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Application of carbon nanotubes(CNT) on the computer science and electrical engineering: a review

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ABSTRACT

In recent years, dimensions and sizes of components and parts in the computer and electronic industries have been steadily reducing, as they are now considered very tiny tools and there is always a need to store and process information stronger. Nanotubes have poor magnetic properties. If nanotubes are covered by ferromagnetic nanoparticles, their magnetic properties can be improved and they can be used in the manufacture of nanoelectronic devices in the computer and electronic industries. In addition to reviewing the structure and properties of materials made using different nanomaterials for use in the computer and electronic industries, the present paper aimed to study different applications of nanomaterials, especially carbon nanotubes, in the manufacture of electronic devices. The present study showed that the corporation of nanomaterials into electronic devices is a promising approach for future applications which can revolutionize the computer industry.

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1. INTRODUCTION

After the discovery of carbon nanotubes (CNTs) in 1991 [1], many studies have been carried out on their applications in the manufacture of nanoelectronic devices. Based on their geometrical shape, CNTs can be either metal or semiconductor [2], diversifying their use in the manufacture of nanoelectronic devices such as diodes and transistors [3-5]. In some of these applications, nanotube topological defects are used [6]. These topological defects cause a change in the chirality of the hexagonal network of carbon and thereby change the electronic properties of nanotubes. Some examples of these defects include metal-metal, metal-semiconductor, and semiconductor-semiconductor connections in cloud networks [7-10]. Given the reduced scale of semiconductor components and integrated circuits to the nanometer range, the semiconductor industry will face many challenges. Today's electronics industry is based on silicon. The history of this industry is about 50 years and now it has reached a peak in terms of industrial and commercial technology [11]. Therefore, alternative technologies for silicon transistors are being explored and studied. Carbon nanotube field-effect transistor is a good option for transistor because of the possibility of further dimensions reduction and development of new structures [12]. According to Gordon Moore, the number of transistors used in microprocessors is doubled every 18 months. The halved dimensions of transistor gate with a constant size of silicon chip can be the result of this rule, known as Moore's law. This halved dimension signaled economic messages, that is to say, the smaller the gate would be, the faster the transistor could switch and use less energy. As a result, more transistors can be embedded in a chip. Increased number of transistors and their efficiency can reduce the costs. Therefore, each transistor was more cost-effective to be as small as possible. This reduction was finally stopped. Hence, alternative technologies should be come up with for the growth of the electronics and computer industries in order to both solve previous problems and achieve an economic justification. It was the nanotechnology that came with to help the electronics and computer industries, establishing a new area of science called nanoelectronics [13].

The electronics industry is one of the fields in which carbon nanotubes can be widely used. With the rapid progress of integrated circuits and approaching the end of Moore’s prediction, scientists are looking for new ways to design circuits. After the discovery of the unique structure of carbon nanotube and its characteristics such as very small dimensions, high mobility, and projectile transmission, the carbon nanotube has been raised as a suitable alternative to silicon [14]. CNTs have used for the manufacture of carbon nanotube field-effect transistor (CNFET). This transistor is one of the new technologies that scientists are studying its great benefits and more and more studies are being conducted on this field. Benefits such as ballistic transmission, high mobility, and low power consumption have led to the focus of many studies on their application in electronic circuits [15]. Carbon nanotube transistors are one of the most important and attractive options for the manufacture of electronic circuits of new generation computers. Compared to current circuits, these transistors both have higher performance and lower power consumption. These circuits have many applications, as they can be used for the manufacture of different devices from personal computers and mobile phone to supercomputers. There are two major challenges in the manufacture of carbon nanotube circuits: the presence of metal nanotubes and alignment of nanotubes. Electronic circuits based on carbon nanotubes can be active at voltages lower than those at which silicon circuits operate. Circuits that operate at low voltages produce less heat. The issue of heat generation is a limiting factor to the production of high-density circuits. Because of their high speed, CNT-based electronic circuits have gained great attention. They make it possible to install more transistors on a chip without generating much heat. Therefore, Moore’s law will continue to be established. In addition, CNTs highly increase the system efficiency. To solve the structural defects of nanotubes, researchers have linked them to electricity in order to burn metal nanotubes and keep semiconducting nanotubes sound. Semiconducting nanotubes are suitable for making chips. Using this method, researchers have managed to produce CNT-based chips.

2. CARBON NANOTUBES (CNT)

Nanotubes are based on the graphite structure, which consists of separate layers of carbon atoms with a hexagonal arrangement. The diameter of nanotubes ranges between 1 and 2 nanometers and their length sometimes reaches several micrometers. The ends of nanotubes can be blocked with a half of a Fullerene, so that they can also have pentagon components at their ends [16]. However, the most important feature that plays a role in determining the properties of nanotubes is referred to as chirality [16-19]. Despite having a very little diameter, nanotubes have a high tensile strength of about 100 gigaPascal [17, 19]. The existence of a Van der Waals bond between the atoms is another feature of nanotubes which causes their very low ability to stick together (unique electrical properties) in metal and semiconducting nanotubes [16, 17, 19, 20], conductivity only in the longitudinal direction [16, 17], thermal conductivity, and field transmission properties [17, 21, 22]. Field transmission is observed in structures with a high length-to-diameter ratio (greater than 1000), a sharp atomic head, high thermal and chemical stability, and high electrical and thermal conductivity [22, 23].

Graphene is one of the most important carbon materials used in nanotechnology. A graphene sheet forms when carbon atoms are put together. If a graphene sheet is rolled around a central axis, it forms a carbon nanotube. There are two types of carbon nanotubes as follows [24].

2.1. Single-walled nanotubes (SWNT)

Single-walled nanotubes are formed when a graphene sheet is rolled around a central axis. As shown in Figure 1, SWNT is a hollow cylinder with a diameter of 1-2 nm.

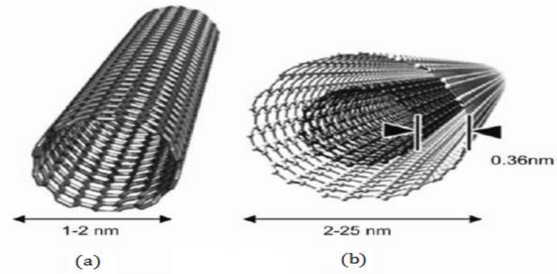

Figure 1. (a) Single-walled carbon nanotube (b) Multi-walled carbon nanotube [25]

2.2. Multi-walled nanotube (MWNT)

Multi-walled nanotubes (MWNT) are formed when several graphene sheets are rolled around a central axis. As shown in Figure 2, MWNT consists of several concentric holes with a diameter of 2-25 nm separated by a distance of 0.36 nm [25].

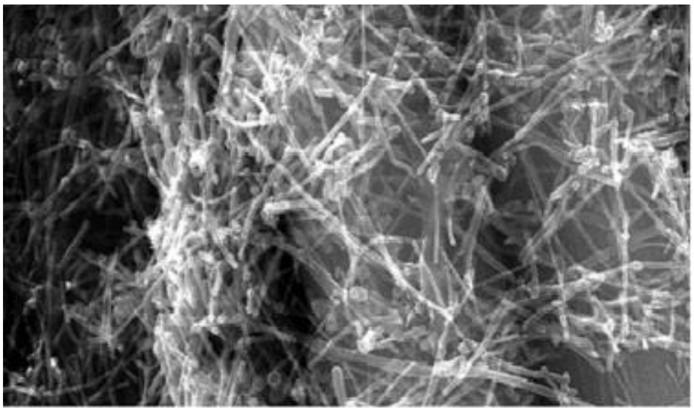

Figure 2. Images taken from MWNTs by an electron microscope [26]

Researchers have reported that carbon nanotubes have great elastic properties of about 1 terapascal (1000 MPa) and a strength several times higher than hard steels in a similar weight fraction. The fiber structure of carbon nanotubes has made them be used as a reinforcer in composite materials. Previous studies have shown that any change in the length of carbon nanotubes relative to carbon fibers provides local enhancement in the polymer context enclosing a carbon fiber [27]. Local stiffness caused by the presence of carbon nanotubes improve the transfer of load in the joint part of fiber/ground. The high aspect ratio of nanotubes causes more effective load bearing capabilities [28].

