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AN OVERVIEW ON ADVANCEMENT IN WEARABLE TEXTILES: INTELLIGENT TEXTILES

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Abstract
Intelligent textile also referred as stimuli-response textiles are those which are intelligent enough to identify the stimuli from surroundings, analyze it and respond accordingly. It's not only limited to apparel and clothing sector but also play a significant role in safety, protection, fashion and convenience textile sector too. It is a composition of a sensor, processor and an actuator which coordinate with each other to sense a signal, process it and behave appropriately. Phase changing materials, shape memory materials, chromic materials, conductive materials and electronics incorporated textiles are some examples of intelligent textiles which are widely used in textile industry. Intelligent textiles are also used for protective clothing, to safeguard against extreme hazardous environmental conditions, such as radiations, effects of space travel, to safeguard fire-fighters against fire and heat etc. These textiles also serve in health and beauty industry with their innovations, which range from drug-releasing medicated textiles, to fabric with moisturizer, perfume, cosmetics and anti-aging properties.
Keywords:Intelligent textile, stimuli-response, sensor, processor, actuator, Phase changing material, shape memory material, chromic material, conductive material, protective clothing, medicated textiles.

I. Introduction

Intelligent textiles are the next generation of fibres, fabrics and articles specially produced to respond in time. As the name suggests, intelligent textiles are those which are intelligent enough to identify the stimuli from the environment, analyze it and give response to them and modify accordingly by blended functionalities in that textile material by themselves. They help to keep wearer warm in cold weather, cool down the body temperature in hot sunny days, and elevate the productivity by providing the convenience in the normal day to day activity. Intelligent textile is not limited to only apparel and clothing sector but also play an important role in safety, protection, fashion and convenience textiles too. It sometimes also referred as stimuli-response textiles which consists of three parts, which are; a sensor, a processor and an actuator. Sometimes all three parts are connected with each other through wires or sometimes they have wireless information transfer capabilities with each other. For example, temperature of the body is monitored by the sensor, which is transferred to the processor for processing the signal, which finds the solution according to the giveninformation and then sends a command to the actuator for the regulation of the temperature [1]. In other words, intelligent textiles have to perform some primary functions to do its main task. These are executed by:

- ***Sensors***- The sensors provide a nerve system to detect and send signals to textile [2], it is used to collect the main stimuli, which can be heat, pressure, moisture or anything else from

the environment. These sensors must have high sensitivity and accuracy, so they can quickly catch the signal and send them for processing. Small size and light weight particles are helpful for making sensors which are useful for a variety of application [3].

- ***Processor-*** This helps in processing, monitoring and analyzing signals send by sensors to take an appropriate action as per the stimulation and some predetermined data feed into it. It may contain some electronic circuits which catch the signals sends by sensors and check that which action should be taken for it [3].
- ***Actuators-*** This is the main unit which is responsible for the response given by intelligent textile as per the signals received by the sensors and command sends by processing unit. [3]

The processing of Intelligent textiles is shown in figure.01.

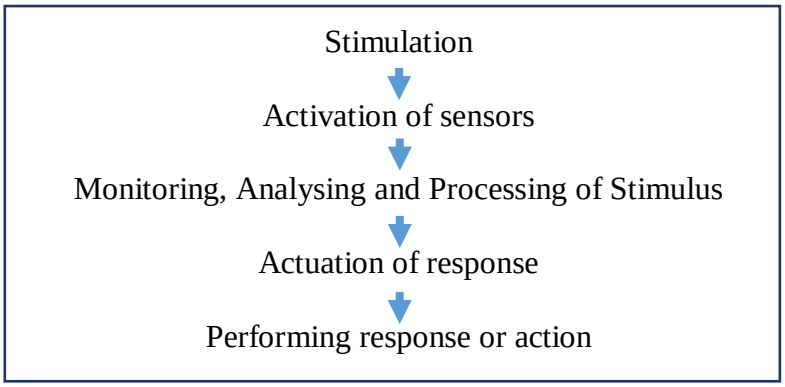

Figure 1: Working process of Intelligent Textiles

Intelligent textiles have two major categories, which are - aesthetic textile and performance enhancing textiles.

- Aesthetic Intelligent Textiles – These are the textiles which use intelligence to enhance the aesthetic beauty of the fabric. Most popular example of this category is the fabric that glows in dark and fabrics which changes their colour after catching specific signals. These fabrics assemble energy from the surrounding environment by catching sensations, sound or heat and react by these stimulis. The colour changing and lighting technology (Figure 02 and 03) generally work with the help of electronic batteries or cell which provide power into it.

