Journal of Medicinal and Nanomaterials Chemistry, 2019, 1(2), 131-148.

Mini review

Nano Fabrics in the 21st century: a review

Munima Haque *

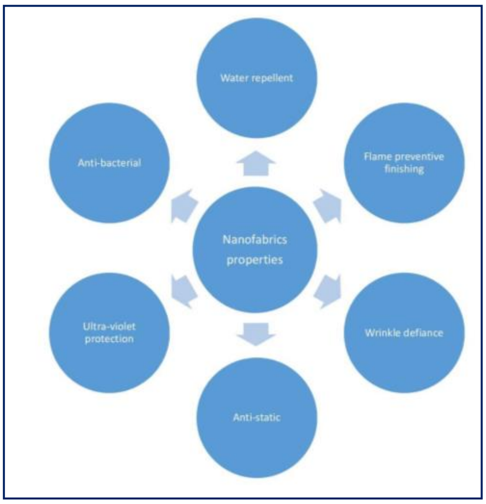
Research Fellow, Relevant Science & Technology Society, Bangladesh.

Received: 17 January 2019, Revised: 25 February 2019 and Accepted: 29 March 2019.

ABSTRACT: Nano technology refers to enhancing the function and delivering the upcoming smart solutions to products at the nanoscale level. It relates to organizing the molecules for altering in dimension and characteristic for improvement like smart fabric. These fabrics could assist producers with the added prominence on a standard of living, visual attraction, and system wanted technological produces. Nanosize particles can unveil unpredicted characteristics dissimilar from the bulk matter. The fundamental principle is that the features could radically be altered after the material is decreased to the nanometer scale. Nanotechnology has multipurpose functions in fabric manufacturing in producing the stain and wrinkles defiance, flame retardant, antimicrobial and antistatic properties, moisture control, ultraviolet protection, and release features. The nanomaterials inside the fabric could influence numerous qualities, comprising reduction, electrical conductivity, flammability, and strength. Nanotechnology has additionally created a significant impression on various application and implementation. Nano-doctored fabrics may advance numerous fabrications as the nano-science progresses further.

KEYWORDS: Nanotechnology; Fabrics; Water-Repellent; Anti-Microbial; Anti-Static.

GRAPHICAL ABSTRACT:



1. Introduction

Nanoscience and nanotechnology are the analysis and function of tiny objects and could be utilized through other science areas such as physics, biology, materials science, engineering, and chemistry. Nanotechnology is defined by these extents of engineering and science where incidents happen at sizes in the nanometer scale and are exploited in the plan, categorization, fabrication, material functions, structures, systems, and devices [1]. Nanotechnology is the contriving of working arrangements at the molecule scale. It is intrinsic that these nanomaterials would show varying characteristics from larger substances due to their size. These variations comprise the electrical conductance, optical effects, physical strength, chemical reactivity, and magnetism [2]. Nanotechnology has an incredible ability to provide humanity, thriving environmentally, and socially in justifiable processes [3]. Producing the nanoparticles is one of the

***Corresponding author:** Munima Haque, E-mail: munima.haque@gmail.com

Journal of Medicinal
and Nanomaterials
Chemistry

exciting developments in the nanotechnology arena. Nanoparticles occur extensively in nature, and currently they are purposefully produced from metal oxides.

Nanomaterials are developed and used because they have superior specific physical and chemical characteristics compared to that of the common substance with similar chemical arrangement. Nanotechnology conquers the restriction of applying traditional methods to impart particular characteristics to fabrics. At the present, clothing is predicted to be waterproof, self-cleaning, flame resistant, antimicrobial, and insect repellent to prevent disease, protected from Ultraviolet light, also temperature controlled clothes for comfort [4]. Nano-objects can display various properties compared with that of the bigger dimension. Integrating the nano substances inside the fabric may influence various characteristics including, the electrical conductivity, strength, shrinkage, and flammability. Widely reviewed nano-related topics in history are nanofibers, nanocoated fibers, and nanocomposite fibers [5].

2. Nanotechnology History

The history of nanotechnology started its journey in December 1959 by Professor Richard Feynman's famous lecture at CalTech where he recognized the capability of nanotechnology. Feynman said it would be achievable for machines to manufacture objects small enough having microscopic precision. First, Norio Taniguchi introduced the term "nanotechnology," in 1974 referring to the precision and refinement of one-nanometer scale. Eric Drexler wrote a famous nanotechnology book, Engines of Creation, in 1980s, where the perception of molecular assembly was introduced to public. Nanotechnology has been moving forward quickly since 1990s [6]. Nowadays, the next industrial revolution is going to be nanotechnology. Nanotechnology will drastically alter the technology in 21st century. Nanotechnology has an incredible influence on the physical, medical science, and chemical fields along with the substances and informatics. Nanotechnology overpowers the restriction of implementing conventional techniques for exposing particular characteristics into fabrics. In a couple of years, nanotechnology will access in all areas of the fabrics business. [7] Nanotechnology comprises imaging, measuring, modeling, and maneuvering substance at this smaller level in various fields encompassing engineering, science, and technology. Elements engineered to such a minute size are frequently indicated as engineered nanomaterials, that has distinguishing electrical, magnetic, and additional evolving characteristics that have the capability aimed at immense influence taking part in electronics, medicine, and other areas. [8], [9]

3. Fabrics: A Fast-Growing Sector

Nowadays, nanotechnology is considered one of the most assuring skills. In a couple of years, nanotechnology would invade all areas of the fabric industry. Nanofabrics are nano level harsh substances that can be workable by multiple ranges of new characteristics. These materials are utilized both as fabric for clothes and filter substances, sterile food wrapping elements in foodstuff processing, and gauzes for curing of injury. Recently it was demonstrated that nanotechnology could be utilized to elevate fabric qualities. The development of smart nano fabrics can transform the manufacture of fibers, fabrics or nonwovens, usefulness of the cloth, and various sorts of fabric merchandises and usage.

Fabrics sector is one in which nanotechnology is rapidly growing. Fabrics and clothing perform a significant part in the progress and industrialization process of countries and their incorporation into the world economy. All world regions have

Journal of Medicinal and Nanomaterials Chemistry

undergone over ten-fold increase in the manufactured goods sectors within the last few years: regions with an above average share include Asia and for clothing Central and South America, Africa and Asia [19, 20]. The primary fields of fabric applications are healthcare, packaging, sports and leisure, defense, home and household, industry and machinery, environmental protection, geotextiles and civil engineering materials, clothing.