3. ADDITION OF CHEMICAL AGENTS TO THE SURFACE OF THE NANOTUBES

The addition of chemical agents to the surface of the nanotube is called Functionalization, which in turn facilitates the use of nanotubes in various industries. Functionalization of the surface, by overcoming the Van der Waals gravity forces in multi-walled carbon nanotubes, can prevent them from being bundled together. If the mechanical, thermal, and conductive properties of carbon nanotubes are enhanced through chemical improvement of the surface, applications of carbon nanotubes can be expanded to a wider range [29, 30]. Metal nanoparticles have potential applications in various fields, especially magnetic materials [31]. Dujardin et al. showed that high-energy materials such as metals cannot spontaneously wet the surface of carbon nanotubes [32]. If metal nanoparticles or metal oxide can be added to carbon nanotubes through chemical improvement of their surface, substantial changes may occur in physical, mechanical, electrical, and magnetic properties of carbon nanotubes. As a result, they can be used in the production of catalysts, optoelectronic devices, shielding films, electromagnetic tools, and hydrogen storage [33, 34]. Scientific findings suggest that the bonding energy between metals and CNTs is very low [35] and, consequently, a good adhesion between them cannot be achieved, which causes increased contact resistance and declined strength of carbon nanotubes [36]. A general method for increasing the reactivity of carbon nanotubes is the creation of functional groups and defects on the surface of carbon nanotubes. In fact, functional groups on the surface of CNTs mediate the bond between the metal and carbon nanotube. Studies have shown that the bonding energy between metals and CNTs can be greatly increased by creating functional groups on the surface of carbon nanotubes [36]. Since crude CNT is completely neutral and has a low reactivity level, it is necessary to create active and reactive sites in their structure using functional groups in order to locate any compound on their surface [36]. CNT oxidation by strong acids such as sulfuric acid or nitric acid is a desirable strategy for the formation of functional groups such as carboxyl, hydroxyl, and carbonyl [37, 38]. The formation of the above-mentioned functional groups can change the CNT's reactivity and improve their wettability. So far, a large number of metal nanoparticles or metal oxides such as gold, platinum, silver, palladium, cobalt, and nickel have been added to the surface of CNTs [39, 40]. The addition of nickel nanoparticles to the surface of CNTs aims to improve magnetic properties, reduce contact resistance with CNT, improve catalytic properties, and increase the power of energy storage of CNTs. Other methods such as electrochemistry and wet chemistry are also used for the substitution [41, 42].

4. SYNTHESIS OF CARBON NANOTUBES

CNTs are synthesized through three general methods of electric arc discharge, laser ablation, and chemical vapor deposition. One of the techniques of chemical vapor deposition, referred to as combustion chemical vapor deposition (CCVD), is the use of a simple carbon source in the gas phase and decomposing it on a catalyst at high enough temperature. Among different methods of carbon nanotubes synthesis, CCVD is the best and most suitable method, especially for large-scale industrial applications. This is due to the relative ease of this method in the stages of preparation and purification and also the scalability, the possibility of controlling the diameter, quality, and quantity of nanotubes, and high speed of production. Synthesis of nanotubes using CCVD is a two-step process including the preparation of catalyst and nanotubes. Various parameters affect this method such as the type of catalyst (type of metal and base), carbon source, carrier gas, gas flow velocity, reaction temperature and time, and diameter of catalyst particles [43]. The catalyst used in the preparation of carbon nanotubes consists of two components (metal and base). Common catalysts include mixtures of one or two of metals such as cobalt, iron, nickel, molybdenum, and iron oxide. In addition, uncommon metals used as the catalyst in the preparation of carbon nanotubes include aluminum, indium, platinum, titanium, manganese, palladium, potassium, cesium, tungsten, iridium, and carbide nickel (Ni3C) [44].

5. APPLICATION OF CARBON NANOTUBES FOR THE ABSORPTION OF RADAR WAVES

The most common method for camouflage and hidden motion against radars is to reduce the radar cross-section (RCS) of targets under their surveillance. The most important and simplest way to reduce the radar cross-section is the use of radar-absorbing materials. Research on electromagnetic waves was started in 1930 and is still ongoing [17]. In fact, the main role of radar-absorbing materials is to absorb the waves and signals received from radar like a small electrical resistor and prevent their reflection. From the standpoint of component parts, radar-absorbing materials are generally classified into two groups of dielectric absorbent materials and magnetic absorbent material. Based on dielectric and magnetic properties, absorbent materials can include ferromagnetic materials, carbon-based materials, and conductive polymers. To improve absorption, radar absorbent nanostructures are prepared as a hybrid of magnetic and dielectric compounds, because magnetic adsorbents are of heavyweight and dielectric adsorbents have a narrow absorption width. To overcome these two problems with the manufacture of adsorbents, both types of adsorbents are used together [45]. Nanocomposites that consist of a combination of carbon nanotubes and minerals (compounds of magnetic elements) have a higher impedance matching and thus improve the reflection loss [46]. Absorption properties of metal nanoalloys absorbing electromagnetic compounds are better than pure metals or metal oxides. Among the various nanoalloys, iron-nickel nanoalloy, because of stable structure and excellent electromagnetic properties as well as high magnetic permeability, has a wide range of application in electromagnetic wave absorbers, magnetic sensors, antennas, catalysts, and magnetic stability systems. CNTs have a low weight and a very good dielectric loss, but their use as radar-absorbent materials is limited due to their poor magnetic properties. Nanotubes are often covered with magnetic materials, such as ferromagnetic or superparamagnetic compounds, in order to be added to CNTs as a filler and improve their magnetic properties [47]. Therefore, nanostructures containing CNTs modified with Fe-Ni nanoalloy consist of materials absorbing electromagnetic waves with a high absorption potential and a very good absorption bandwidth, due to high dielectric and magnetic loss.

Many studies have been conducted on the manufacture and evaluation of absorption properties of radar-absorbing materials. Keqiang He et al. [48] prepared CNT/BaFe12O19 composite. This composite, in a thickness of 3 mm and at a frequency of 10.5 GHz, has a reflection loss of -30.79 dB. Haiyan [49] prepared a nanocomposite of CNTs filled with iron. In a thickness of 3.5 mm and at a frequency of 15.60 GHz, this nanocomposite had a reflection loss of -22.73 dB. Ghasemi [50] prepared the CNT/Strontium composite with a reflection loss of -29 dB in a thickness of 1.5 mm and at a frequency of 9.7 GHz. Hekmatara [51] prepared a hybrid compound of MWCNT/Fe3O4 which had a reflection loss of -27 dB at a frequency of 10.6 GHz. Cell-gel is one of the methods for the preparation of microemulsion nanoparticles. In addition, chemical vapor sequestration and chemical reduction are among the methods for the preparation of nanocomposites containing CNTs and magnetic compounds. The chemical reduction of metal salts in a solution using a suitable reducing agent such as H2 and NaBH4 is one of the most widely used methods for synthesizing metal nanoparticles. This method can also be used to synthesize nanoparticles containing two metals, where two metal salts are used and reduced. During the reduction process, different types of metals with a higher potential reduction are firstly reduced to form a core and then the other metal covers a layer on the core. Compared to the synthesis of single-metal nanoparticles, the simultaneous control of nucleation and the process of reducing two types of metals with different reduction potential and chemical characteristics is very difficult. Wang and Li [52, 53] proposed the selection of a suitable reducing agent to solve this problem. Table 1 shows the values of electromagnetic properties of the compound synthesized with other radar-absorbing compounds.

