administer single conducting molecules. The concept of electrostatic trapping was also emphasised, whereby nanoparticles that are polarized by electric field gets attracted to the gap between the electrodes to the region of maximum field. It was also revealed that the principle of Brownian motion was also used for the design synthetic molecular machines in [31], which project prospects in nanotechnology.

This section of literature review shows the desire for chemist to use nanomaterials to build devices that would be useful in nanotechnology. But in [35], it clarifies that DNA being the best medium to create isoenergetic and orthogonal interactions is based on Watson-crick binding. The paper demonstrates that DNA can be used to create numerous bonds using various principles of chemical bonding. This technique is based on biomolecular interaction of electrons.

In [13], DNA was implemented to be used for signal processing in electronics. This is based on the principles of logic gates. The "OR "and "AND" gates were used for illustrations. With this implementation in signal processing, its application can be very utilitarian in protein-based triggers. Also in [21], a NOR gate was implemented consisting of three transistors. This was aimed at producing strong electrostatic of the nanotube. Further research in [22] demonstrates the use of fluorescence as one of the products from DNA. These devices can further be used for control of antibodies' activities in health [32]. DNA is also useful in fabrication using mechanical devices, which is an application in nanoscience. In [23], research was focused on congregating and hegemonizing artificial molecular machines. These machines are useful tools for nanofabrication. This is another sector where nanomaterials were demonstrated to have been used for fabrication

And finally, in [7], a nano-logical device was proposed that forms a self-assembly property, which can be used to create knotty networks.

III. TYPES OF DNA IN NANOTECHNOLOGY

Structural DNA and M-DNA are considered in this section. The motif and sequence designs of structural DNA are discussed and finally the M-DNA. Structural DNA makes use of DNA molecules to generate higher order structures at nm scale [34]. In order to deploy this technique in structural DNA, DNA origami nanostructures are correlated into stupendous contiguous architectures.

A. Motif design:

To establish new connectivity, motif design reckon on the performance of corresponding exchange by switching the connections between DNA strands into 2 separate double helices. The TX type of motif that can be used for DNA-based computation was implemented in [19].

Figure 2. Reciprocal exchange in Motif design [2].

In Figure 2.0, the red and blue strands experience reciprocal exchange, which results to a red-blue and blue-red strand respectively. This process can be achieved either with a computer or on paper depending on choice. Furthermore, the DX and PX motifs perform exchange due to polarity, both of these motifs are not considered in this article.

B. Sequence design:

The aspiration of sequence design is to corroborate that the molecules form excited states as expected. On the other hand, symmetric sequence method is an effective sequence DNA type that is productive for branched molecules .It is used for assigning small DNA motif sequence [2]. The four arm motif sequence is meant for free energy cost. It is built from four strands, which contains 16 nucleotides (16nt) as shown in Figure 3.0. From this figure, each of the strands is broken into a concatenation of 13 overlapping tetramers giving an aggregate of 52 tetramers in the whole molecule. The 12 tetramers at the edge of the branch are forbidden so that the molecule would not be able to conform to a linear duplex DNA at any of the points around the branch point.

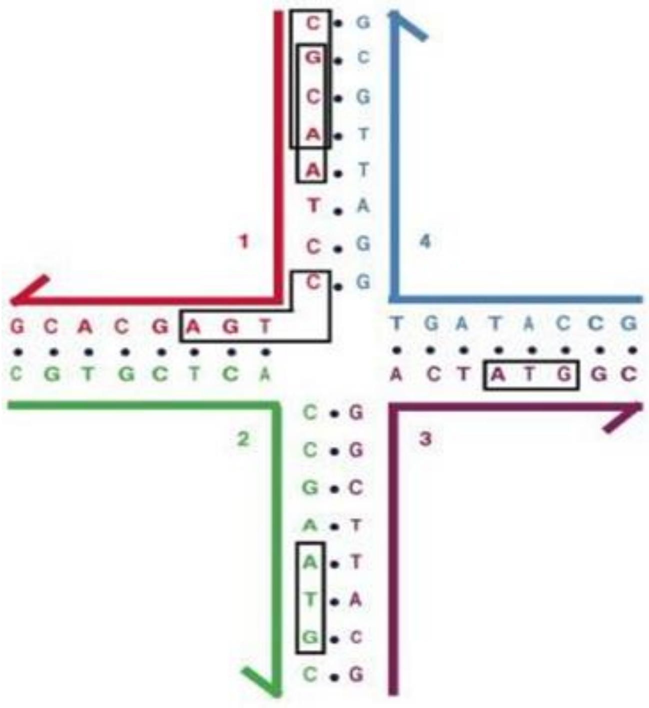

Figure 3: Sequence design [2].

C. M-DNA:

M-DNA is a complex DNA that is formed at pH level beyond 8 in the presence of divalent metals such as $Co2^{+,}$ $Ni2^{+}$, and $Zn2^{+}$, excluding $Ca2^{+}$ or $Mg2^{+}$. When these metals are added to B-DNA at pH level of 8.5, the proton is released per base-pair per metal ion as the pH decreases. Under this condition, all bacteria and synthetic DNA dismutate to M-DNA, but process is reversed by the insertion of ethylenediaminetetraacetic acid (EDTA) [9].