4. Fabric History

Fibers are generally allocated into human-made (artificial/synthetic) and natural (mainly cotton and wool) fibers. Human-made fibers are increasingly being more utilized: in 2007 it explained about 65% of the fiber usage, which had increased from about 62% in 2006. The manufacture of natural fibers is gradually declining. China has been the significant most significant contributor to this change that was around 8.7% in the year 1990, in 2007 it has increased to 55.8%. The global fabrics industry is about USD 4000 billion, and the forecasts show that it will expand to around USD 5000 billion in 2012. Europe also has a significant role to play. In 2001, the EU had been the second largest for clothing export leader of fabric accessories with 10% contribution. China is also a significant participant in globally. The rest of the main fabric business partners are Taiwan (10%), South Korea (10%), and the USA (8%), while some expanding responsibility is acquired by developing countries like India and Brazil. Clothing fabrics have 60% while furnishing fabrics have 35% of the total business. Rest of about 5% are technical non-conventional fabrics of which medical fabrics are 0.75%, outdoor and sports fabrics are 0.20%, and military fabrics are 0.15% of this. The competition is rising, and the scientific invention is vital to move along with it. The transition of European business from labor-concentrated into a knowledge-based for developing high-value yields, novel industrial techniques, consumer demands, endorse progress, ecological and health protection and further prospects, is central to persist driven globally [10].

In the fabrics industry, nanotechnology has been utilized in the manufacture of quantum dot [11, 12] referred to as semiconductor nanocrystals [13]. Dye-molecules are being used for creating threads. The color alters with the growth of the size of the particle in nanocrystals therefore likely to develop various particle sizes from a single substance having varying optical characteristics which span the complete visible spectrum region [14]. There are numerous probable ways nanotechnology [15] can be integrated into fabrics that give excellent functionality [16]. Nanofinishing in fabric technology is very encouraging owing to multiple usages like shielding fabrics for medical textiles, smart textiles, and soldiers [17, 18]. Cotton is the maximum regularly utilized everyday outfit stuff [19, 20], which is the lone renewable reserve, biodegradable [21] and easily accessible. Cotton is comprised majorly of fiber [22] molecules, therefore linking working tags to cotton threads [23] remains a problematic venture, so chemical and physical diversities is essential to be taken care of properly. By accumulating nanoparticles made of metal onto the cotton, increased usage may be obtained [24]. Nanofibers have shorter pores and larger surface area compared to conventional fibers that allow broader usages in tissue scaffolds, nanocatalysis, filtration, shielding outfits, and electronics in optics. The electro-spinning process is where an electric field (high voltage) is utilized to generate electrically excited steams from polymer [25] solutions that on drying using evaporation of the solvent create nanofibers [26]. Production processes for nanomaterials [27] are also complicated dangerous in some cases [28]. Nanotechnology also has real commercial potential mostly as regular

Journal of Medicinal and Nanomaterials Chemistry

methods used to expose various attributes to fabrics frequently does not result in everlasting outcomes, and will not work correctly post wearing and doing laundry. This technology provides excellent stability for fabrics as nanoparticles [29] exhibit a vast area of surface vs. volume ratio also elevated surface energy, therefore, containing an improved attraction to fabrics, advancing toughness [30]. The nano-emulsions particles have provided a distinctive characteristic of readily being taken up by the skin which is very much desired as valuable in fabric business [31].

5. Achievement of Nanotechnology in Fabrics Industry

Human lifestyle has been changed with fast development. The new generation has been very comfort-oriented and needed all things smaller to carry them easily, cheaper, safer and want quick working products. Nanotechnology is contributing with its unique properties in textile for everyday fabric like water and oil repellent, self-cleaning, anti-bacterial, anti-static, ultraviolet shielding, stain proof, moisture control in synthetic fabrics instead of depriving in the unique breathability and toughness of the fabric. The novel characteristics of nanotechnology have fascinated researchers and scientists resulting in the use of nanotechnology which is rapidly increased in fabric industries. In last decade Nanotechnology has given the achievements in the field of the fabrics by various fabric cures for promoting the superiority of fabric concerning smoothness, sturdiness, rip potency, crease and scratch defiance, etc. Natural fibers used commonly (like silk, cotton, and wool) also synthetic fibers (like nylon and polyester). Synthetic fibers are mostly useful for industrial and household purposes. Also, nanotechnology provides various benefits than the traditional procedures regarding the energy saving, economy, eco-friendly, controlled discharge of matter, storage, wrapping, and isolating material on a minute grade. Fabrics and fabric-based composites are anticipated to substitute most of the plastic and metallic and equipment used in, e.g., the automobile business, construction areas, machinery and machine tools manufacturing, electronics, leather, wood, and other regular resources, sports merchandises, and several different usages. Therefore, it is evident that nanotechnology portrays an essential part of the fabric industry.

6. Impact of Nanomaterials in Fabric Production

When using nanomaterials in the production, these materials are either integrated into the fiber volume or applied as a coating onto the textiles. Nanoparticles give great robustness for remedied fabrics owing to having essential surface area and energy that safeguard enhanced attraction for fabrics leading to an improved toughness for the preferred fabric [32].

Nanofibers: Nanofibers have a diameter < 1 mm or 1000 nm. Nanofibers are mainly manufactured by the electrospinning procedure used starting from the beginning of the 1930s. Nanofibers can be produced having various diameters. There are multiple usages of nanofibers. Nanofibers have a small pore size and an elevated upper exterior area to volume ratio, which permits spore-forming bacterium like Anthrax or viruses to be caught. Examples are filtration devices and wound dressings. Researchers are working on trying to utilize nanofibers having diameters in the 4 nm scale to replace for an artery which is injured or ailing, efficient of imitating the natural process of the wall of an artery. New usage of nanofibers can be sensors and drug delivery systems.

Nanocomposite Fibers: These are made with diffusing nano-size fillers inside a matrix of fiber. The biological, optical, mechanical

Journal of Medicinal and Nanomaterials Chemistry

characteristics of the fabric could be changed contingent to the sort and quantity of the nano-material utilized. Nanocomposite fibers are rigorously utilized in aerospace, automotive, and military field. Most nanocomposite fibers utilize a filler, e.g., metal oxide nanoparticles, graphite nanofiber, nanosilicates, also single wall and multiwall carbon nanotube. SiO_2 increase the durability of fiber, control fragrance and make that antibacterial, self-cleaning and water/dirt repellent [31].

Nanoparticles: These comprise of metal oxides, carbon black, and clay. In nano level, metal oxides are naturally photocatalytic, ultraviolet absorptive, conductive electrically, and photo-oxidizing alongside biological and chemical types. Metal oxides examples are ZnO, TiO_2, MgO, and Al_2O_3. Swim attire fabric is assembled by including ZnO to nylon for creating complex fibers which are anti-static and prevent ultraviolet radiation. Clay nanoparticles are resilient to chemicals, heat, electricity, and can shield ultraviolet radiation. So including it into fabric can have fabric alongside enhanced flexural and tensile strength and modulus. Nanocomposite fibers that use clay nanoparticles could become ultraviolet light and flame resilient, corrosion shielding. Clay nanoparticles are included inside nylon for being flame resilient to the fabric devoid of discharging lethal gas. Carbon nanofiber and nanoparticles are able to raise the tensile strength of composite fibers successfully.

