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Future Trends for Carbon Nanotube Transistors in Sensing and Transmitting Data

G. Rajakumar

Professor, Department of Electronics and Communication Engineering, Francis Xavier Engineering College, Tirunelveli, India

E-mail: rajakumar@francisxavier.ac.in

Abstract

Recently, the printing technologies for mass producing flexible and elastic electronics might significantly broaden the range of uses for electronics and transform the way people think about them. This document offers a summary of the most current research in this area. The structure that allows for the transmission of data involves the transfer of information from one channel to another by way of a very flexible film model transistor assisted by an integrated circuit procedure. The semiconductor industry makes extensive use of wall-based carbon nanotubes for the purpose of developing models with improved efficiency. This study provides a comprehensive explanation of single and multi-channel field-effect transistors, both of which are used for the process of data transmission using flexible carbon nanotube transistors in applications such as hearing aid equipment. This research work go through all the recent tweaks to the printing process for sensing and transmitting data from one to another source. All of these modifications are ideal for the mass-production of stretchy and flexible electronics.

Keywords: Carbon nanotube, Moore's law, nano-electronics, metallic conductors, sensing technology, Field-Effect Transistors

1. Background Theory

Carbon Nanotubes (CNTs) were initially found in 1991 by Sumio Iijima. By rolling the graphene sheet, they take on a hollow cylindrical shape. There are two different kinds of CNTs i.e., single-walled and multi-walled. Wrapping a single sheet of graphene around itself creates a Single-Walled Carbon Nanotube (SWCNT). After a catalytic material, Fe or Co is coupled with a carbon source at a high temperature, to generate Multi-Walled Carbon

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Nanotube (MWCNT) [1, 2]. The average size of a SWCNT is around 4 nm. The diameter of MWCNT ranges based on the composed multiple coaxial shells of carbon. MWCNT are more easily manufactured than SWCNT [3] and may be thought of as metallic conductors. MWCNT's complicated structure, however, makes it a more difficult model to create than SWCNT. In accordance with their chirality, SWCNTs may either behave as semiconductors or as metals [3-5].

As stated by Moore's law, the number of transistors is increased and integrated circuit is doubled every 2 years. To accommodate this increase in transistor density, transistor size must be decreased, necessitating a reduction in transistor geometry. Its success may be attributed in part to its capacity to shrink in size while increasing in speed. The first statement of Moore's law sums up this quality. According to this theory, both the transistor's size and its processing speed will drop exponentially in the future. Thanks to Moore's law, the IT industry has advanced and maintained its competitive edge. As a result, Moore's law is crucial to the development of modern technology and to the maintenance of our way of life [6, 7]. The basic structure of Carbon Nanotube Field-Effect Transistor (CNTFET) has been shown in figure 1.

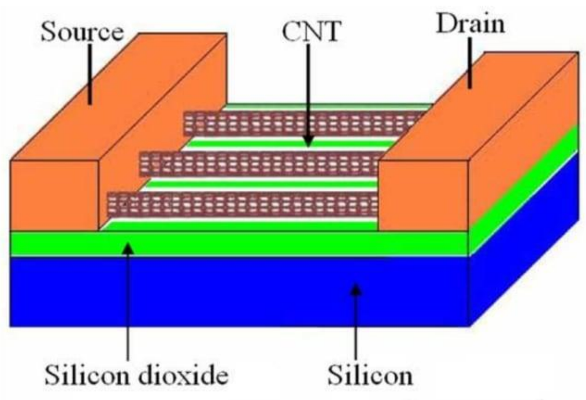

Figure 1. Basic structure of CNTFET [4]

Macro electronics, in contrast to traditional microelectronics and nano electronics, is being prioritized recently. Progress in material science is crucial to the creation of these novel electronic forms. One of the most important parts of macro electronics is the Thin-Film Transistor (TFT), which has been investigated for decades as a channel material [3-9]. Many scientists have become interested in nano materials in recent years due to their superior performance over organic semiconductors and their ease of processing compared to polysilicon. Source, drain, gate, and body are the four terminal units that make up the heart of a CNTFET, which is implemented on a single chip recently. The source and drain receive electricity, and the gate may be triggered. If it's set to a high value, the design will be active; otherwise, it will be in the disabled condition [10].

1.1 Existing Technology

The speed, scalability, and power are the three most important qualities of every transistor. The success or failure of a transistor may be gauged by these three features since they are immediately apparent to the user. To succeed in replacing silicon Metal-Oxide Semiconductor Field-Effect Transistors (MOSFETs), any potential successor transistor technology must be at least as good as these three features.

1.1.1 Speed

Partially because of their special one-dimensional structure, carbon nanotubes may use ballistic transport. When traveling using ballistic methods, the mean free route is much longer than the actual distance. As a result, there is almost little resistance since the charge carriers don't interact with one another. As a consequence, chip speeds may increase to 1 terahertz or more, which is far faster than the current limit of 3 gigahertz.

