UNIT IV
SMART TEXTILE

Introduction to smart textile- Passive smart textile, active smart textile. Fabrication Techniques Conductive Fibres, Treated Conductive Fibres, Conductive Fabrics, Conductive Inks. Case study smart fabric for monitoring biological parameters - ECG, respiration.

4.1. INTRODUCTION TO SMART TEXTILES

Smart textiles are fabrics that have technological components woven into them, monitoring external stimuli, translating that into data, and responding accordingly. Smart textiles may be aesthetic, driven by design and fashion purposes, or performance enhancing, including technologies like biometric monitoring.

Smart textiles, also known as electronic textiles (e-textiles) or smart fabrics, are textiles that contain electronic components and enhance the features of wearables, automobiles, and other products. They are either made into a textile-based product, or created with the intention of being integrated into a textile.

Some other words related to smart textiles

- Technical textile
- Intelligent textile
- Functional material
- Functional textile
- Functional fabric
- Nano-fabric
- Electronic fabric
- Smart fibre
- Soft circuit

Definition and Overview

- Smart textiles, also known as e-textiles or electronic textiles, refer to fabrics and textiles that incorporate advanced technologies to enhance their functionality.
- These textiles can sense and respond to various environmental stimuli, such as temperature, moisture, light, and even human interaction.

Evolution of Textiles

- Traditional textiles have been used for clothing and shelter for thousands of years.
- Smart textiles represent the fusion of traditional textiles with modern technology.

Types of Smart Textiles

Passive Smart Textiles

- These textiles are not actively respond to stimuli but have unique properties.
- Examples include fabrics with UV protection, flame resistance, or water repellency.

Active Smart Textiles

- These textiles can sense and respond to external stimuli.Active smart textiles are those that adapt and change their functionality in response to changes in the external environment or in response to a user input. These materials may change shape, store and regulate heat, and be applied to a wide range of flexible applications.
- Examples include fabrics with embedded sensors, actuators, and microelectronics.

Components of Smart Textiles

Sensors

- Sensors are crucial for collecting data from the environment.
- Common sensors in smart textiles include temperature sensors, pressure sensors, and moisture sensors.

Actuators

- Actuators are responsible for initiating a response in the textile.
- Examples include shape-memory alloys that change shape in response to an electrical current.

Microelectronics

- Smart textiles often contain miniaturized electronic components like microcontrollers, batteries, and conductive threads.
- These components enable data processing and communication.

Applications of Smart Textiles

Healthcare

- Monitoring vital signs (heart rate, respiration rate) through wearable garments.
- Smart bandages that detect and treat wounds.
- Posture-correcting clothing for rehabilitation.

Fashion

- Illuminated clothing with LED integration for artistic expression.
- Temperature-regulating fabrics for comfort in extreme conditions.
- Adaptive clothing for individuals with disabilities.

Sports and Fitness

- Smart athletic wear that tracks performance metrics (e.g., heart rate, distance, steps).

- Moisture-wicking and cooling fabrics for enhanced comfort during physical activities.

Military and Defense

- Camouflage textiles that adjust their color and pattern based on the environment.
- Bulletproof vests with integrated sensors for injury detection.

Automotive and Transportation

- Smart car seats that monitor driver fatigue and adjust for comfort.
- Airbags built into clothing for motorcyclists and cyclists.

Architecture and Design

- Smart curtains that adjust to the level of natural light.
- Acoustic textiles for sound insulation in buildings.

Entertainment and Gaming

- Virtual reality (VR) suits with haptic feedback for immersive gaming experiences.
- Clothing that changes color or pattern in response to music or sound.

Challenges and Future Trends

Integration

- Achieving seamless integration of technology into textiles without compromising comfort and aesthetics.

Durability

- Ensuring that smart textiles can withstand washing and everyday wear and tear.

Power Supply

- Developing efficient and long-lasting power sources for electronic components.

Sustainability

- Addressing environmental concerns related to the production and disposal of smart textiles.

Future Trends

- Advances in nanotechnology for more compact and lightweight components.
- Integration of AI and machine learning for improved responsiveness.
- Growth in the market for smart textiles as technology continues to evolve.