Carbon black nanoparticles and graphite nanofibers (GNF): These are frequently used nanofillers in the fabric business that enhance their abrasion endurance and durability of composite fibers. Complex fibers which include GNFs have improved tensile power. For these nanofillers, matrices, e.g., polyester, nylon, and polyethylene have been utilized.

Carbon Nanotubes (CNT): These comprise of small graphite shells made as cylinders, and categorized as single walled and multi-walled. CNTs have 100 fold the potency of steel and 1/6 its weight. CNTs possess electrical conductivity like copper, has the capability of conducting more significant amounts of currents compared to copper. CNTs have a thermal conductivity greater than the untainted diamond. Some usages are sensors, screen displays, airplane configurations, detonation resistant covers, electromagnetic defense, and electronic fabrics. Looking like regular fabrics, nanotubes can be utilized for clothing that includes wearable computers, electronic appliances, etc. due to its appearance like Attire that uses nanotubes can endure several home laundry cycles.

Nano-coated Fibers: These are manufactured by accumulating coatings of varnish on top of thread surface. The width of each layer is on the nanometer scale. Few techniques were utilized for operating a nano-coating on the fiber surface [5].

Silver nanoparticles: When silver nanoparticles are applied to the fabric, it can destroy bacteria [33] that produces clothes odor resist. Nanosilver particles possess a vast surface area, assisting in the growth of their assembly amongst multiple microsystems [34] as well as enhancing the prevention of growth for bacteria and fungi [35, 36].

Titanium dioxide: TiO_2 is a photo-catalyst. Fabric remedied with nano-TiO_2 can deliver a valuable shield to bacteria and staining color owing to the photocatalytic action. When lit by light having greater energy gaps in the band, the TiO_2 electron [37] leaps beginning from valence towards conduction band. When an organic amalgam plummets to the exterior to a photo-catalyst, it merges and converts to water and carbon dioxide [38]. This effect is named "oxidation-

Journal of Medicinal and Nanomaterials Chemistry

reduction" [39-41]. By this, the photo-catalyst can decay typical airborne organic substances like a virus, bacteria, and odor particles [42, 43].

The utilities portrayed here are the primary tasks of the nanoparticles on the fabric. The utilization of the gold and silver nanoparticles [44] enables the anti-bacterial, antifungal, and odor resistance properties [45, 46]. Nanowhiskers are utilized for the water repellent characteristics, and titanium dioxide is used for the ultraviolet shielding. Nano-silica and Nano-titanium dioxide improve the crease defiance of silk and cotton. Carbon nanotubes CNTs are essential substances owing to their high strength and greater electrical conductivity. CNTs could be utilized in the cloth making that includes wearable computers or electronic appliances. CNTs offers electro-conductivity, fire resistance, self-cleaning, antistatic, water repellent, and high toughness for fiber [32]. Highly durable, reliable and necessary tasks-related nano fabrics are proficiently manufactured for many usages, e.g., sports, medical and industrial purposes, and military. Nanotechnology has a bright future with its excellent characteristics and the marvelous outcomes [47, 48].

7. Current Nanofabric Properties

7.1 Water-repellent property:

This characteristic of the tissue is adjusted through generating nano whiskers [49]. Nano whiskers are hydro-carbons and one-thousandth of the dimension of a conventional fiber made of cotton which is adjoined to the fabric. Gaps inside the cotton whiskers are lesser compared to regular water drop yet more significant than molecules of water. Therefore water stays over the hairs or whiskers and top of the fabric exterior [50]; however, the liquid can even now slip via the cotton material in the usage of pressure. Nanospheres impregnation includes 3D surface configures with gel-forming extracts that resist H_2O and avoid dust particles from connecting. Lotus plants [51] have superhydrophobic surfaces that are strong and have raised surface. When water drops cascade on lotus leaves, water drops slopes the surface a little and rolls off keeping the surfaces dry still in the substantial rain. Also, the droplets collect small dirt particles while rolling and the lotus leaves stay spotless yet in the drizzle. This hydrophobicity [52] characteristic may be used in the clothing of cotton by layering it by slim nano-particle plasma coating. Self-cleaning fabrics utilize nanocrystals treatment by regulating surface interaction and wettability.

7.2 . Anti-Bacterial Property

In favorable situations, numerous microorganisms (fungi, virus, and bacteria) buildup as well as numbers escalating by body contact. In contact, this increase may instigate staining, staining, fabric surface ruin, and creates an indecent smell. It is reported that microorganisms can outlive on fabric substances for over ninety days in hospital surroundings. With this elevated lasting duration of pathogens on medical fabrics can provide to the spread of diseases in clinical settings. Therefore, the application of antimicrobial fabrics in healthcare services is deliberated as a possible answer [53]. The alteration of the surface of fabrics gives novel characteristics to fabrics keeping mechanical potency and coziness. Recently, the antimicrobial finishing of fabrics has also expanded to various usages in the medical, textile, engineering, agricultural, pharmaceutical, and food industries [54]. For this, the various anti-microbial agents appropriate for fabric usage in the marketplace has significantly raised. These anti-microbial products vary in their usefulness, the usage technique, and chemical assembly, consequence on surroundings and humans, and price [55-59].

Journal of Medicinal and Nanomaterials Chemistry

Bound antimicrobials are ecologically welcoming varnishes with no leakage of toxins into the atmosphere. The particle numbers per area are augmented by inclusion of nano-sized elements, and so anti-bacterial outcomes may be exploited. Nano-silver is significantly responsive to proteins, and with contact with fungus and bacteria, it will harmfully influence cellular digestion and restrain cell development. It also overpowers respiration and prohibits the increase and progress of these fungi and bacteria that instigate odor, infection, sores, and itchiness. So, nano-silver particles are considerably utilized in socks for evading bacterial development. Moreover, nano-silver can be useful for other health-related areas like skin donor, burn to dress, scald, and recipient locations. Nano-sized silver [60], zinc oxide and titanium dioxide are used for utilizing anti-bacterial characteristics. Metallic ions [61, 62] and metallic compounds show specific sterilizing reaction [63]. Anti-microbial finish is vital so that (1) to defend the fabric consumer opposed to pathogenic systems, (2) to safeguard wearer opposed to micro-organisms that causes odor, (3) to endure the laundry procedure, (4) to defend the fabrics from destruction affected by rot, mold, mildew generating micro-organisms (5) to defend the fabrics from decline, staining, (6) to help keep a harmless hygienic setting, and (7) anti-microbial completions and cures in fabrics may assist to regulate septic situation, and by halting microbial evolution may increase the lifespan of the merchandise [64].