M-DNA can also be ameliorated to B-DNA by insertion of EDTA by all sequences (except perhaps poly[d(AT)]). Also, absorption and CD spectra of M-DNA are similar to B-DNA. It is also enthralling to know that M-DNA act like an electron conductor. This property is exhibited with a 20 basepairs with fluroscein as the donor and the acceptor of electron as rhodamine. More details about electron transfer are discussed in later section when considering semiconductors.

IV. THE POTENTIAL OF DNA ELECTRONICS

This section concentrates on the principles of semiconductors and its application in DNA.

A. Electronic device principles:

DNA is a vital abstraction in the application of bionatechnology in nanomedicine. The unique structure of DNA allows various alterations to its material properties such as its sequence, diameter, and stiffness, which could all modify its electrical properties. This property of DNA is manifested at oxidation process. During this process, electron becomes positively charged as a result of electron loses that occurs during oxidative stress.

i. P-type semiconductor:

From electronic fundamentals, semiconductors are originally made from materials that do not conduct electric currents. They are made from silicon, which have four electrons in the outer most shell. The **P-type** is made by an addition of extra materials from aluminium or boron to that of silicon; this leaves a hole in silicon as a result of the extra material from any of these elements as shown in figure 4.0. The **P-type** semiconductor is an electron acceptor since it needs extra electron to complete its shell.

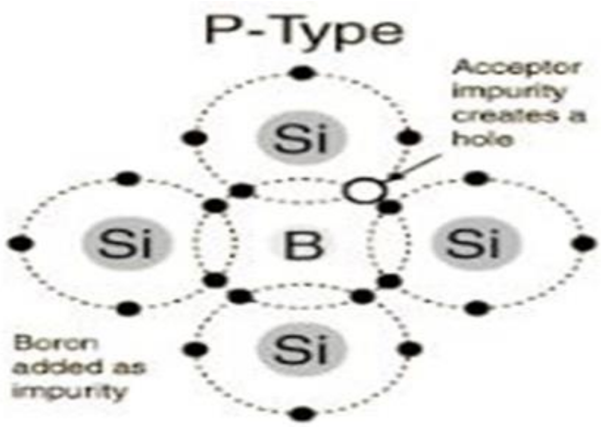

Figure 4: Electron acceptor (P-type) semiconductor.

i. N-type semiconductor:

The **N-type** semiconductor is a donor of electrons since it emits electron unlike the **P-type.** An **N-type** is formed by an addition of a pentavalent impurity to elements such as arsenic, antimony, and phosphorus that are in need of electron. Figure 5.0 shows how it donates electron.

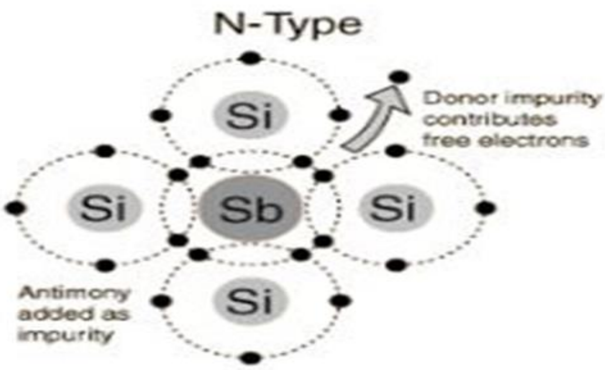

Figure 5: Electron donor (N-type) semiconductor.

From the principles of semiconductor, the duplex DNA also model similar behaviour of electron transfer. In regards to electron transfer, duplex DNA seems to be more dynamic than proteins, but unfortunately does not consummate as a molecular wire. This property is also demonstrated by DNA during oxidation process. During the process, distance is seen as a dependent factor for charge transfer rate [8, 12, 15]. This implies that distance influences DNA charge transfer, which is an inherent principle in semiconductors. Electrical transport plays a major role in DNA electronics, which is achieved by electrostatic trapping principle. This technique is to ensure that gap between the electrodes are attracted to the field where there is maximum electric field. These principles demonstrate that nanoparticles can be polarized with metal-cluster molecules in a controlled way. In [6], the field gradient near the nm-size gap was demonstrated to be attracted to the region between the electrodes. Single particles currents flow between the electrodes after trapping, which result to voltage drop across the resistor if the resistor is absolutely high, thereby reducing the electric field in the gap and preventing the second particle from trapping.

V. CONCLUSION AND FUTURE WORK

A. Conclusion:

DNA electronics constitute an indispensable entreaty in nanotechnology. This article unveiled useful uniqueness of DNA as a blue print of live, and its thrilling entity to combine with electronics in production of devices in nanoelectronics. In conclusion, DNA and electronics unfold a weird field in nanotechnology called nanoelectronics. The devices identified in this paper, are very imperative in health sector to save the life of humanity.

DNA and electronics appear to be two different things altogether, but this paper has shown how these two concept are perfectly matched to produce lifesaving services. It has also demonstrated the relationship between science and engineering. We have seen how molecules from DNA can produce electronic products which pose more challenges to explore the capability of DNA in regards to electronic engineering.

B. Future work:

Further interest would be focused on the scope of DNA in the production of electronic products and devices. This would unveil the much usefulness of DNA molecules in the production of electronic devices that can be very essential in nanomedicine. We will also look at other areas of engineering that DNA could have much usefulness from the capacity exhibited by DNA in this article.

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