Table 1. The values of electromagnetic properties of the compound synthesized with other radar-absorbing compounds

Reference	Peak width (RL<-10dB)	Optimal reflection loss (dB)	Frequency (GHz)	Thickness (mm)	Compounds
[54]	1	-16.43	10.3	10	Ce-doped barium hexaferrite
[55]	2.5	-26.52	10.0	8	Carbonyl iron-graphite
[56]	2.9	-31.52	11.3	5	$BaCe_{0.05}Fe_{11.95}O_{19}$
[48]	4	-30.79	10.5	3	barium ferrite/CNT
[57]	2	-33.1	10.8	2.5	Graphite-coated Fe
[58]	2	-33	9.1	2.1	SiO_2-coated carbonyl iron/polyimide
[59]	4	-43.36	11.9	2.2	Carbon nanotube composite/dielectric (carbon nanotube) and magnetic (Fe-Ni nanoalloy) compounds

According to Table 1, it can be stated that there is a multiple interfacial polarization and dispersion at the surface of the nanoparticles in the nanocomposite. In addition, both dielectric loss and magnetic loss increase in the nanocomposite and thereby electromagnetic parameters, especially reflection loss, improve. Fe-Ni carbon nanotube nanocomposite is a suitable option as a microwave absorber.

6. DISSOLVING CNTS IN A SOLVENT AND NONLINEAR OPTICAL PROPERTIES OF CNTS

Nanofluid is a term which was first introduced by Choi in 1995 to refer to a new category of heat-transferring fluids based on nanotechnology. Nanoparticles are made of suspending nanoparticles of an average size of less than 100 nm in common heat-transferring fluids such as water, oil, and ethylene glycol [60]. With a high thermal conductivity capacity or, in other words, a high latent heat, nanofluids can be used as an energy saver in the form of latent heat. The use of fluids containing silver nanoparticles, carbon nanotubes, or graphite causes a 5% increase in the efficiency of solar energy heat transfer systems. Magnetic nanoparticles are used to filter certain optical waves. This property is activated by applying an external magnetic force. Magnetic nanoparticles can be also used to sense vibrations. Studies have shown that a vibrating ferrofluid in a static magnetic field can induce an electric voltage in an actuator coil.

Due to their unique properties including high thermal conductivity, low density, chemical stability, and high specific surface area, CNTs are used in the manufacture of nanofluids in order to increase the thermal conductivity of common fluids. Stability is considered the most important factor in the production of nanofluids, because the instability of CNTs in the fluid reduces thermal conductivity. To stabilize CNTs in polar solvents, it is necessary to make their surface hydrophile using modifying factors. Among the methods for functionalizing the surface of CNTs, the main and the most common method is to functionalize the beginning, end, and outer surface of CNTs. Regarding the chemistry of CNTs, this method consists of two covalent and non-covalent techniques. Among the available methods for functionalizing the surface of CNTs, the creation of oxygen-containing groups through oxidation of an acid, one of the subsets of covalent technique, is a convenient way to improve the dispersion of CNTs in polar fluids such as water. Nanotubes oxidation is done using acids such as nitric acid [61], a mixture of nitric acid and sulfuric acid [62], and a mixture of sulfuric acid and hydrogen peroxide [63], making the highest superficial modifications. It is very important to obtain proper and uniform dispersion and distribution of CNTs in a solvent. Because of the very small size of CNTs, they tend to be agglomerated when they are dissolved in a solvent. In order to improve the reinforcement of composites, it is a critical issue to achieve the uniform dispersion of CNTs in the background phase. Moreover, the slipping of nanotubes not attached to the substrate and creation of nanotube masses effectively reduces the aspect ratio of the reinforcer. Agglomeration is of importance in the development of nanotubes by chemical vapor deposition (CVD), because nanotubes sink into each other during growth and cause nanotube clusters. Solving the problems and obtaining the proper and uniform dispersion of carbon nanotubes are of great interest to the researchers. Sandler et al. achieved a uniform distribution of nanotubes in an epoxy substrate by stirring multiple times at 2,000 rpm before and after the addition of the curing agent. Other researchers have used methods such as solution evaporation using ultrasonic at high power [64], the use of dispersing agents during the formation of the intermediate colloidal solution [65], and functionalization of nanotubes in a polymer substrate [66]. Sun et al. produced CNT-alumina nanocomposite in the cationic solution of polyethyleneimine (PEI) using the colloidal method [67]. In another study, by dispersing CNTs in the anionic solution of sodium dodecyl sulfate (SDS) and generating negative loads on the surface of CNTs, the surface of nanotubes was covered with alumina particles as a result of electrostatic gravity [68]. Other researchers have also used the colloidal process to prepare CNT-alumina nanocomposites in the presence of SDS [69-71].

To study nonlinear optical properties of CNTs, they can be suspended in organic solvents. The major problem associated with the dissolution of CNTs is that they are soluble in solvents. Hence, MWCNTs with carboxyl (COOH) are used. Since the carboxyl agent is easier to be solved in polar solvents, MWCNTs with carboxyl can be easily dispersed and suspended in organic solvents. Suspended MWCNTs exhibit restrictive properties, that is to say, serve as an optic restrictor. The optic restriction is an important nonlinear phenomenon that can be used to protect fine optical devices, including the human eye, from high-intensity laser radiation. Nonlinear absorption, which leads to optic restriction here, has already been studied on different nanoparticles by many researchers [72].

7. CNT-BASED COBALT CATALYSTS FOR THE MANUFACTURE OF NANOELECTRONIC DEVICES

Cobalt is a hard-ferromagnetic element colored white-silver which is glossy and fragile. As one of the elements of the 8B group of the periodic table of chemical elements, cobalt has physical properties similar to iron and nickel. This element is chemically active and forms many compounds. Cobalt is stable in the air and water cannot affect it, but it is attacked by diluted acids. Many studies have been conducted on the thermal, mechanical, and structural properties of cobalt and alloys formed with this metal. M.Jiang et al. simulated the molecular dynamics of cobalt phase transition [73]. Chen et al. experimentally studied thermal and mechanical properties of cobalt nanowires and its nanocomposites using the finite difference method [74]. In another study, the electrochemical and mechanical properties of the cobalt-chromium alloy were experimentally evaluated [75]. In an experimental study, Shi et al. showed that the addition of cobalt to Al2O3/TiC can substantially improve mechanical properties and thermal shock resistance [76]. Synthesis of hydrocarbons in the Fischer-Tropsch Synthesis (FTS) process is commonly done using active metals such as cobalt, iron, and ruthenium [77]. Cobalt catalysts have the highest efficiency and the longest lifespan. Compared to linear alkanes, they are more selective and can be used for the production of semi-distilled products and also products with high molecular weight from gas synthesized of natural gas [78-80].