7.3 Ultra-violet protection property: Inorganic ultraviolet-shields are far desirable than organic ultraviolet-shields as being chemically stable and non-lethal under contact to extreme temperatures and ultra-violet. Inorganic ultraviolet-shields are generally specific semiconductor oxides like SiO_2, TiO_2, ZnO, and Al_2O_3. Amongst them, TiO_2 [65] [66] and ZnO [67] are regularly utilized. Zinc oxide and titanium dioxide in nanometer level were extra effective in scattering and absorbing ultraviolet radiation than the traditional size, also could obstruct ultraviolet [68] [69]. Nanoparticles possess a greater surface-area/mass and volume compared to traditional substances, directing to the rise of the usefulness of shielding ultraviolet radiation. Ultraviolet shielding therapy was utilized for cotton fabrics. A slim coating of TiO_2 is founded outside the doctored cotton cloth exterior providing outstanding ultraviolet-defense which could be continued following fifty home laundry [70]. Besides the TiO_2, ZnO nanorods with 10 to 50 nm length are used in cotton clothes for providing ultraviolet defense [71].

7.4 Anti-Static Property

A static charge generally develops in synthetic fibers (like polyester and nylon), as they engross less water. Cellulosic fibers provide increased dampness due to carrying static charges to prevent any static charge to accumulate. Because artificial fibers provide distressed static free characteristics, the study showed that nano TiO_2 [72], ZnO whiskers [73], nano ATO, [74] and silane nanosol [75] could provide static free characteristics to artificial strands. ATO, TiO_2, and ZnO deliver static free outcomes as these possess electrical conducting properties. Whereas, silane nanosol increases antistatic characteristics because the silane gels on fiber engross humidity in the water and air regarding amino and hydroxyl groups and constrained water. The anti-static procedure can get rid of regular method limitation where the anti-static agent can be effortlessly diminished after a couple of laundries.

7.5 Wrinkle defiance property: Resin is generally utilized to add wrinkle resistance to a piece of fabric. The limitations for applying raisins include a reduction in the fiber tensile strength, water permeability and dye properties, abrasion resistance, and

Journal of Medicinal
and Nanomaterials
Chemistry

breathing ability. For this, multiple researchers have used nano TiO_2 [76] and nano silica [77] for recovering the crinkle defiance of silk also cotton. The outcome showed that when nano silica used as a catalyst with maleic anhydride can effectively recover the wrinkle resistance of silk.

7.6 Flame preventive finishing:

Nyacol nanotechnologies TM has devised colloidal antimony pentoxide that can be used for a flame retardant finish in the fabric. Nano antimony-pentoxide is utilized along with halogenated blaze preventive substances in clothing [78]

8. Nano-Products Available Commercially

Nanotechnology is improving with exploration, depending on the communal and private research and development funding. Nanotechnology utilized in consumer goods is increasing, while the nanotechnology products industry is projected to increase at a fast pace.

8.1 Nano-Tex

It originated in 1998 in California, [79] is a pioneer for nano-cures particularly made for fabrics. The 1st commercial Nanotex product was introduced in December 2000. Today, over a hundred fabric industries globally are using Nanotech's patented nano cures. Nano-treatments are everlasting and do not endanger the visual or automated characteristics of the fabric. Cures can be done to some fibers comprising polyester, silk, wool, and cotton. Nano treated fabrics can be wrinkle and spill resistant, stain and static proof. (a) Resists Spills: This can be used to [80] silk, cotton, polyester, rayon, or wool. After utilizing the Resists Spills treatment, the fabric turns out to be stain resistant and liquid repellent. Liquids like water, oil, wine, coffee, and tea. bundle and rolls down the fabric and never pervade it, as the fabric is created as ultra-hydrophobic. (b) Coolest Comfort: This is introduced in December 2000, was primarily intended for synthetics. The remedied fabric drags sweat from body permitting the person to remain sweat-less and relaxing. It was particularly devised for refurbishing the intrinsic wicking characteristics of cotton which is treated by rasin. (c) Repels Static: This is the 1st everlasting static-less cure used in artificial fibers. The treatment further prevents statically attractive materials like lint, dust, and dog hair. (d) Resists and reliefs spots: This is pertained to cotton, and also cotton with polyester mixes. When the liquid comes in connection to the fabric, it bundles and reels down. Merchandises that use Nano-Tex cures meet health, environmental, and safety criteria authorized by some globally recognized standard and safety organizations.

8.2 . Sensatex

Sensatex (USA) is cooperating with emergency workers, military, and doctors to create a smart shirt that has small minuscular wires intertwined inside the fabric. This garment turned interaction equipment can assist outfit of the future soldier clothes by checking on the necessary measurements and also hot or cold weather. This method can distantly watch patients staying at home wearing Sensatex shirts, resourcing essential physical measurement and sending it to a hospital, doctor, family wherever important.

9. Future Applications

Nanotechnology is being utilized to produce clothing with sensors. Attires have already been developed for checking on tasks like the temperature of physique and essential clinical measurements. Garments incorporated with sensors can be utilized for numerous usage including, military uniforms and hospital gowns. Outfits that can self-iron are acquired utilizing nano-materials which react to temperature. A heat supply can be

Journal of Medicinal and Nanomaterials Chemistry

operated on any crumpled region; the nanomaterial is thermally stimulated once attaining a particular temperature, thereby eradicating the wrinkles. A scientist is working on preparing bio-reactive plastic varnishes that can shield the person wearing the outfit from chemical and biological assaults. Researchers are working on to furnish the layer which could aware the person wearing the suit to the unseen assault, evolving military attires that can alter colors on the directive to disguise the wearer.

9.1 Graphene-based Band-Aid

Graphene is a single atom thin nanomaterial having two dimensions with special mechanical, structural, and electronic characteristics, has already expanded its footprint in various areas, including biomedical applications, also giving uncertainty on cytotoxicity and biosafety to living cells. The graphene interrupts bacterial cell membranes by cutting and the damaging direct removal of lipid molecules. This cytotoxicity has been associated with the *de novo* blueprint of nanomedicine, like grapheme built band-aid, antibiotics owing to its robust anti-bacterial competence [81].

9.2 Advanced Fabrics

Construction and functionality of advanced clothing hint to groundbreaking novel technical fabrics and fabric related combinations. An application consists of novel productive, electrochromic, glowing polymers in fibers, chemical detecting, clothes which track bio-functional situation. Fabrics fortified with superior elevated powered fibers, absorbents have been utilized to defend the person wearing the fabric from effects, lethal contact. Other novel material combinations can be included in the fabrics to produce unique energy-interactive fabric structures. The integration may include alteration, accommodation, and supervision of multiple sorts of energy, e.g., electromagnetic, electrical, magnetic, thermal, chemical or mechanical. Majority of the current achievements have originated from the incorporation of electronic substances inside knitted or otherwise-alternately handled fabric materials [82].