1.1.2 Expandability

The scalability of CNTFETs was found to be a desirable attribute by a team at IBM. CNTFETs aren't average devices, despite the fact that they become better as they're scaled up. It seems that their operation mimics that of Schottky barrier MOSFETs rather than that of standard MOSFETs. This is why the IBM team has doubts about the scalability of CNTFETs. They do, however, point out that the CNTFETs will provide sufficient gain and fanout in a structured array to be useful in practical settings. Furthermore, CNTFETs will outperform silicon MOSFETs even if their scaling limitations are less clear.

1.2 Organization of the Article

The article is organized as follows: Section 2 provides a summary of the many filtering applications and field effect transistor layouts that are now in use, along with a discussion of the benefits and drawbacks of each. In the next section, which is titled "Section 3," a comprehensive view of the use of carbon nanotube filtration is provided. Last but not the least, the general overview and planned improvements may be found in section 4.

2. Literature Survey

This section looks at the pros and cons of the various Field-Effect Transistors (FETs) layout designs utilized in hearing aid filters. The hearing-aid system is used to compensate for hearing loss, and it has a number of functions, including amplification, noise cancellation, feedback suppression, and automated program switching. The primary functions of a hearing aid are sound amplification and transmission to the ear. To make the necessary modifications to the voice signals, filter bank-based algorithms were used.

To compensate for different degrees of hearing impairment, Wei and Wang [11] designed a filter bank that generates different kinds of waves. Control over the quantity and placement of subbands is determined by a single 4-bit signal. The focus of the investigations was on optimizing the size of the filters used in hearing-aid systems to create a rapid, efficient filter with minimal power consumption. FIR (Finite Impulse Response) compressors were explored by Kotha et al. [12]. It used the same method for making multi-walled carbon nanotubes, that provides the designed details of manufactured single-walled carbon nanotubes. The single-walled nanotubes usually have a diameter of 1-2 nm, which is much smaller than the diameters of their multi-walled counterparts. The special structural, electrical, mechanical, electromechanical, and chemical features of CNTs have been extensively studied during the last decade. The quality of nanotubes formed via catalysis has been studied extensively recently.

Recent advances in wireless communications technologies have altered modern lifestyles and prompted widespread adoption of high-tech gadgets. Environmental monitoring and medical monitoring are only two examples of fields that informed the definition of the frequency bands used. According to Trivedi et al. [13], the hearing aid is only capable of picking up frequencies up to 6 kHz. Sub-threshold operation was used to study the power dissipation across the components under different biasing circumstances. It was shown that in certain situations the degree of hearing loss was more detrimental than the temporal fluctuations.

For the profoundly deaf, the acoustic-based amplification did not provide an adequate experience [14]. The next step in the research process for the FET-based models used in the construction of multiple models was to develop the hearing aid filter in light of these operational limits. Changes in temperature necessitated lengthy and power-hungry transition stages during operation. This meant that mitigation strategies were essential. Low-Cost In-ear

Bioelectrical Sensing (LIBS) is a novel sensing technology created by Nguyen et al. [15] for use in medical settings. The data gathering and signal separation allowed it to automatically capture the signal from the ear canal. To further disentangle the break's signal, the Nonnegative Matrix Factorization (NMF) technique was used. The hearing aid's drain current and delay were lastly studied by Yogeshwaran et al. [16]. In this case, the ON/OFF characteristics were used to verify the link between these metrics.

2.1 Transmitting Data

For the development of a digital hearing aid, Kuo et al. [17] used an ANSI S1.11 filter. The goal of developing this software was to improve voice quality by eliminating echo and decreasing background noise. This design included the steps of filtered bank architecture construction, low power optimization, calculation reordering, clock gating, and operand isolation. To get rid of probing noise in a hearing aid filter, Guo et al. [18] utilized acoustic feedback cancellation. Using probing noise augmentation filters, this work aimed to slow down the convergence rate. However, the computational complexity could not be reduced using this design approach.

2.2 Overview of the Paper's Goals

By taking stock of previous efforts, researchers may go on with their own projects without having to devote as much time to catching up. The progress of CNTFETs should be sped up as a result of this. It is hoped that this study will also serve to educate the general public about CNTFETs by answering the questions of those who are just intrigued by this cutting-edge technology. Investors will gain knowledge from this, and CNTFET research and development will get additional funding as a result [19].

3. Carbon Nanotube Constructions

3.1 Outward Appearance

The hexagonal configuration of a carbon nanotube greatly increases its strength. They're a fourth of the density of steel but have 50 times the strength of it. Moreover, carbon nanotubes are quite elastic. Nanotubes can be bent or buckled without breaking, no matter how tightly they are compressed. On the contrary, they always return to their original form after being bent. It also has excellent heat transmission properties. Nanotubes made of carbon are even more effective heat conductors than diamond. Carbon nanotube-based products, such as transistors, have excellent durability and reliability because to these three characteristics.

3.2 Electrical Properties

Carbon nanotubes (CNT) have exceptional and modifiable electrical characteristics. They differ from most substances in that they may be either metallic or semiconducting. In addition, by manipulating a few physical properties, their band gaps may be tuned to suit certain applications. Above room temperature, they also exhibit the unusual trait of being one-dimensional ballistic conductors.