Because of special properties of carbon structures such as carbon fibers or carbon nano-strings and nanotubes, they are used in catalytic applications. The use of CNTs as the base results in a better distribution of cobalt masses [81]. Due to the highly active level and high volume of holes, more cobalt is added to the base and the agglomeration of cobalt is lower than common bases. As a result, the selectivity of C5+ increases and the inactivation rate of catalyst reduce. The hydrocarbon efficiency resulting from cobalt catalysts based on CNTs is considerably more than that of cobalt catalyst made on various organic and mineral bases. In addition to high activity, the resulting catalyst has a high selectivity for heavy hydrocarbons [81]. In the Fischer-Tropsch Synthesis (FTS) process of cobalt catalysts based on CNTs, in addition to the benefits mentioned, the interaction of cobalt with the base is greatly lower than conventional catalysts. This prevents the formation of compounds with a high degree of reduction and hard reduction and causes the reduction peaks to shift to lower temperatures, improving the reduction efficiency. However, as mentioned in the history of catalysts [81], to achieve an optimal and continuous efficiency for catalysts with a neutral base, there should be a good interaction between the base and the active phase in order to prevent the glomeration of the active phase in the process of calcination, reduction, and reaction. As a result, there will be a continuous production of hydrocarbons on these catalysts and the catalyst inaction during the reaction will be prevented [81]. Functionalization of the surface of CNTs is one of the effective ways to solve these problems in CNT-based cobalt catalysts. Functional groups on the base surface are considered a place for the interaction of the active phase particles with the base. Therefore, it causes a better distribution of particles and smaller size of cobalt particles. On the other hand, these functional groups cause better interaction of the active phase with the base and prevent the glomeration of the active phase. This will increase the lifespan of the catalyst. On the other hand, functional groups activate the hydrogen molecule and decompose it into hydrogen atoms, resulting in hydrogen penetration (Hydrogen Spill-over Effect). They also increase the reduction ability of catalysts and cause the reduction peaks to shift to lower temperatures. All of the above factors will increase the catalytic efficiency and cause its selectivity to be more than C5+ compounds lower than methane [82] [83]. Since the type of base is an important factor in the activity of the catalyst, the higher the base surface and pore volume, the higher the percentage of cobalt which can be placed on the base. Among the various types of bases used for heterogenic catalysts, carbon materials are of special importance due to their properties. Noble metals such as Ru, Re, Pt are widely used as elements enhancing cobalt catalysts. The oxides of intermediate, alkaline, and alkaline earth metals have also exhibited remarkable effects on this process [84-86].

8. CHARACTERIZATION OF BORON NITRIDE NANOTUBES FOR THE PRODUCTION OF NANOELECTRONIC DEVICES

One of the most important properties that distinguish CNTs in the electronics industry is their pseudo-metallic property. SWCNTs with a diameter of 1 nm can have similar behavior to both metals and pseudo-metals. So far, the purification or controlled combination of SWCNTs have not been fully implemented. This has made it difficult to produce nanoelectronic devices from these materials [87]. There is another type of nanotubes named boron nitride nanotubes whose inherent pseudo-metallic behavior resolve this problem. Boron nitride nanotubes have a high biocompatibility that makes it possible to use the parts and tools made of them in the tissues of living creatures. As we know, transistor is a voltage-controlled current source. To get a favorable piece with the desired efficiency, the existence of energy band gap with the appropriate size in the materials of the piece is essential. In this regard, CNTs face two major problems: first, the internal structure of CNTs is such that a number of nanotubes behave like conductors (energy overlap) and some of them behave similar to semiconductors (appropriate energy band gap for making electronic devices). Currently, there is no technology for the purification or controlled combination of these nanotubes. Therefore, it is not possible to precisely produce transistors from these materials with the appropriate energy band gap [88]. Second, the energy band gap of nanotubes forming these materials is strongly influenced by the diameter of constituting tubes. Currently, there is no technology to control the diameter of these tubes during their synthesis [89]. This leads to low efficiency of transistors made of these materials.

The inherent semi-conductivity of the nanotubes forming boron nitride nanotubes and their appropriate energy band gap (about 5.5 e-volts) eliminate the above-mentioned problems and make it possible to make components with high precision and optimal function. Figure 3 shows the approximate value of energy band gap of boron nitride nanotubes obtained from the density functional theory [90].

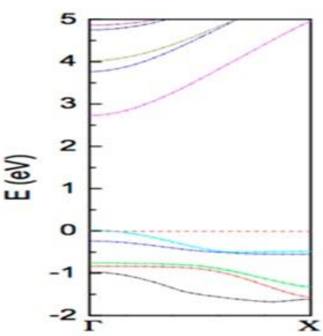

Figure 3. The structure of electron bands of boron nitride nanotubes

In memories of MRAM types, there are ferromagnetic materials whose equivalent resistance varies depending on the direction of their magnetic layers. These memories work based on the difference in electrical resistance caused by the direction of ferromagnetic layers [91]. Because of the impossibility of being polarized, CNTs cannot be a good option for the manufacture of these devices. By contrast, boron nitride nanotubes, with permanent polarization (0.25 to 0.4 colons per square meter), can be one of the possible options for making these memories.

9. SYNTHESIS OF NICKEL OXIDE NANOSTRUCTURES FOR THE MANUFACTURE OF NANOELECTRONIC DEVICES

Nickel oxide is a positive semiconductor (p-type) whose energy band gap is in the range of 3.4-4 eV. It has a wide bandwidth and high optic clarity in the visible area. In addition, it can act as an electron recipient [92-96]. Nickel oxide is an important transition metal oxide with a cubic network structure. In nanoscale, nickel oxide has better properties and, consequently, more applications compared to its bulk [97-99]. Reduction of the particle size of nickel oxide semiconductors usually leads to the substantial reduction in the width of capacity and conduction bands, resulting in the increase in energy band gap [100]. Very fine particles of nickel oxide are used for the manufacture of electrochromic films [101], magnetic materials [102], alkaline battery cathodes [103], and solid oxide fuel cell anodes [104]. Very fine particles of nickel oxide exhibit spermatogenic behaviors. If the surface-to-volume ratio for anti-ferromagnetic particles is large enough, there will be a momentary non-zero magnetic network due to non-coupled spins in the particle surface. As a result, the magnetic properties of this particle can be very different from the similar bulk [105, 106-109]. It has been shown that nickel oxide nanoparticles create large compulsory fields at low temperatures due to the anisotropy of the surface and ring transitions due to the non-coupling of the boundary transformation between the antiferromagnetic nucleus and the irregular magnetic fields. The magnetic behavior of nickel oxide particles is very complex and is strongly influenced by temperature, nucleus particles size, surface, and boundary [110-114].

Nickel oxide possesses chemical sensitivity, especially as a negative electrode, in lithium batteries and, hence, it is important to produce its nanostructure [115, 116]. Implementation of the nickel oxide cycle has a higher return capability than other transitional oxides such as cobalt oxide and copper oxide and, as a result, the producing batteries are less expensive. Production of semi-porous carbon materials using nickel oxide nanoparticles causes remarkable improvement in their properties to be used in the manufacture of catalysts, sensors, and advanced electrode materials. There are various methods for synthesizing NiO nanoparticles such as thermal decomposition [117], hydrothermal [118], coprecipitation [119], cell-gel [120], and microemulsion [121]. Wang et al. [122] produced copper nanostructure film using electrostatic deposition on a copper substrate. Then, placed the coating at a temperature of 350°C for one hour, so that a layer of copper oxide is formed on its surface. Their results showed that this coat is highly hydrophile at first but it turns into a highly hydrophobic state with a degree of 156° after being placed at the ambient temperature for 3 weeks. They proposed that the reason for this change is the physical absorption of oxygen molecules on the surface of copper oxide. Tian et al. [123] created a cover of nickel on copper through electrical deposition and then applied Ni-P alloy on nickel nanostructures using the electroless method. The resulting nickel coating had a cone-shaped structure with a wetting angle of 135°. Geng et al. [124] produced a superhydrophobic nickel coating with a micro-nano hierarchical structure by two stages of electrical deposition and observed a change in the wetting behavior of the coating from superhydrophilicity to superhydrophobicity over time. They attributed this change in the wettability behavior of these coatings to the formation of nickel oxide on the surface of the coating.