9.3 Smart fabrics

Smart fabrics can feel and respond to environmental situations or incentives, from various forms of energy. Fabric outputs that functions contrarily compared to most fabrics and can operate a specific task are regarded as smart fabrics [83].

9.3.1 Category of Smart Fabrics

Passive smart fabrics comprise of first stage productions of smart fabric that offer an extra feature in an inactive manner regardless of the variation of the surrounding [84]. Active-smart fabrics comprise of second level production active smart fabrics have both sensors and actuators that modify their usefulness in altering the environment automatically. Active smart fabrics are shape memory, heat storage, vapor permeable and absorbing, water-resistant, thermo-regulated, can absorb vapor, can change the fabric by heat, and outfits heated by electricity. Ultra-smart fabrics comprise of a third stage production of smart fabrics that can feel, respond with adaptation to surrounding circumstances. A very smart fabric comprises of a brain-like unit having reasoning and cognition, activating abilities. New fiber and fabric materials, and reduced size electronic constituents prepare smart textiles possible, to create smart clothes, which are worn as regular clothes offering assistance in diverse circumstances considering its usage.

9.3.2 Application of Smart Fabrics

a) Health: In "Telemedicine," wearable appliances permit physical signals to be checked throughout regular activities for healthcare [85]. It may avoid the difficulty of seldom medical checks which merely depicts a small display of the patient physical

Journal of Medicinal and Nanomaterials Chemistry

condition like ECG, EMG, and physical activity, a dress with wireless inserted fabric sensors intended for constant monitoring of respiration, etc. Wearable sensitized dress evaluates heart rate and breathing utilizing a 3-lead ECG shirt. The sensors and conductive fiber net are completely incorporated by knitting into the shirt.

b) Life jacket and belt: A life jacket is an examination appliance used as a dress by the patient which subsequently checks the heart and blood pressure. The data obtained from a life jacket is communicated to a computer and examined by medical staffs. Utilizing the life jacket, cuff-less blood pressure could be processed. Life belt is an appliance to be worn trans-abdominally for long duration health checking that enables supervising methods for mother and unborn baby. It is beneficial for pregnant women who live in secluded regions, working while pregnant and facing specific fitness issues. Life belt enables the obstetrician to monitor patients distantly, assess automatic initial diagnosis of their situation by collecting and examining vital indications, access patients' medical data all the time and be warned.

c) The smart baby-vest: This baby vest is loaded employing sensors which permit steady supervising of vital functions like lungs, heart, body and skin heat that could be utilized in the initial finding, checking of circulatory and heart-related disease. This vest is aimed to avert cot death and further life-threatening conditions in neonates and children.

d) The smart bra: The Smart Bra, which is created in Australia, has been established that will vary its characteristics in reaction to breast motion: relax and stiffen its cups, or loosen and tighten its straps to limit breast movement inhibiting breast discomfort and drop.

d) Fashion and entertainment: With the technology turning more adaptable numerous electronic devices and components clothes turning portable appliances. Light emitting fabrics are being used in the fashion runways, indicating technical garments for future design.

e) Sports (1) Sportswear: Smart devices or clothing can be utilized in sports which comprise observation, computing action, stimulate muscles, perform resistance training, record activity, and guard against a wound. (2) Sports shoe: Global Positioning Systems is included in shoes permitting the walker to be tracked by mountain rescue teams and the location of youngsters. Gloves that have heaters or radiating light from LED are used for visualizing a cyclist in the darkness.

f) Military/defense: In dangerous surroundings, there is a need for live news techniques to elevate the defense and survival of the personals functioning in these situations. Advances in execution and further abilities will be of great help in the defense and emergency response facilities. Wireless interaction permits medics to handle a distant investigation of casualties to assist them to react more quickly and securely [86].

9.3.3 Present Smart Fabrics with Nanotechnology

Ultrasonic assembly: It happens once electrical energy at high-frequency is converted to mechanical, acoustical tremors, canaled past a spine producing a fast heat development at the connection area of the substance, instigating the fabric connecting the anvil and horn to soften and fuse. The device trims and seals instead of thread, glue, or any other substances in one delivery, up to 4 folds quicker compared to regular sewing devices, while ten folds swifter compared to glue methods. The Seamaster is additionally easier to maneuver having simple guidance.

Innovative sportswear: Novel product growths in sportswear provides the garments to fit and look superior, as well as facilitate players to perform well. Several of these garments need usage of a novel or specific

Journal of Medicinal and Nanomaterials Chemistry

technique inside the garments in addition to the materials they are made; Smart fabrics are an illustration. The Adidas miCoach Elite System is linked with football to assist for game supervision and training. Fastskin Racing System was shown by Speedo that integrates the goggles, cap, and swimsuit as a system for the Olympics, which Speedo claim improves hydrodynamic competence and comfort. CAD 3-D software is used to draw for sports attire [87].

Prospect of Smart Fabrics: Initial expansion for interactive smart fabrics came from the request from the transportation industry. Moreover, smart fabrics also are progressing into the medical arena. Nonetheless, business expansion probably will be slow owing to elevated values of completed products of smart fabrics than to natural fabrics. Novel usages like heating of seats, measuring heart rate, smart car seat-belts, and operative steering wheels possess extensive prospect in the automobile business. Also work is ongoing about firefighter clothing. Many researchers are creating new ideas, solutions, and outcomes with the growing requests for smart fabrics in different stages of the lifespan. The international business for smart fabrics is anticipated to extend to 1500 million United States dollars.

9.4 Self-healing Fabrics

Composite materials are structural polymers that are susceptible to damage like cracks. These cracks have a harmful effect on the structure and detection of cracks and repair is nearly unfeasible. Once a crack is formed within the composite, the stability of the material is significantly compromised. Fabric composites are comprised of fabric support merged with a fastening matrix typically made of polymeric substance. Functional spaces for fabric compounds are mainly in the marine, aerospace, defense, land transportation, power generation, construction sectors. [88] These polymer compounds present high probability with long-lived structural substance [89]. Self-healing coating is launched to shield the original fabric substrate; the task is to explore the suitable microcapsules for the particular usage [90]. Future applications: Recently the expansion of self-healing substances is in the initial and some in the product level. Hence these materials are not available for many applications. The use of composite materials with self-healing polymer in the aviation industry has grown in the last few years. The hollow fibers fortified composites are a probable explanation to regain cracking or breaks. Self-healing polymers have shown applications to space science. Micro-cracking is hidden damages which are not easy to detect and also leads to failure for any structural component. Whereas, high repairing cost makes some products unacceptable for customers. The repairing in a remote location is a difficult task and in this context self-healing materials have tremendous opportunity to increase the lifetime of any structural elements by healing or repairing automatically without any intervention. A considerable percentage of researchers around the globe have been involved actively in this research field for a previous couple of years. Self-healing substances in physical forms can in the future be nearly replicated after living organisms, efficient of numerous and quick repairs.