Working Procedure of a Smart Textile

1. Sensing

- Basically, sensing is the function of transforming a signal into another signal that can be read and understood by a predefined reader which can be real device or a person.
- For real devices all the signals should be ultimately converted into electrical ones.

2. Data Processing

- Data processing is one of the components that are required only when active processing is necessary.
- The electronics are used for data processing are now available in miniaturized and even in flexible form.
- Problems need to be overcome before imparting textile material for this function are; fastness to washing, deformation, interconnections etc.

Working Principles of Smart Textiles

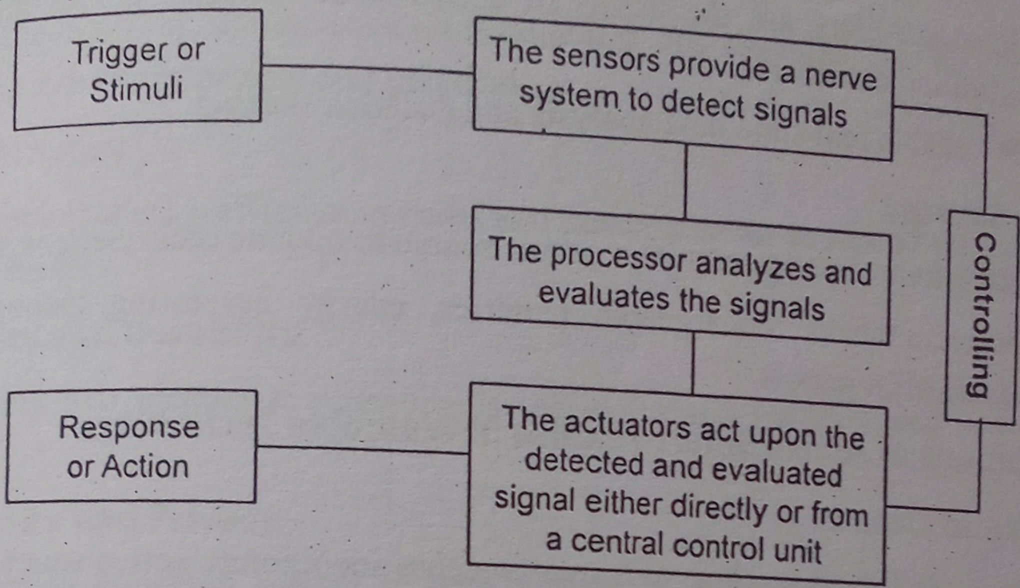


Fig. 4.1.

4.2. PASSIVE SMART TEXTILES

Introduction to Passive Smart Textiles

- Passive smart textiles are a category of smart textiles that possess unique properties and characteristics without requiring active external intervention or energy sources.
- They offer specific benefits related to comfort, safety, and protection, making them valuable in various applications.

Characteristics of Passive Smart Textiles

- Passive smart textiles do not contain electronic components like sensors or actuators but excel in other areas.
- These textiles exhibit properties such as UV resistance, flame resistance, and water repellency.

Types of Passive Smart Textiles

UV-Protective Textiles

- UV-resistant fabrics are designed to block or absorb harmful ultraviolet (UV) radiation from the sun.
- They protect the wearer from sunburn, skin damage, and the risk of skin cancer.

- Commonly used in outdoor clothing, swimwear, and hats.

Flame-Resistant Textiles

- Flame-resistant textiles are engineered to resist ignition and combustion when exposed to flames or high temperatures.
- These textiles are crucial in industries like firefighting, welding, and chemical manufacturing.
- Flame-resistant workwear ensures worker safety.

Water-Repellent Textiles

- Water-repellent textiles have a surface treatment that prevents water from being absorbed into the fabric.
- They keep the wearer dry and comfortable in wet conditions.
- Used in raincoats, outdoor gear, and sports clothing.

Fabric Technologies in Passive Smart Textiles

Coatings and Finishes

- Many passive smart textiles incorporate special coatings or finishes to achieve their properties.
- For example, UV protection is often achieved through chemical coatings that absorb or reflect UV radiation.