10. NANOSWITCHES

Nowadays, nanoswitches and nanoactuators are one of the most important components of nanoelectromechanical systems because of their numerous benefits such as low cost, low energy waste, low power requirements, high deformability, and relatively easy construction. The efficiency and function of an actuator are highly dependent on its geometry and type of materials used in the design of the actuator or the deformable part. Beam-like nanoactuators are widely used for their simplicity compared to other geometric shapes. The beam used in these systems is usually one-head clipper or two-head clipper. Silicon, silicon nitride, carbon nanotube, plutonium, and gold are commonly used for the construction of the actuator part. Considering the recent advances in the science of making various materials, nanomaterials are highly recommended to be used in the manufacture of nanoactuators and microactuators. The main components of an electromechanical nanoswitch are shown in Figure 4. These components are as follows:

- Source electrode: Displayed with S, this electrode connects to the source voltage.
- Gate electrode: Displayed with G, this electrode actuates the switch through an electrical connection.
- Drain electrode: Displayed with D, this electrode causes the electrical current to pass through after switch actuation.
- One-head clipper beam: A bridge that is used to transfer electrical current from the source electrode to the drain electrode.
- Insulating layer: Silicon dioxide is commonly used

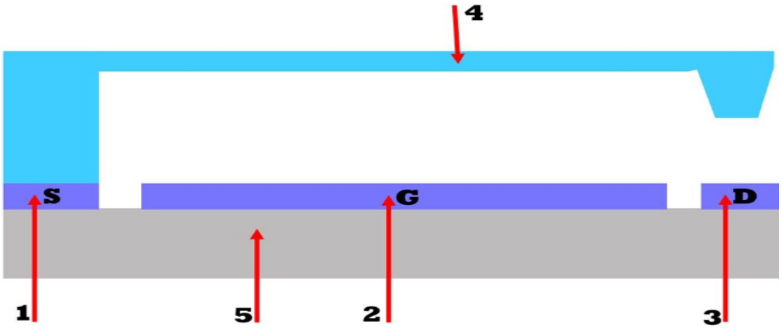

Figure 4. The structure of an electromechanical nanoswitch [125]

The three forces that play a major role in the function of electromechanical nanoswitches include electrostatic, elastic, and Van der Waals. Electrostatic force, by applying electrical voltage and creating opposite charges on two sheets, creates an electrical force between them that causes the plates to be absorbed. The elastic force is like a spring that returns to its original state after lengthening and Van Der Waals force is a force that links the molecules of a substance in liquid or solid state. When the potential difference is applied between electrodes G and S, opposite charges in the beam and Electrode G cause the formation of the electrostatic force (Figure 5). With increased electrical voltage, electrostatic force overcomes the elastic force of the beam and causes the bending and connecting of the end of the beam to the electrode D. According to Figure 6, the switch is on and the electrical current is transferred from the electrode S to the electrode D. When the voltage is disconnected in the electrode G, the elastic force causes the beam to return to the initial state and the switch turns off (Figure 5) [126].

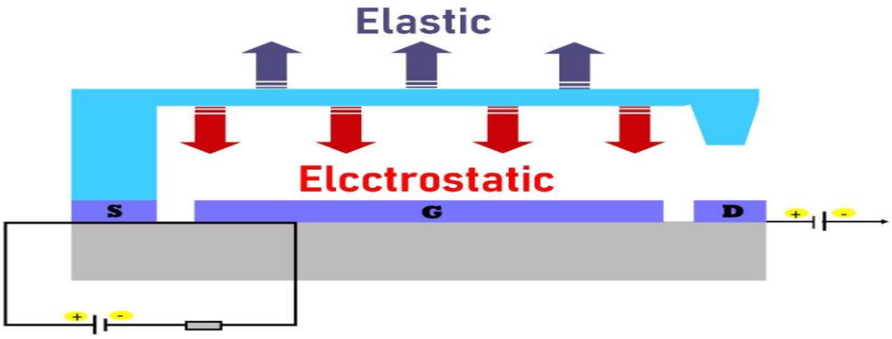

Figure 5. The off mode [125]

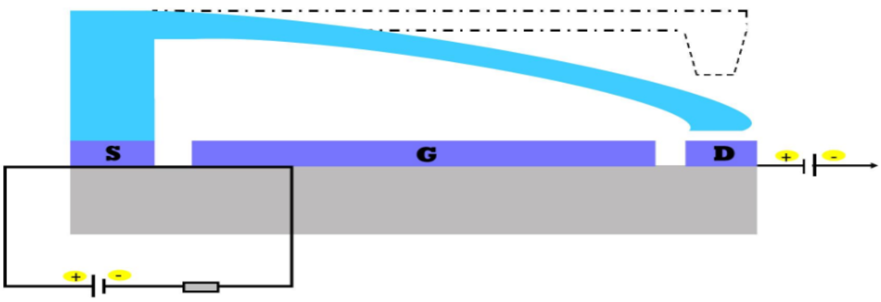

Figure 6. The on mode [125]

CNTs play a major role in the structure of electromechanical nanoswitches. Because of their exceptional physical properties, CNTs have caused many advances in nanoelectromechanical systems, such as the manufacture of a variety of memories sensors with a high sensitivity.

11. TRANSISTORS BASED ON GRAPHENE AND CARBON NANOTUBES

Transistors are the main electronic components used as amplifiers in analog circuits or electronic switches in digital circuits. The first field effect transistors based on CNTs were inverted a few years after the discovery of carbon nanotubes. In the simple elementary structure as shown in Figure 7, two metal connections play the role of source and drain electrodes and the carbon nanotube serves as the transistor tunnel, which is separated by a layer of oxide from a high-density silicon substrate. In this electronic part, the silicon bed plays the role of the back gate. Then, an upper gate transistor was introduced which is suitable to be used in integrated circuits [127-130].

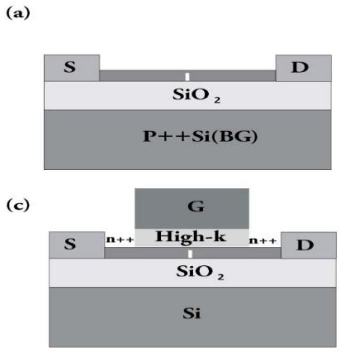

Figure 7. A cross-section of 4 different structures of carbon nanotube-based transistors; (a) back gate with doped silicon bed of p-type (b) a combination of upper and back gates (c) a combination of upper and back gates with nanotubes and impurities (d) CNTFET with upper gate and covered tunnel

Like transistors based on carbon nanotubes (CNTFET), there was a short time between the discovery of graphene in 2004 and the construction of graphene-based transistors, as the first graphene field effect transistors were produced only three years after the discovery of graphene in 2007. These transistors are like transistors based on carbon nanotubes with a difference that their canals are filled with graphene instead of CNT as shown in Figure 8.