9.5 Wearable Technologies and Electronics

Wearables are linked to those clothing and hard or soft fixtures that integrate electronic components, or which are made of smart fabrics. Smart fabrics study signifies the latest example for producing original and fresh key/answers for assimilating electronics into different settings and will result in novel innovations for future science. Tiny objects that can be embedded in any

Journal of Medicinal and Nanomaterials Chemistry

structure especially textile structure. As fabrics are a primary and alternating element of our everyday lives for centuries, fabrics exemplify an appealing channel for electronic incorporation. Smart fabrics symbolize the initiative to incorporate novel detecting implementations into previously unreachable exteriors providing further progress in the development of fabrics. The wearable technology consists of two main categories: (1) devices and (2) fabrics. Smart fabrics are where the fabric functions as an attachment for an add-on for sensors, printed circuits, and output devices. Wearable Future: The prediction for the wearable is very encouraging [91] having multiple research indicating that there will be a surplus in this arena in the coming years. Predictions can be obtained in 5 wearable categories: wristband, jewelry, glasses, clothes, and embedded. The big surge will come with the clothing. An immense number of companies are investing in this field [9].

10. **Quality label for nanotechnology.**

Nanotechnology testing consists of: (a) Category of nano-technological completion, (b) graphic scrutiny of nanotech completion products utilizing a scanning electron microscope, (c) measure the outcome of the final product, (d) measure of mechanical fitness, (e) cleaning durability, (f) measure of breathability, and (g) measure of biocompatibility. The verification is fitted to the fabrics and its usage. The challenge of the nano-varnish to the outcomes of deterioration and maintenance are verified, as well as the working is assured for a distinct least quantity of wash and dry rounds for care handlings. The supplementary factors are discussed on the Hohenstein Quality Label [92].

11. Economic and Environmental Aspects

World requirement for nanomaterials is forecast to rise to $90 billion in 2020. The world marketplace for nano is projected to surge to $100 billion by 2025. Near the 2025 year, nanoproducts are predicted to spread up to 34 billion dollars in deals, having rarely started its journey. In the year 2025, more than $25 billion is anticipated to be utilized on articulations and transitional materials for wearables predicted by IdTechEx. [93] The United States is the leading region for nano products. Japan is a slightly smaller nanoproduct market compared to the USA, still is considerably more prominent in other countries. UK, Germany, and France are the biggest marketplaces in the European Union region. Some of the developing areas like China and India will turn into gradually vital nano-objects marketplaces. It is forecasted that by the year 2025, China will escalate to surpass Japan to be the 2nd biggest sell of nano-materials globally after the USA, responsible for 12% of world requirement. The expenditure would be a considerable limitation for the evolution of nano items, especially in underdeveloped countries. Further restrictions are rising anxiety related to toxicity and ecosystem effect due to nano-substances.

Distinctive characteristics of the nanomaterials have fascinated scientists, research workers and businesses due to their enormous financial perspective. The national science foundation reported that the products associated with nanotechnology would rise to a one trillion United States dollar industry by 2015. This figure is more significant than the blended companies of the information technology businesses. Quite a few hundreds of billions of Euros are projected to be generated utilizing nanotechnology in the upcoming years. Two million latest job possibilities can be created to sustain the global yearly assembly requirement of one trillion United States dollars from 10 to 15 years. Also, nanotechnology can have a positive influence on the ecosystem. Utilizing a lesser supply instead of preceding

Journal of Medicinal and Nanomaterials Chemistry

implementation, nanotechnology, therefore, might conserve crude substances while enhancing the standard of living [94].

12. Nano Fabrics Toxicity and Risks

Emerging science on the utilization of nanotechnology has raised anxieties about the lack of regulatory oversight of the industry, the lack of safety analysis, and limited health statistics about potential environmental and human health consequences. Early science on nanotechnology delivers adequate proof to show that nanoparticles might have poisonous properties that are distinctive. It has been stated that the very qualities that make nano-materials commercially desirable can also make them more toxic than their normal-sized counterparts. Nano-fibers, also known as “nano-whiskers,” may contain problematic chemicals such as fluorotelomers. International organizations are calling for sufficient and applicable oversight, safety testing and valuation of the evolving arena of nanotechnology, including those nano-materials that are already in widespread commercial use [95].

It is a difficult task for making the nanoscale production from a laboratory to an industrial level. Only a few research has been done on the adverse effects of nanomaterials in commercial production. (1) Possible explosions and (2) if toxic hazards are mishandled, nanomaterials can suddenly be in flames in the presence of air. Multiple scientists have shown anxieties on (3) probable contamination. Nanomaterials freed from layers can turn out to be a novel sort of pollution. Nanomaterials could be a threat to (4) mammals and bacteria. Research has shown that carbon nano-tubes could collect into a mass, triggering breathing difficulties and impairment to tissues. Future endeavor suggests that nano-crystals liquefied in water could demolish a current bacteria populace, becoming a tremendous antibiotic substance. Though there is an attempt to brand nano-processing matching with a regular textile instrument, it is foreseeable that there are financial implications. Novel appliances aiming for nano substances preparation is needed. Also, (5) nanomaterials may be incredibly costly [96].

13. Conclusion

Fabrics sector has already been impacted by nanotechnology. The progress in the functions of nanoparticles has been significantly swift in the last few years, primarily in fabric finishing. These nanosized substances can improve the physical characteristics of traditional arenas such as self-cleaning fabrics, water repellency, ultraviolet-protection, anti-bacterial, anti-static, wrinkle resistant, flame retardant characteristics of fabrics substances. Nanofibers too occupy in the arena of fabrics, and it has an incredible possibility. Investigations concerning nanotechnology to enhance functioning or to establish unparalleled operations of textile fabrics is booming. There is a high possibility that in the upcoming years, nanotechnology will invade into all spaces of fabrics.

References:

1. The appropriateness of existing methodologies to assess the potential risks associated with engineered and adventitious products of nanotechnologies. European Commission. http://ec.europa.eu/health/ph_risk/documents/synth_report.pdf Accessed on 14 Nov 2018.

2. Joseph T, Morrison M (**2006**) Nanotechnology in Agriculture and Food. A Nanoforum report, European Nanotechnology Gateway. https://www.nanowerk.com/nanotechnology/

Journal of Medicinal and Nanomaterials Chemistry

reports/reportpdf/report61.pdf Accessed on 14 Nov 2018.

3. Sandler R (**2009**) Nanotechnology: The Social and Ethical Issues. Project on Emerging Nanotechnologies. Woodrow Wilson International Center for Scholars. Washington, DC

4. Sharma P, Udeniyan A, Mishra PK, Kantharia M, Sharma US (**2015**) *International Journal of Scientific Research*. **4**(10): 216-218.