Figure 2&3: Intelligent fabric that glows in dark or after catching signals [5,6]

- Performance Enhancing Intelligent Textiles – These are the textiles which are used to lift up the performance of the wearer, so generally used in athletic, extreme sports, military and other related fields. They are designed in such a way that they can regulate body temperature and blood pressure of the wearer, control the vibration of muscles and reduces wind resistance, which results in improved performance of the wearer. Some examples of intelligent textiles which helps in enhancing performance of the wearer are shown in Figure 04 and 05.

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Figure 04&05: Intelligent textiles in healthcare to collect biometric data [7,8]

1.2 Types of Intelligent Textiles

Phase change materials (PCM), shape memory materials (SMM), chromic materials (color changing materials), conductive materials and electronics incorporated textiles are the some examples of intelligent textiles[1]. The materials used for these applications are photosensitive materials, fiber optics, conductive polymers, thermal sensitive materials, shape memory materials, intelligent coating materials, chemical responsive materials, microcapsules and micro- and nanomaterialsetc [2]. The different types of materials used for the production of intelligent textiles are mentioned below:

1.2.1*Phase change material* – These are thermal storage materials which are used to manage the fluctuation of temperature in environment. They use chemical bonds as a thermal barrier to absorb and release heat and thus control the transfer of heat. The thermal energy transmits when a material converts from solid to liquid state or from liquid to solid state. This process is called a 'conversion of state', or phase. Phase change technology in clothing requires to combine microcapsules of PCM in the textile material [1].

The foundation of Phase change technology was developed in early 1980's by NASA to protect the astronauts and instruments from the rapid fluctuation of temperature in space. Triangle Research and Development Corporation (USA) in 1987 also displays the successful workability of incorporating phase change material with in the textile material [1].

Every material absorbs a little or more amount of heat while in heating process and its temperature rises continuously. The temperature of PCM materials rises until it reaches its melting point[1]. Generally clothes are not capable to balance the heat generated by human body by releasing it in to the environment. A common textile material can take up to about 1kJ/kg (one kilo joule per kilogram) of heat while its temperature rises by 10C. Whereas, fabrics facilitated with PCM provides good thermal balance due to its thermo regulating effect. They take up higher amount of heat when it melts. So, thermo regulating quality of textiles can be achieved by the application of PCM in textiles. It controls the fluctuationof heat through the garment layers and adjusts the heat fluctuation to the thermal conditions [9].

At the time when the physical state of the material changes, the temperature of the material still remains same until the PCM become solid to liquid. During this process, PCM stored a large amount of latent heat. During the cooling process the stored heat in PCM is released in the environment and a phase of PCM reverses from liquid to solid again[1]. Intensity and duration of the PCM's active thermal insulation effect depends mainly on the heat storage capacity of the PCM-microcapsules and the quantity of the material applied on the fabric. For the desirable thermal properties, it is important to apply the appropriate PCM in an adequate quantity. The desired PCM is generally microencapsulated and integrated in the textile materials. In apparel, covering of PCM microcapsules are applied on the surface of the textiles. It is used in summer and winter wears both, especially in the field of active wears including footwear, innerwear, gloves, bedding, helmets etc. It is also popular in medical textiles like acrylic blankets, bed covers, and surgical gowns to control the micro climate of the patient [1].

Functions of textiles using PCM –

- They produce cooling effect by absorption of heat.
- They produce heating effect by release of heat.

• They produce thermos-regulating effect by either absorption or release of heat, in this PCM keeps the temperature almost constant of surrounding substances [1].

Limitations of PCM –

The desired thermal effects have to be decided before choosing PCM. The effectiveness and duration of these PCM depends on the amount on which they are used as well as on material in which they are applied.[1].

1.2.2 *Shape Memory Polymers (SMP)*- Shape memory material (SMMs) are a set of materials, which can change their shape from some temporary deformed shape to a previously 'programmed' or "memorized" shape when external stimulus are provided to them [10].

The shape change material is activated most often by changing the surrounding temperature, but with certain materials, magnetic field, electric field, pH-value, UV light and even water can be the triggering stimulus to these materials [10].