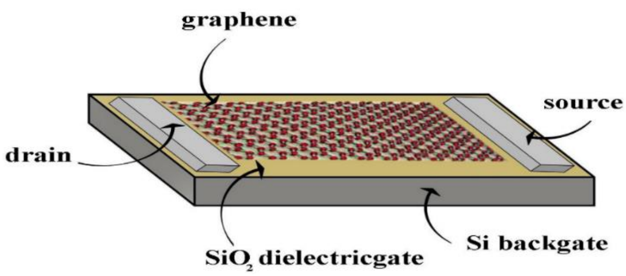

Figure 8. Graphene field effect transistor with a back gate

Unrivaled properties of graphene such as high electron mobility and thermal conductivity, resistance to fraction, low light absorption, and appropriate bandgap make it possible to make high-speed electronic components and flexible and transparent electronic circuits. Graphene transistors, like CNTFET, can have a variety of back gates and combined gates (upper and lower) [131, 132]. Single-layer graphene field effect transistors with an energy band gap of zero and two-layer ones with finite energy band gap have been theoretically studied and their characteristics have been reported by many studies [133-141]. With a honeycomb structure of an atomic layer width, graphene was mechanically separated from graphite for the first time in late 2004 [142]. Due to high mobility and two-dimensional structure, this material is very suitable for use in electronics. Since graphene has an energy band gap of almost equal to zero, it is necessary to create energy band gap in its structure before use in the channel of field effect transistors. This can be achieved by converting graphene into graphene nanoribbon (GNR), which can be easily done using the available standard lithography techniques. GNRs do not have the problem with chirality control that is observed in CNTs [143, 144]. GNR-based field effect transistors can be also divided into three categories including Schottky-barrier-type Graphene nano-ribbon field-effect transistors (SB-FET), metal-oxide-semiconductor field-effect transistors (MOSFET), and tunnel field-effect transistors (T-FET). In MOSFET structures, the lighting flow is of the thermal type. With the change in the gate voltage, the potential barrier is modulated in front of carriers moving from the source to the canal and the flow will change. Depending on the width of tunneling area in the drain and source side, the offset flow in the MOSFET structure is of band-to-band tunneling (BTBT) type. In tunnel structures, the on and off currents both are of BTBT type. Due to the nature of flow in tunnel structures, tunnel transistors have a much more appropriate subthreshold swing compared to MOSFET structures. However, both tunnel and MOSFET structures suffer from an inappropriate ambipolar flow. Many methods have been used to engineer the structure of CNT-based field-effect transistors [145-147], such as the use of a linearly-arranged area in the source and drain side [145], the use of light-arranged areas in the source and drain side [146], and ohmic-Schottky asymmetric structure [147]. All these methods improved the device performance in terms of off flow, the ratio of the on current to the off current (on/off), inherent delay (τ), and PDP. In addition, there are structures with the electrical arrangement in the source and drain areas [148-150]. Instead of using an arrangement in the source or drain areas, a gate with a suitable constant voltage is used in these areas in the above-mentioned structures. The use of areas with electrical arrangement creates a step in the energy band structure which leads to increased tunneling area width and reduced ambipolar flow in MOSFET structures. In addition, the creation of a potential step reduces the effects of a short canal. Hence, these structures are called MOSFET transistors with the electrical arrangement in the source and drain areas. This has been also studied in other studies [149] [150]. GNR-based field-effect transistors with a channel consisting of an array of graphene nanoribbons have been modeled and its electrostatic potential distribution was calculated by solving the Poisson equation [151].

12. NANO-ANTENNAS

The idea of turning solar energy into electricity was first proposed by Bailey [152]. Yet due to inability in making nano-scale structures, his idea was not commercially used until 2005. However, in recent years with the advancement in Nano technology and the possibility of constructing nanometer antennas and rectifiers, it has been proposed that solar rectenna systems could be a substitute for current photovoltaic panels for making electricity. The idea behind harvesting solar energy using nanoantennas is based on the fact that when solar electromagnetic waves hit the nanoantenna, an alternating current is produced on the antenna and as a result a voltage is created at the feed gap. Therefore by inserting a suitable rectifier at nonoantenna’s feed point, the desired DC current can be obtained. Such solar energy systems which include a nano-sized antenna and rectified are known as “Rectenna solar cell”. Nanoantennas normally consist of one or two metal nanoparticles placed at a distance of a few nanometers from the molecule. Given the extensive application of nanoantennas in modern technologies, much research has been conducted in recent years on their functionality, usage and modeling [153-159]. Enhancing the efficiency of solar cells [160], sensors [161] and molecules fluorescence rate [162, 163] are some of the usages of nanoantennas. In the fluorescence rate increase phenomenon, the nano-antenna acts as a two-way antenna: It first drastically increases the excitation rate by amplifying the electric field of the light shone around it (the location of the molecule) and then through a significant increase in decay rate of the molecule (transition from excited level to ground level) the molecule’s radiation capability is enhanced so much that molecule signal detection becomes possible. This process is based on formation of Surface Plasmon localized in the metal nanoparticle (gold, silver, etc). Surface Plasmon refers to the group fluctuations of electrons inside the nanoparticle under the influence of incident light, and it depends on the shape, material, nanoparticle’s size and permeability coefficient of the surrounding environment. However the energy dissipation inside the metal nanoparticle in the optical area is not negligible. Therefore, in designing nanoantennas various parameters must be carefully adjusted so that maximum fluorescence rate boost can be achieved with minimum energy dissipation. Several general principles have been suggested for designing nanoantennas, including adjusting the shape of nanoparticle, [154, 155], the nanoparticle substance [156], and the use of coupled nanoparticles [157]. The results of the modeling conform with the results of laboratory tests conducted for this purpose [159].

To increase the efficiency of solar cell technology it is proposed that optical nanoantennas with a suitable rectifier could be used at the nanoantenna’s feeding point, together they form a single unit called Rectenna. Conventional solar cells can achieve 30% efficiency at best, whereas nanoantennas are capable of reaching 100% efficiency in theory [164]. Nanoantennas have many applications in the frequency range of visible and infrared light, and therefore they make it possible to increase the interaction between light rays and nano-scale material [165]. Nanoantennas are a new concept in optical physics and they function similar to radio and microwave antennas. In using optical antennas the goal is to convert free space radiation energy into a localized energy and vice versa [166]. Figure 9 shows different types of nanoantennas.

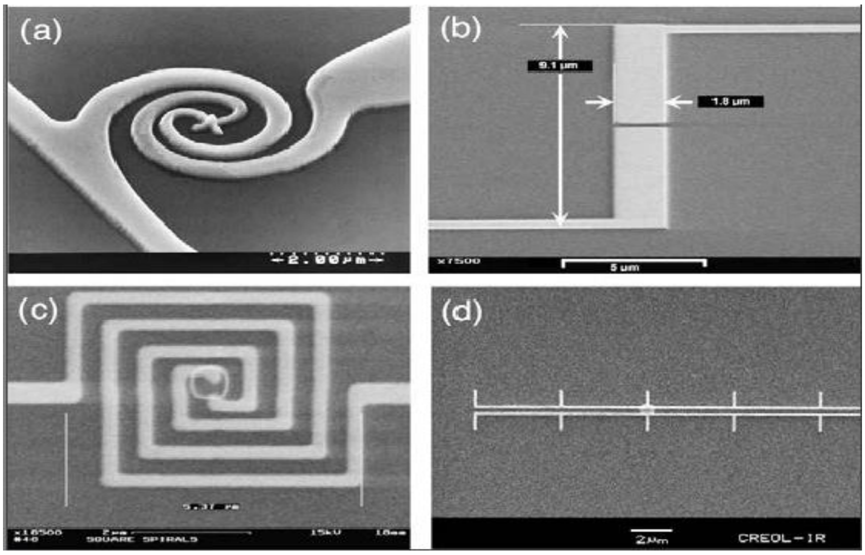

Figure 9. Different types of nanoantennas including; a) circular spiral, b) bipolar, c) square spiral, d) array [166]

Nanoantennas do not need a tracking system to follow sun's movement as they have a high capacity for angular absorption. And thus they retain a high efficiency even when the sunrays come at an angle [167]. The system can even absorb the energy reflected from the ground, in the other words the earth's thermal radiation, which is caused by sunshine during the day, occurring over the wavelengths of 10 micrometers (at frequencies of 30 terahertz), therefore the solar rectenna system can collect these radiations to produce electrical energy even at night or in bad weather conditions [168].