5. Anderson K (**2009**) Nanotechnology in the Textile Industry *Techexchange Library* 1-4.

6. US EPA (**2007**) Introduction to nanotechnology. pp 1–29. http://www.epa.gov/rpdweb00/docs/cleanup/nanotechnology/chapter-1-introduction.pdf. Accessed 14 Nov 2018.

7. De Schrijver I, Eufinger K, Heyse P, Vanneste M, Ruys L, et al. (**2009**) Textiles of the future? Incorporation of nanotechnology in Textile applications. UNITEX nr. 2.

8. Nanomaterials (**2018**) National Institute of Environmental Health Sciences. http://www.niehs.nih.gov/health/topics/agents/sya-nano/ Accessed 14 Nov 2018.

9. Mariana R (**2015**) Nano Technology in Textile Industry (Review), Annals of the University of Oradea. Fascicle of Textiles, Leatherwork **16(2)**: 83-88.

10. ObservatoryNANO (**2018**) European observatory on nanotechnologies. http://www.observatorynano.eu/ Accessed 14 Nov 2018.

11. Nguyen KT (**2011**) *J Nanomedic Nanotechnol*. **2**:5 103e.

12. Chen MS, Liu CY, Wang WT, Hsu CT, Cheng CM (**2011**) *J Nanomedic Nanotechnol.* **2**: 117.

13. Nanjwade BK, Derkar GK, Bechra HM, Nanjwade VK, Manvi FV (**2011**) *J Nanomedic Nanotechnol.* **2**: 107.

14. Nanotextiles (**2018**) www.fibre2fashion.com/industry-article/8/713/nano-textiles1.asp Accessed 14 Nov 2018.

15. Shih MF, Wu CH, Cherng JY (**2011**) *J Nanomedic Nanotechnol.* **S3**: 001.

16. Smartgarments (**2011**) http://www.smartgarmentpeople.com/index.php?q=Nanotextiles Accessed 14 Nov 2018.

17. Vigneshwaran N (**2006**) Nanotechnology finishing in textiles. www.nanowerk.com Accessed 14 Nov 2018

18. Rosen JE, Yoffe S, Meerasa A, Verma M, Gu FX (**2011**) *J Nanomedic Nanotechnol.* **2**: 115.

19. Hinestroza JP (**2007**) *Materials Today* **10**: 56.

20. Zeng D, Shan W, Xiao Q (**2011**) *J Glycom Lipidom* **1**: 102.

Journal of Medicinal and Nanomaterials Chemistry

21. Saboktakin MR, Tabatabaie RM, Maharramov A, Ramazanov MA (**2011**) *J Nanomedic Nanotechnol.* **S4**: 001.

22. Brown L, Webster GK, Kott L, Rao NKR, Luu TA, et al. (**2011**) *Pharm Anal Acta* **2**: 134.

23. Liu D, Dong W (**2009**) *Modern Applied Science* **3**: 154-157.

24. Singh KV, Sawhney PS, Sachinvala ND, Li G, Su-Seng P (**2006**) *Beltwide Cotton Conferences* 2497-2503.

25. Wong YWH, Yuen CWM, Leung MYS, Ku SKA, Lam HLI (**2006**) *Autex Research Journal* **6**: 1-8.

26. Subbiah T, Bhat GS, Tock RW, Parameswaran S, Ramkumar SS (**2004**) *J Appl Polym Sci*. **96**: 1-13.

27. Sun CZ, Lu CT, Zhao YZ, Guo P, Tian JL, et al. (**2011**) *J Nanomedic Nanotechnol.* **2**: 114.

28. Achyuthan K (**2011**) *J Biosens Bioelectron* **2**: 102e.

29. Thomas S, Waterman P, Chen S, Marinelli B, Seaman M, et al. (**2011**) *J Nanomedic Nanotechnol.* **2**: 112.

30. Qian L, Hinestroza JP (**2004**) *JTATM* **4**: 1-7.

31. Salim N, Basri M, Abd. Rahman MB, Abdullah DK, Basri H, et al. (**2011**) *J Nanomedic Nanotechnol.* **2**: 11.

32. Jeevani T (**2011**) *J Nanomedic Nanotechnol.* **2**(7): 1-5.

33. Amin GA (**2010**) *J Pet Environ Biotechnol.* **1**: 104.

34. Rodrigues DF (**2011**) *J Bioremed Biodegrad.* **2**:e101.

35. Lee HJ, Yeo SY, Jeong SH (**2003**) *J Mater Sci.* **38**: 2199-2204.

36. Zheng J, Clogston JD, Patri AK, Dobrovolskaia MA, McNeil SE (**2011**) *J Nanomedic Nanotechnol.* **S5**: 001.

37. Pandurangappa C, Lakshminarasappa BN (**2011**) *J Nanomedic Nanotechnol.* **2**:108.

38. Patil A, Chirmade UN, Trivedi V, Lamprou DA, Urquhart A, Douroumis D (**2011**) *J Nanomedic Nanotechnol.* **2(3)**:111.

39. Adjah AD (**2011**) *Hydrol Current Res.* **2**: 116.

40. Go YM, Duong DM, Peng J, Jones DP (**2011**) *J Proteomics Bioinform.* **4**: 196-209.

41. Jaiswal S (**2011**) *J Bioremed Biodegrad.* **2(4)**: 126.

42. Hashimoto K, Irie H, Fujishima A (**2005**) *Jpn J Appl Phys.* **44**: 8269-8285.

43. Denery JR, Cooney M.J, Li QX (**2011**) *J Bioengineer & Biomedical Sci.* **1**: 101.

44. Lukianova-Hleb EY, Oginsky AO, Shenefelt DL, Drezek RA, Hafner JH, et al. (**2011**) *J Nanomedic Nanotechnol*. **2**: 104.