A multi-SMP means a polymer which are capable of "memorizing" more than one temporary shape and subsequently recovering in a highly controllable manner [10]. Because of the variety of different level of activation and the ability to exhibit actuation or some other pre-determined response, SMMs can be utilised to control or tune many technical parameters in smart material systems in response to environmental changes – such as shape, position, strain, stiffness, natural frequency, damping, friction and water vapour penetration. Nowadays, large variety of alloys, ceramics, polymers and gels have been found which exhibits shape memory behaviour [1].

General Principles of Shape Memory Alloys –

Shape-memory alloys are the metal compounds, which can memorise a predetermined shape, and after being bent, stretched or otherwise mechanically deformed they can return to their shape under certain temperature conditions. Shape memory polymers (SMPs) are one type of shape memory materials defined as polymeric materials with the ability to sense and respond to external stimuli by returning to predetermined shape. Polymers such as polynorbornene, trans-polyisoprene, styrene-butadiene copolymer, crystalline polyethylene, some block copolymers, ethylene-vinyl acetate copolymer and segmented polyurethane, etc. has been discovered with property of shape memory effect. Organic shape memory polymers have a lower recovery force than shape memory alloys but they offer easier process ability, light weight, lower production costs, biocompatibility and colour variation. SSPs yield fabrics with such properties as air permeability, hydrophilicity, heat transfer, shape, and light reflectance that are responsive to environmental stimuli's as temperature, pH, moisture, light and electricity. They offer greater deformation capacities, easier shaping, and greater shape stability. Small changes to the chemical structure and composition of SMPs result in a wide variety of transition temperatures and mechanical properties [1]. Shape memory alloys, such as nickel-titanium are used for providing increased protection against different sources of extreme heat. A shape memory alloy displays different properties below and above the temperature at which it is activated. The temperature of activation can be chosen by altering the ratio of nickel to titanium in the alloy. They can be laminated, coated, foamed, and even directly converted to fibers. There are many possible end uses of these intelligent textiles [1].

Shape memory alloy is quite strong and hard in its austenite (parent) form, but in the martensitic form it is soft and pliable and can easily be deformed. SMAs also exhibit super-elasticity (or pseudoelasticity) giving the material a rubber-like behaviour. The application specific overall austenitic shape (parent shape) of SMA is formed and locked (programmed) through a specific high-temperature tempering process. On the other hand, if the SMM is prevented from recovering this initial strain, a recovery stress (tensile stress) is induced, and the SMM actuator can perform work. This situation where SMA deforms under load is called restrained recovery [1].

Fabrication of Shape Memory Alloys –

SMA materials can be fabricated into bars, strips, fibers or wires, tubing, foils, thin films, particles and even porous bulks too. Recently, thin film SMA has become a promising material in the field of micro-electro-mechanical system (MEMS) applications (such as micro-grippers, micro-pumps, micro-mirror, sensors and actuators). Thin film can be patterned with standard lithography techniques and fabricated in a batch process. Thin film SMA has only a small amount of thermal mass to heat or cool, thus the cycle (response) time can be reduced substantially and the speed of operation may be increased significantly [1]. The other fields where SMA is used are;

1.2.2.1 Medical Textiles-

i) Smart fibers – They are made from the shape memory polymers so can tie itself into a perfect knot. Its features includes the compatibility with body fluid, shape retention, retention of two shapes in memory, high shape fixity, high shape recovery, and its abilityto form temporary and permanent shapes. The sutures contacts to its permanent shape when heated and its self-knotting action take place when it is heated a few degrees above normal body temperature. The suture therefore can be used to seal difficult wounds where access is limited [1].

ii) Surgical protective garments – Shape memory polymers coated or laminated materials can improve the thermo-physiological comfort or surgical protective garments, bedding and incontinence products because of their temperature adaptive moisture management features [1].

1.2.2.2 Outdoor Clothing-

Films of shape memory polymers can be put together in multilayer garments, such as those that are often used in the protective clothing or leisurewear industry. Using a composite film of shape memory polymers as an inter-liner in multilayer garments, outdoor clothing provide thermal insulation and can be used as protective clothing[1].

1.2.2.3 Casual Clothing-

Permeability of SMP coated or laminated fabrics changes as the wearer's environment and body temperature changes to form an ideal combination of thermal insulation and vapour permeability for inner wear and outer wear. When the body temperature is low, the fabric remains less permeable and keeps the body warm and when the body is in sweating condition, it allows the water vapour to escape into the environment as its moisture permeability becomes very high with increasing body temperature. This releases heat from the apparel [1].