To convert alternative signals to DC a rectifier with proper power needs to be connected to the nanoantenna. At present, no rectifier can operate at very high frequencies (more than 30 terahertz). A Schottky diode which is a semiconductor diode with low voltage drop and a rather fast switching action has the ability of rectifying and detecting signals of up to 5 terahertz [169]. The most common rectifier used in solar rectenna cells is the MIM diode (Metal Insulator Metal Diode). This diode consists of a thin insulating layer of several nanometers in width placed between two metal electrode plates. The input signals are rectified based on electron tunneling process through the insulation layer. Due to the femtosecond tunneling time of an electron through a barrier and a drastic increase in response speed, the MIM diode can be used as an alternative to a Schottky diode in the infrared and visible light frequency range [169]. The MIM diodes have had a reasonably good performance in converting terahertz signals to DC output [169].

Certain conditions are needed for the rectifying process to happen, for instance the thickness of the insulating layer of the MIM diode should ensure the occurrence of the tunneling effect, while the passage of electric current should be very small and only a few nanometers. Moreover the area of the insulating layer needs to be very small so as to increase the diode cut-off frequency [170]. According to (1) the cut-off frequency of a MIM diode depends on the diode's resistance (R_D) and its capacitance (C_D) [171].

$$fc=1/(2\pi R_D C_D) \quad (1)$$

Since the diode's resistance value depends on its manufacturing process, the only determining parameter for MIM diode's cut-off frequency is the diode's capacitance value as expressed in (2) [169]:

$$CD=(\varepsilon_r \varepsilon_0 A)/d \quad (2)$$

ε_r refers to the relative permittivity of the insulating layer used in the MIM diode and ε_0 denotes free space permittivity, A and d are the area and the thickness of the insulating layer respectively.

As shown by (1), in order to achieve a high cutoff frequency, and consequently rectifying the terahertz frequencies of the infrared and visible regions, it is necessary to have a very low diode capacitance; therefore, according to (2), this can be achieved by either reducing the area of the insulating layer (A) or increasing its thickness (d).

However, increasing the thickness of the insulating layer decreases the tunneling probability of the MIM diode and therefore its response speed; on the other hand, although minimizing the insulation area would increase the diode's cut-off frequency and thus improve its performance in rectifying terahertz frequencies, but it would also make the manufacturing process complicated due to a few-nanometer structure [169]. Figure 10 shows an MIM diode connected to a nanoantenna. Nowadays, nano transfer printing or electron beam lithography methods are used to make MIM diodes, which can convert signals of up to 30 terahertz to DC [164].

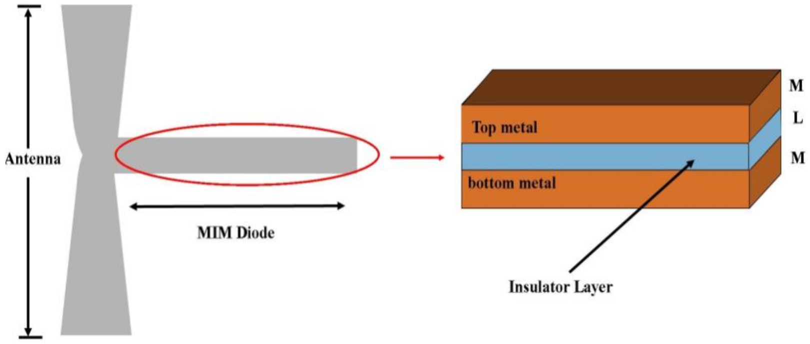

Figure 10. MIM diode connected to nanoantenna [172]

Another category of antennas is the graphene reflectarray antenna, an example of which is presented in [173]. Nanoantennas tend to have a much more significant amplifying effect on the fluorescence signal of molecules with quantum efficiency lower than one. Due to noise and other technical problem it is not possible to measure the fluorescence signal of a single molecule. But, this signal can be amplified several thousand times by using a nanoantenna in such a way that it can be measured by conventional detectors. For the first time, researchers at the Nano-optics department of ETH University managed to place a molecule at controlled intervals from a gold nanoparticle and measure fluorescence enhancement as a function of the molecule's location [159].

Microstrip antennas are one of the most widely used antennas in the terahertz band due to their strength, simplicity and low cost. Therefore choosing a microstrip antenna can be a good option for implementing nanoantennas in the terahertz band [174]. A graphene-based microstrip antenna with micrometer dimensions is able to resonate in the terahertz band. Furthermore by changing the graphene's chemical potential, we can easily change the resonant frequency of the antenna in a wide range of terahertz band [175]. In the [174] study, graphene was suggested as a general method for designing nano-based terahertz antennas. Akimov et al. [176] experimentally showed a 2.5-fold increase in the emission of a single quantum dot for the SPP mode of silver nanowires. Kühn et al. [177] reported a 20-fold increase in spontaneous emission by placing a single molecule in the LSP mode of a gold spherical nanoparticle. Further efforts to develop the designs improved the Purcell factor.

For example, Kuttge et al. [178] predicted the value of 2000 for the Purcell factor of a nano-cylinder made of Ag/SiO_2/Ag. The quality factor of this cavity was reported as 32 and its mode volume was 0.0026 $(\lambda / 2n)^3$. By making a V-shaped groove in a gold cube Vesseur et al. [179] managed to design a nanocavity with a quality factor of 10 to 50 and mode volume of 0.006 $(\lambda / 2n)^3$. The Purcell factor of this plasmonic nanocavity was predicted to be more than 2000. In their experiments Kinkhabwalas et al. [180] reported a 1340-fold increase in the fluorescence radiation of organic molecules in a system which included gold bowtie nanoantennas. For an emitter at the center of the golden bowtie nanoantenna Rogobete et al. [181] theoretically predicted a radiant emission increase of 1700 at 870 nm wavelength. Mohammadi et al. [154] examined the effect of the shape and size of gold nanoantennas on Purcell factor's value and Plasmon wavelength. In the research [182], the plasmonic bowtie nanoantennas (in form of two opposing prisms) were designed to enhance the electric field and the Purcell factor of the quantum dot emitters InGaN / GaN in the green region. The results showed that aluminum bowtie nanoantennas with a prism length of 63.6 nm, thickness of 30 nm, a vertex angle of 30 ° and the gap of 20 nm, when grown under a gallium nitride layer will have a Purcell factor of 81 at 535 nm wavelength. If, instead of gallium nitride-glass, aluminum nitride-glass is used the Purcell factor reaches 86.3 and resonance wavelength becomes 495 nm. Among the four metals (gold, silver, copper and aluminum) studied, the highest Purcell factor belongs to gold nanoantennas, nevertheless given the wavelength of the quantum dots InGaN / GaN in the green region, the best choice is Aluminum nanoantenna.

13. NANO PIEZOELECTRIC

The term piezoelectric refers to the electricity produced by pressure. Piezoelectrics are materials that when pressed or stressed, will produce electric charge on certain surfaces. Piezoelectric phenomenon is one of the most unusual features of certain ceramics. The bipolars of the ceramic are stimulated into creating an electric field when external force is applied [183]. A complete formulation of piezoelectricity was done by Pockels and Duhem [184]. The advancement of nanotechnology has made it possible to manipulate piezoelectric effects at nanoscale level. Given their electric-mechanical energy conversion characteristics, Piezoelectric composites have found a wide range of applicability in sensors and operators to control various systems. Piezoelectric composites have drawn much attention in the quest for simultaneous metal-ceramic properties found in inorganic nano composites such and nanowires, nanotubes, nanorings and nanostraps. Piezoelectric composites acquire isotropic properties around the axis along which they are polarized [185].