45. Sarker M, Chopra S, Mortelmans K, Kodukula K, Talcott C, et al. (**2011**) *J Comput Sci Syst Biol*. **4**: 021-026.

Journal of Medicinal and Nanomaterials Chemistry

46. Mizuno K, Zhiyentayev T, Huang L, Khalil S, Nasim F, et al. (**2011**) *J Nanomedic Nanotechnol.* **2**: 109.

47. Zhang J, France P, Radomyselskiy A, Datta S, Zhao J, Ooij WV (**2003**) *J Appl Polym Sci*. **88**: 1473-1481.

48. Khare PK, Banger G, Mishra P, Mishra J (**2008**) *Indian Journal of Physics* **82(10)**:1301-1308.

49. Li GL, Wang GH (**1999**) *J Mater Res*. **14**: 3346-3354.

50. Nakamura J, Nakajima N, Matsumura K, Hyon SH (**2011**) *J Nanomedic Nanotechnol.* **2**:106.

51. Beringer J (**2005**) Nanotechnology in textile finishing state of art and future aspects

52. Lu M, Whitelegge JP, Whelan SA, He J, Saxton RE (**2010**) *J Proteomics Bioinform* **3**: 029-038.

53. Qian L, Sun G (**2003**) *Journal of Applied Polymer Science* **89**: 2418-2425.

54. Simoncic B, Tomsic B (**2010**) *Textile Research Journal* **80(16):**1721-1737.

55. Gao Y, Cranston R (**2008**) *Text. Res. J.* **78**: 60–72.

56. Schindler WD, Hauser PJ (**2004**) In: Chemical Finishing of Textiles, Woodhead Publishing Ltd, Cambridge.

57. Dring I (**2003**) In: Heywood, D. (Ed.) Textile Finishing, Society of Dyers and Colourists, Bradford, p. 351–371.

58. Mahltig B, Haufe H, Böttcher H (**2005**) *J. Mater. Chem.* **15**:4385–4398.

59. Vigo TL (**1983**) In: Sello SB (Ed.) Functional Finishes, Part A, Chemical Processing of Fibres and Fabrics, Handbook of Fiber Science and Technology. Marcel Dekker, Inc., New York: p. 367–426.

60. Yeo SY, Lee HJ, Jeong SH (**2003**) *J Mater Sci*. **38**: 2143-2147.

61. Narasimhulu K, Rao PS, Vinod AV (**2010**) *J Microbial Biochem Technol.* **2**: 074-076.

62. Liu ZS, Rempel GL (**2011**) *Hydrol Current Res.* **2**: 107.

63. Shimizu K, Komuro Y, Tatematsu S, Blajan M (**2011**) *Pharm Anal Acta* **S1**: 001.

64. Anita S, Ramachandran T (**2012**) *J Textile Sci Eng.* **2(4)**:1-5.

65. Burniston N, Bygott C, Stratton J (**2004**) *Surface Coatings International* **Part A**: 179-814.

66. Sherman J (**2003**) Nanoparticulate titanium dioxide coatings, and processes for the production and use thereof. Pat. No 736-738.

67. Xiong MN, Gu GX, You B, Wu LM (**2003**) *Journal of Applied Polymer Science* **90**: 923-1931.

Journal of Medicinal and Nanomaterials Chemistry

68. Xin JH, Daoud WA, Kong YY (**2004**) *Textile Research Journal* **74**:97-100.

69. Saito M (**1993**) *Journal of Coated Fabrics* **23**: 150-164.

70. Daoud WA, Xin JH (**2004**) *Journal of Sol-Gel Science and Technology* **29**:25-29.

71. Wang RH, Xin JH, Tao XM, Daoud WA (**2004**) *Chemical Physics Letters* **398(1-3)**:250-255.

72. Dong WG, Huang G (**2002**) *Journal of Textile Research* **23**: 22-23.

73. Zhou ZW, Chu LS, Tang WM, Gu LX (**2003**) *Journal of Electrostatics* **57**: 347-354.

74. Wu Y, Chi YB, Nie JX, Yu AP, Chen XH, Gu HC (**2002**) *Journal of Functional Polymers* **15**: 43-47.

75. Xu P, Wang W, Chen SL (**2005**) *Melliand International* **11**: 56-59.

76. Wang CC, Chen CC (**2005**) *Journal of Applied Polymer Science* **97**: 2450-2456.

77. Song XQ, Liu A, Ji CT, Li HT (**2001**) *Journal of Jilin Institute of Technology* **22**: 24-27.

78. Bangladesh, the land of textiles: review & outlook (**2012**) textiletoday.com.bd/bangladesh-the-land-of-textiles-review-outlook/ Accessed 14 Nov 2018.

79. Hurwitz M (**2006**) l Physics Letters **398**: 250-255.

80. Glashauser A, Denk L, Minuth WW (**2011**) *J Tissue Sci Eng.* **2**: 105.

81. Zhou R, Gao H (**2014**) *WIREs Nanomed Nanobiotechnol*. **6**:452–474.

82. Motyl E (**2003**) Energy-saving materials and Technologies-Nanomaterials, New Smart Materials. Prace Naukowe Instytutu Podstaw Elektrotechniki I Elektrotechnologii. Politechniki Wroclawskiej nr 39, seria: Konferencje nr 14, 2003. Pp. 42-48.

83. Mahesh G, Sornapudi SD (**2017**) *International Journal of Computer Science* **5(2)**: 2133-2141.

84. Oakes J, Batchelor SN, Dixon S (**2005**) *Coloration Technology* **12**: 237-244.

85. Jamadar S (**2013**) Applications of Smart and Interactive Textiles. Smart and interactive textiles. http://textilelearner.blogspot.com/2013/04/applications-of-smart-andinteractive.html Accessed 14 Nov 2018.

86. New technologies for innovative sportswear (**2013**) Stitch & Print International. http://www.stitchprint.eu/news/new-technologies-for-innovative-sportswear/ Accessed 14 Nov 2018.

87. Transparency market research (**2015**) http://www.transparencymarketresearch.com/pressrelease/smart-fabrics-and interactive-textiles-market.htm Accessed 14 Nov 2018.

88. Ghosh SK (**2006**) Functional Coatings by Polymer Microencapsulation. 1st ed. Federal

Journal of Medicinal and Nanomaterials Chemistry

Republic of Germany: WILEY-VCH Verlag GmbH & Co. KG

89. White SR, Sottos NR, Moore J, Geubelle P, Kessler M, Brown E, Suresh S, Viswanathan S (**2001**) *Nature* **409**:794-797.

90. Rama D, Shami TC, Bhasker Rao KU (**2009**) *Defence Science Journal* **59(1)**: 82-95.

91. Çiçek M (**2015**) *International Journal of Electrical, Electronics and Data Communication* **3(4)**: 45-50.

92. Hohenstein Institute (**2014**) www.hohenstein.de Accessed 14 Nov 2018.

93. Harrop P (**2015**) Wearable Technology: a materials goldmine http://www.idtechex.com/research/articles/wearable-technology-a-materials-goldmine-00007241.asp?donotredirect=true Accessed 14 Nov 2018.

94. Kathiervelu SS (**2003**) *Synthetic Fibres* **32**: 20-22.

95. Silas J, Hansen J, Lent T (**2007**) The Future of Fabric. Health Care. In conjunction with health care without harm's research collaborative. http://www.noharm.org/us Accessed 14 Nov 2018.

96. Siegfried B. (**2007**) NanoTextiles: Functions, nanoparticles and commercial applications. *EMPA material Science and Technology.* https://www.empa.ch/documents/56122/328606/NanoSafeTextiles_1.pdf/b2add656-265b-42df-9196-f2768d773748 Accessed 14 Nov 2018.

How to cite this manuscript: Munima Haque. Nano Fabrics in the 21st century: a review Journal of Medicinal and Nanomaterials Chemistry, 2019, **1**(2) , 131-148.