1.2.2.4 Sportswear-

Sportswears provide protection from wind and weather, dissolute perspiration, and have excellent stretch and recovery properties. Shape memory polyurethane fibers respond to external stimuli in a predetermined manner and are useful in sportswear[1].

1.2.3 *Chromic Materials*- Chromism as a suffix means reversible change of colour and by extension, a reversible change of other physical properties. Chromic materials are the general term referring to materials which radiate the colour, erase the colour or just change it because of induction caused by the external stimuli [9]. Due to colour changing properties, chromic materials are also called chameleon materials. This colour changing phenomenon is caused by the response of chromic materials to external stimulus and can be classified depending on the external stimulus of induction:

- Photochromic: external stimuli energy is light.
- Thermochromics: external stimuli energy is heat.
- Ionochromic: external stimuli energy is pH value.
- Electrochromic: external stimuli energy is electricity.
- Piezorochromic: external stimuli energy is pressure.
- Solvatechromic: external stimuli energy is liquid [9].

The most applied chromic solutions in textiles and fiber materials are the first two groups, i.e. photochromic and thermochromic.

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1.2.3.1 Photochromic:

Photochromic materials change their colour by light and these materials are both organic and inorganic. Usually they are colourless in dark place and when sunlight or UV- radiation is applied, the molecular structure of the material changes and it exhibits colour. When the relevant light source is removed, the colour disappears. There are also photochromic materials called heliochromic compounds, which are activated by unfiltered sunlight and deactivated under diffuse daylight conditions. They are suitable for sun lens application [1]. Photochromism is of two types: positive and negative. In Positive Photochromism the colourless substance is converted in to coloured object when exposed to the light. Whereas, Bi molecular reaction system is called Negative Photochromism i.e. from coloured to colourless [9].

Photochromic compounds in textiles are used mainly for decorative effects in jacquard fabrics, embroideries and print in different garments. As shown in Figure 06 and 07 nightwear which remains colourless or white in indoor or dark while in daylight its colour changes to blue, green, purple etc. Since the photochromic material is not just a coating but a part of the polypropylene, the materials does not wash off and remains with the fiber for the life of the product[1].

Figure 6&7: Photochromic nightwear which changes their colour in response to light [11,12]

1.2.3.2 Thermochromic:

Thermochromic materials change their colours as a result of contact to heat. The change in colours occurs at a predetermined temperature called the thermochromic transition. It especially occurs with the application of thermochromic dyes whose colours change at particular temperatures. The thermochromiccolour change is distinguished by being quite noticeable, often dramatic and occurring over a small or sharp temperature interval. There are two types of thermochromics systems used successfully in textiles, the liquid crystal type and the molecular rearrangement type[1].

The thermochromic dyes used extensively in the printing of Textiles, Micro encapsulation coating or dope dyeing[9]. Some products printed with leuco dye thermochromic inks changes from one colour to another, rather than transforming from coloured to colourless. This is achieved with an ink that combines a leuco dye with a permanent-colored ink formulation. For e.g. the ink manufacturer formulates a green ink by adding a blue leuco dye with a yellow ink. In its cool state the printed ink layer is green and once warmed reverts to yellow as the leuco dye becomes clear or translucent (Figure.08 and 09). Leuco dyes can also be designed to change colours at various temperature ranges[1].

Figure 8&9: Thermochromic textile materials [13,14]

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1.2.3.3 Ionochromic:

These chromic materials are sensitive to pH. The dyes classes widely used are Phthalides, Triarylmethans and Fluorans. In analytical chemistry these dyes are used extensively. In this process substrate carries both the colour former and acid co reactant in a single layer. So, when the fabric surface come in contact with acidic or alkaline medium it produces colour [9] (Figure 10 and 11).

Figure 10 &11: Sweat reactive t-shirts which change their colour when come in contact with acidic or alkaline sweat[15,16].

1.2.2.4 Electrochromic:

The materials that change colour upon the application of voltage are called electrochromes. In this, the colour change is commonly between a transparent (bleached) state and a coloured state, or between two coloured states. When more than two redox states are electrochemically available, the electrochromic material may exhibit several colour and can be termed as polyelectrochromic or said to possess multicolour-electrochromism.

Textile integrated display applications are a flexible, battery-powered optical fibre screen which is woven into clothing. Each plastic fiber-optic thread is illuminated by tiny LEDs that are fixed along the edge of the display panel and controlled by a microchip. The threads are set up so that certain portions are light when the LEDs are switched on, while other sections remain dark. As shown in Figure 12 and 13 these light and dark patches essentially act as pixels for the display screen. The novel fabric contains interwoven electronic circuits made from stainless steel yarns and thermochromiccolour-changing ink, which are connected to drive electronics. Flexible wall hangings can then be programmed to change colour in response to heat from the conducting wires[1].