3.3 Transistor-Field-Effect Constructed from Carbon Nanotubes

Similar to modern Metal-Oxide Semiconductor Field-Effect Transistors (MOSFETs), Carbon Nanotube Field-Effect Transistors (CNTFETs) are also being developed. Source, drain, and gate are the three required terminals. The gate empties the terminal and regulates the current across the head. Once the gate is open, wind may blow over the water and down the drain. The channel in CNTFETs is made of carbon nanotubes, whereas the track in MOSFETs is made of strongly doped silicon. P-type and n-type semiconductors are used interchangeably in both technologies. This improves efficiency, boosts gain, is more stable, and can be simply integrated into existing logic circuits.

The p-type transistor allows holes to flow through it, whereas the n-type allows electrons to move freely. The construction and switching mechanisms of these and other devices are the subject of the investigation. The transistor's gate might be found on its side or its bottom. To further separate the gate from the nanotube, an insulator like silicon dioxide is placed between the entry and the gate. It is possible for the electric field from the gate to turn on and off the transistor because of its isolated position. Without the shielding, there would be a short circuit, and the transistor would not function.

It's clear that there are flaws in these plans. First, when exposed to air, a nanotube transistor can only function as a p-type Field-Effect Transistor (p-FET). In addition, there are issues with the location of the gates. Whether the gate sits on top of the nanotube or below it, large voltages are needed to break through the thick gate oxide and turn on the transistor. Since each transistor utilizes the same gate for access, there is an additional issue brought on by the gate below i.e., the transistors turn on at the same time. The production of big circuits or chips becomes unfeasible as a result [20 -24].

3.4 Application

About 10% of the population has some kind of hearing loss today, and only a fraction of those individuals use hearing aids. When using this equipment, you may expect a high level of productivity with little interruption from background noise or distorted sound. Moreover, a number of digital signal processing techniques are needed for the hearing aid's development. The development of a filter for use in hearing aids has been the focus of some recent research, namely in the area of very-low-power-integrated-circuit design. However, it does present certain difficulties, such as higher power and space requirements compared to other portable devices. So, designs like MOSFET and CNTFET [25, 26] have been developed to provide this filtering software. Since the MOS capacitor is at the heart of this circuit, applying gate voltages transforms the semiconductor's function from p-type to n-type, allowing for voltage gain and signal power gain. Deflective and enhancing modes are fundamental to its operation as well [2]. Yet it suffers from significant flaws such as, high leakage current, process fluctuations, and short-channel effects.

3.5 Problems with Recent CNTFET

The use of CNTFETs has been advocated as a viable alternative to conventional CMOS technology. However, there are significant obstacles that must be overcome before this technology can really thrive. Below, a few of them are discussed in more detail. This research article provides some of the future challenges and problem solvation here.

1. For optimal performance, the integrated circuit chip's billions of carbon nanotubes must be fabricated in precise positions. They should also mostly have the same electrical features. Making CNTFETs in such huge numbers and at such a cheap cost is, however, challenging.
2. The scalability of CNTFETs presents a distinct technical obstacle.
3. CNTFETs are unreliable because of temperature gradients when subjected to strong electric fields.
4. Oxidation causes CNTFETs to deteriorate.
5. Methods of passivating carbon nanotubes need to be developed.
6. To be manufactured in large numbers, CNTFETs need a uniform model that can be utilized for both analog and digital applications.
7. It is important to study how well CNTFET circuits can withstand faults.

8. It is important to look at the scalability of CNTFETs.
9. In order to fabricate CNTFETs, novel materials should be identified.

4. Conclusion

Carbon Nanotube Field-Effect Transistor (CNTFET) technology is well suited to replace Si-based CMOS technology due to its rapid development over the last several decades. This article provides a concise introduction to carbon nanotubes, their potential uses, and the difficulties that lie ahead. A ring oscillator built using CNTFETs is also examined, and its performance is compared with others. It is possible for CNTFET technology to go down to dimensions less than 7 nm. Compared to traditional CMOS, CNTFETs have been discovered to provide superior performance while using much less energy. Carbon nanotube transistors will likely become a viable choice to replace conventional transistors as they continue to be optimized and developed. Many issues, including chirality control, must be worked out before carbon nanotube-based VLSI devices can be manufactured.

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Author's biography

G. Rajakumar is a Professor in Department of Electronics and Communication Engineering in Francis Xavier Engineering College, Tirunelveli. He has 14.5 years of experience. Received his B.E (Electronics and Instrumentation Engineering) in National Engineering College, Kovilpatti under M.S University Tirunelveli, 2004, M.E (VLSI Design) in Arulmigu Kalasalingam College of Engineering – Srivilliputhur under Anna University-Chennai, 2006, M.B.A (Human Resource Management) under Annamalai University, 2009, Ph.D in Information and Communication Engineering with the specialization in VLSI Design under M.S University 2014, Post-Doctoral Fellow in VLSI Design under Delhi Technological University, Delhi, 2016 and Honorary and Doctor of Letters (D.Litt.) in Information and Communication Engineering, under University of South America, USA 2017.