Korayem and Ghaderi studied the vibrating motion of piezoelectric microbeams in non-contact mode and obtained the non-linear microbeam response near sample surface by using multiscale numerical solution. They also made use of the Sobel method and examined the effect of microbeam geometric parameters on its vibrational behavior [186]. An analysis on nano-wires and nanobelts was done by Wang [187]. Park et al. [188] studied the thin layer of barium-titanium film in nano-generators. While Galan et al. [189] investigated the effect of zinc oxide nanowire on the resistance of carbon coated nanowire. Research [190], dealt with the analysis of free vibration and Timoshenko nanobeam bending of functionally graded Piezoelectric by using strain gradient theory. Research [191], studied the thermo-mechanical bending of nanoplates on an elastic bed in a humid environment. An analysis of nonlinear bending of orthotropic nanoplates in elastic forms has been done in [192]. Şimşek and Yurtcu [193] have provided an exact solution to the bending and buckling of functionally graded nanobeams based on the Timoshenko beam theory. Also, Hosseini-Hashemi et al[194]. Worked on the exact solution of rectangular nanoplate free vibration based on the first-order shear deformation theory. Wang et al. [195] investigated the propagation of waves in alternating layered nanostructures. Sobhy [196] analyzed multi-layer graphene shells under different boundary conditions using bivariate plate theory. Liu et al. [197] offered the exact solution of the free vibration of piezoelectric composite nano-plate based on the classical plate theory, along with the effects of the nanoscale coefficient and thermos-electro-mechanical loads on the natural frequencies of the piezoelectric composite nanoplate. Arani et al. [198-201] focused their studies on the nonlinear bending- buckling behavior of Boron nitride nanotube using beam, plate and shell models. Studies [202-204] investigated the free vibration, nonlinear vibration, and thermos-electro-mechanical post-buckling in piezoelectric nanobeams based on Timoshenko beam theory using nonlocal theory. L.L.Liu et al. [205] studied the analytical solution for piezoelectric composite nanoplate based on the first order shear deformation theory, using nonlocal theory and the effect of the measurement scale and thermos-electro-mechanical loads on natural frequencies.

Research [206] studied the bending and free vibration of thick isotropic plates based on exponential shear deformation theory. They also performed a stress analysis on thick laminated plates based on trigonometric shear deformation theory [207]. Torsional vibration analysis of the thick plate was done in study [208] based on the exponential shear deformation theory. Soares [209] presented trigonometric shear deformation theory for isotropic composite laminated and sandwich plates. Liu et al. [197] presented the exact solution of free vibration of piezoelectric composite nanoplate based on the classical plate theory, along with the effects of the nanoscale coefficient and thermos-electro-mechanical loads on the natural frequencies of the piezoelectric composite nanoplate. L.L. Liu et al. [205] also studied the analytical solution for piezoelectric composite nanoplates based on the first-order shear deformation theory and by using nonlocal theory and the effect of the size scale and thermos-electro-mechanical loads on the natural frequency. Tounsi et al. [210] studied the thermos-elastic bending of functionally graded sandwich plates using the trigonometric theory, the development of a trigonometric shear deformation theory for analyzing the free vibration of a symmetric laminated composite plates was investigated by Rango et al. [211]. Khorshidi and Fallah [212] studied the buckling of the functionally graded nanoplates using exponential shear deformation theory based on the theory of nonlocal elasticity. Also Khorshidi et al. [213] analyzed the free vibration of a functionally graded nanoplate using exponential shear deformation theory.

14. CARBON NANOTUBE-BASED NANOCOMPOSITE MAGNETITE

Magnetite nanoparticles are very sensitive due to their high surface area, and the presence of Van der Waals forces and magnetic force among them leads to their concentration. Therefore, it is necessary to modify the nanoparticles' surface using organic or inorganic materials [214]. In recent years, much research, especially in the field of nanotechnology, has gone into the study of magnetite synthesis with different shapes and sizes, and so far various forms such as nanowires, nano-spheres and hollow nanostructures have been synthesized and analyzed by researchers [215-219]. Employed the solvothermal method to produce spherical magnetite nanostructures using iron chloride precursor and applied Polyvinylpyrrolidone (PVP) as a protective agent and sodium acetate as a precipitating agent for the resulting nanostructures [220]. Studies [221, 222], also made use of carbon nanostructures to enhance the performance of spherical iron oxide nanostructures, and produced a composite of carbon-based iron oxide by carbon coating the spherical magnetite surfaces.

The researchers In the studies of [221, 222], used carbon nanotubes to enhance the performance of spherical iron oxide formations and thus by creating a carbon coating on surface of spherical magnetite they could produced composite magnetite from iron oxide based on carbon. In recent years, carbon nanotubes have been considered as a carbon allotropic with unique and directional properties. In particular, carbonate nanotubes (Fe_3O_4-CNTs) have significant properties and are used extensively in the production of magnetic dyes [223], lithium ion batteries [224, 225] and printer inks [226].

In research [227] carbon nanotubes-based magnetic nanocomposite (Fe_3O_4-CNTs) was synthesized using the solvothermal method. The research, uses various characterization tools to analyze the structure of nanocomposite Fe_3O_4-CNTs, including Transmission Electron Microscope (TEM), X-ray diffraction (XRD), Fourier- Transform Infrared Ray (FTIR), Magnetometer (VSM) and Zeta Potential. Based on TEM and XRD results, the size of magnetite particles and crystals was found to be about 150-250 nm and 7.3 nm, respectively. After reviewing the results of VSM analysis in this study, it emerged that the resulting nanocomposite has paramagnetic properties that can be applied in the electronics and computer industry; furthermore the thermal behavior of the water-based magnetic nanofluid Fe_3O_4-CNTs was studied in the presence of a magnetic field. The results show a 30% increase in the nanofluid heat transfer coefficient after an increase in the magnetic field intensity of about 2.3 mT, which suggests a possible application in cooling of electronic devices.

15. CONCLUSION

With the rapid progress of science and industry and the growing need for small and fast electronic components with low power consumption and also physical constraints silicon-based technology, nanoelectronic devices have been continuously considered one of the best options. In the meantime, nanotubes have always been at the center of attention of today's scientific communities as the raw material for producing these devices. Developments and advancements in the field of nanoelectronics, have greatly solved problems and limitations in this regard. Because of desirable electronic properties, carbon-based nanometric structures have been to the interest of researchers in recent years and is considered a suitable alternative to silicon structures such as transistors. Considering the properties of CNTs and the lack of an advanced purification technology, CNTs are an excellent choice for use in the nanoelectronics and computer industries because of intrinsic semiconductivity and high chemical resistance. However, it is noteworthy that the exact dimensions of all properties of nanotubes are not yet known. One of the most prominent features of CNTs is increased surface-to-volume ratio in microchips and memories. For example, if about a hundred million keys can be placed in one square centimeter chip of semiconductor type, about a trillion keys can be embedded in one square centimeter of a CNT-based chip. Studies have shown that very small structures with very low energy consumption and high power and efficiency can be produced by incorporating nanotechnology with the processes of manufacturing electronic devices. The present paper aimed to study applications of nanotechnology in the electronics and computer industry and evaluate the structure and properties of nanotubes as one of the options for the manufacture of nanoelectronic devices. Development of multifunctional electric nanostructures can have profound and great effects on studies in the area of electronics and introduce new engineering applications. Therefore, many research opportunities will be provided for the future. The present research dealt with the relationship between nanoelectronics and computer and electronic systems.

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