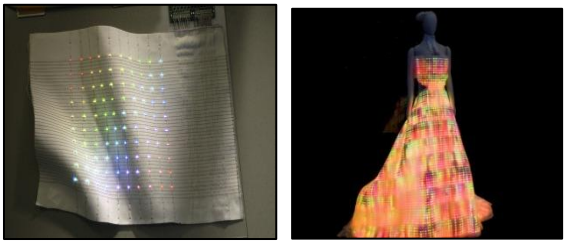

Fig. 12 & 13: Electrochromictextiles[17]

1.2.2.5 Piezochromism:

Piezochromism is the situation where dye crystals go through a major change of colour due to mechanical grinding. The induced colour reverts to the original colour when the fractured crystals are kept in the dark or dissolved in an organic solvent[9] (Figure. 14).

Fig.14: Piezochromictextiles[18]

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1.2.2.6 Solvantochromic:

Solvatechromism is an occurrence, where colour changes when it makes contact with a liquid, e.g. water. Material that respond to water by changing colour are also called hydrochromic and this kind of textile material can be used for swimsuit as shown in Fig. 15 and 16 to make various effects[1]. Chromic dye generally contains highly specialized components that require extraordinary careful manufacturing technique and has great potential for both fashion and higher end market[9].

Fig 15&16: Solvantochromatic dyes [19][20].

II. Uses of Intelligent Textiles

Intelligent textiles are also used for protective clothing, to safeguard against extreme hazardous environmental conditions, such as radiation and the effects of space travel, to safeguard fire-fighters against fire and heat etc. as well as these textiles also serves in health and beauty industry with their innovations, which range from drug-releasing medicated textiles, to fabric with moisturizer, perfume, cosmetics and anti-aging properties[3]. The usages of intelligent textiles in various fields are;

2.1 Sports Activities: A production of smart socks with a foot pressure measurement technology and walking distance measurement that can be used to measure sports performance. The various electronic parts of this product can be separated in order to clean and wash the textile part of the socks. The collected data is sent wirelessly to a mobile application running into a Smartphone. With this intelligent device, the athletes can see and monitor the pressure profile of the foot sole and improve their performance. A sports person can wear intelligent bands, jackets, caps to continuously monitor the pulse rate, blood pressure, body temperature, fatigue. The necessary data can be sent to remote location where it can be analysed and may be used to improve the performance of the sports person[3].

Similar types of devices are available can be used by sky divers, swimmers or other sports persons to monitor, analyse and improve their performance.

2.2 Health sector: Intelligent wearable textile which are basically composed of various embedded sensors, actuators, microcontrollers which not only senses, register monitor and analyze the physical and mental health of the person but it also transmit the necessary data from the patient to the medical expert. There are diverse applications in medical sectors where these electronic or intelligent textiles are extensively used[3].

Intelligent bras are there which have the capability to detect symptoms of breast cancer at an early stage so that it can be treated and cured. For the monitoring of respiration system, heart pumping system, and other physical activity, various wireless enabled intelligent garments have been developed and still some are yet to be discovered. These are going to be very helpful for the persons who are on risk of heart attack as these wearable intelligent textiles will detect the early signs and warn the wearer and simultaneously sent the data to the person who is monitoring such a person[3].

Intelligent shirts are also developed in which the conductive fibers and various sensors are embedded which measures and monitor respiration system. The increasing demand of these wearable intelligent

textiles from health care sector is going to help in developing more advance types of such intelligent textiles embedded with artificial intelligence[3].

2.3 Military and Defence sector: Due to technological advancement in electronic sector it is now possible to develop very small sized electronics devices which can be embedded in textiles and can be used in defence sector. This will give new dimensions to military and defencesecurity[3].
In adverse environmental conditions and hazardous situations faced by soldiers, there is a need of real time information system to give protection and survivability to them. The requirements for such situations are to monitor vital signs and injuries while also monitoring environment hazards such as toxic gases[3].
The intelligent textile in military can be utilized in two ways. Firstly, Personal protective garments and individual equipment which includes battle uniforms, ballistic protection vests and helmets, chemical protection suits, belts, ropes, suspenders and field-packs. Secondly, defence systems and weapons like parachutes, shelters tent houses etc. The enhanced security to both these can be provided with intelligent textiles. If a soldier get injured during war or any other situation and he is wearing an Intelligent jackets than this information is automatically transferred to the nearby controlling and monitoring unit and necessary medical or any other help can be provided to the injured soldier. The soldier can himself monitor his pulse rate, blood pressure and other parameters through the embedded intelligent systems in the jacket.
Further researches are also going on to develop such a uniform that is almost invisible and soft clothing that can become a rigid cast when a soldier break his or her leg or any other body parts.

2.4 Safety Purpose: Intelligent jackets and shirts especially for the protection of public safety personnel, namely firefighters, rescue teams, police officers are being developed with all necessary advanced safety features. They will be used in conjunction with a wireless- enabled radio system. The intelligent jacket or shirt can monitor the health and safety of public safety personnel, victims trapped in a building or underneath rubble with the ability to detect the exact location of the victims through positioning capability. It can also facilitate two- way voice and video communication. An integration of sensors and flexible light emitting displays with textile can help in designing a wearable warning signal generating jacket. This can receive and respond to stimuli from body, enabling a warning signal to be displayed and sent. The sensors in the jacket keep on monitoring the vital body parameters and if something unusual happens, same is indicated through flash of light and a wireless communication system could send a distress signal to a remote location. Textiles integrated with electronic sensor devices driven by global positioning system can detect one's exact location anytime and in any weather. Fabric area networks (FANs) make it possible with the help of electronic devices to exchange required information, power and control signals within the user's personal space and remote locations[3].

2.5 Fashion and Lifestyle: There are fabrics with moisture management systems that are being used for fast evaporation of sweat. Fabrics with UV protection, anti-allergic and anti-bacterial capabilities are available. There are intelligent dresses and sleep suit which emits scents depending on your mood and requirement. Intelligent fibers are being developed that can change colour and its shape as per your command. The conductive fibers could change colour on command from an electric signal that alters the reflective quality of this special fiber. Thereby increasing functions as well as fashion, Intelligent Textile with thermoregulation properties are also being developed. There are also interactive fibers which incorporates electronics that are activated by a power source. There are wearable electronics which can be used in intelligent wearable textiles to dial mobile numbers, control music from mp3 player etc. The examples includes business suit with a mobile phone

incorporated, sportswear to monitor heart rate, aerobic outfits with music players incorporated and club wear which changes colour[3].

IIIFuture of Intelligent Textiles

In the coming years the fibertronics will become advanced and in such situation all the electronic functions such as computing, fast and reliable communication, power sources, etc. are embedded in fiber itself. The Nano-technology will give new horizons to the intelligent textiles. Embedded optical fiber and micro-porous breathable fabrics will be more effectively and efficiently utilized in development of intelligent textiles. Weather proof and water proof systems needs to be developed. Lots of improvements are still needed in current technologies to make it more reliable, authentic, durable and economical so that it will reach to every corners of life of a common man.[3]

IV Conclusion

The majority of applications for intelligent materials in the textile sector today are in the fashion and design area, in leisure and sports garments. In work wear and the furnishing sector a variety of studies and investigations are in the process by industrial companies, universities and research centres. Most photochromic materials are based on organic materials or silver particles. The lifetime of these compositions is rather short forindustrial applications. Most thermochromic materials are organic materials, having a short lifetime and a limited range of temperature. For various applications, especially for textile applications, there is a need to develop the wide range of temperature and lifetime properties of these chromic materials.

Chromic materials are one of the challenging material groups in future textiles. Colour changing textiles are interesting, not only in fashion, where colour changing phenomena will exploit for fun all the rainbow colours, but also in useful and significant applications in work wear and in technical and medical textiles[1]. The challenging side for embedding electronic function in the clothing are flexibility, life, lightweight, comfort-level, conductivity, good process ability, good wear ability and cost effectiveness.

The research in this field is growing so rapidly that with new technologies we can integrate several electronic devices directly into textile & apparel products using common resources enhancing the mobility, comfort & convenience of such device to a great extent[3]. Intelligent textiles are not confined to the clothing sector: they are becoming increasingly prominent, for example, as biomedical and other engineering materials. These developments will be the result of active collaboration between people from a variety of backgrounds and disciplines: engineering, science, design, process development, and business and marketing. If technology is going to be increasing as part of our clothing and skin, there needs to be some serious thinking about what it means for us as humans in future[2].

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