Inherent Fiber Properties

- Some fibers inherently possess properties like flame resistance.
- For instance, aramid fibers (e.g., Nomex) have natural flame-resistant characteristics and are used in firefighter suits.

Nano and Microscale Engineering

- Advanced manufacturing techniques enable the integration of nano and microstructures into textiles.
- Nano-sized particles can enhance UV resistance and water repellency.

Applications of Passive Smart Textiles

Outdoor Apparel

- Outdoor enthusiasts rely on passive smart textiles for UV protection and water resistance.
- Hikers, bikers, and campers benefit from clothing that keeps them dry and safe from the sun.

Workwear and Industrial Clothing

- Flame-resistant textiles are essential for workers in high-risk industries.

- Welders, firefighters, and chemical plant employees wear flame-resistant garments.

Healthcare

- Antimicrobial textiles can be considered passive smart textiles as they inhibit the growth of bacteria without external power.
- Used in medical scrubs, hospital linens, and wound dressings.

Environmental Protection

- Passive smart textiles with water-repellent properties are employed in environmental protection applications.
- They can be used in oil spill cleanup efforts to repel water and selectively absorb oil.

Challenges and Future Directions

Sustainability

- Ensuring that the production and disposal of passive smart textiles are environmentally responsible.

Innovation

- Developing new treatments and coatings for enhanced passive functionalities.

Comfort

- Balancing the passive smart features with comfort and wearability.

Regulations and Standards

- Compliance with industry standards and regulations, particularly in safety-critical applications.

Active Smart Textiles in Wearable Technology

Introduction to Active Smart Textiles

Definition and Overview

- Active smart textiles are a subset of smart textiles that can sense, actuate, and respond to various stimuli, making them a crucial component of wearable technology.
- They integrate electronic components like sensors, actuators, and microcontrollers to enhance their functionality.

Importance in Wearable Technology

- Active smart textiles play a pivotal role in the evolution of wearable technology, offering innovative solutions for monitoring health, enhancing comfort, and augmenting human capabilities.

Components of Active Smart Textiles

Sensors

- Sensors are the sensory organs of active smart textiles, enabling them to collect data from the environment or the wearer.

- Common sensors include temperature sensors, heart rate monitors, accelerometers, and GPS modules.

Actuators

- Actuators are responsible for initiating a response or action based on the data collected by sensors.
- Examples include shape-memory alloys, vibration motors, and pneumatic systems.

Microcontrollers

- Microcontrollers are the brains of active smart textiles, processing sensor data and controlling actuators.
- They enable real-time data analysis and decision-making.

Power Sources

- Active smart textiles require a power source to operate their electronic components.
- Options include rechargeable batteries, energy harvesting technologies, and even flexible solar panels.

Applications of Active Smart Textiles in Wearable Technology

Health and Fitness

- Wearable fitness trackers and smartwatches incorporate active smart textiles to monitor heart rate, sleep patterns, and activity levels.
- Smart clothing can provide biofeedback during exercise or rehabilitation.

Medical Monitoring

- Active smart textiles are used in medical wearables that monitor vital signs, such as ECG (Electrocardiogram) shirts for heart patients or smart bandages for wound care.
- They enable continuous health tracking and early warning systems.

Sports Performance

- Athletes benefit from active smart textiles that provide real-time feedback on performance metrics like posture, muscle activity, and fatigue levels.
- These textiles help improve training and prevent injuries.

Fashion and Aesthetics

- Active smart textiles are used in fashion-forward wearable creations, such as dresses that change color in response to music or mood.
- They enable interactive and artistic expressions through clothing.

Military and Defense

- The military employs active smart textiles in soldier uniforms for monitoring health, environmental data, and communication.

- Smart textiles can help optimize soldier performance and safety.

Augmented Reality (AR) and Virtual Reality (VR)

- AR and VR headsets often incorporate active smart textiles for comfort, sensors for head tracking, and haptic feedback systems for a more immersive experience.
- These textiles enhance the user interface and sensory feedback.

Challenges and Future Trends

Miniaturization

- Advancements in miniaturization techniques are essential for making active smart textiles more comfortable and practical.

Energy Efficiency

- Developing energy-efficient systems and power sources to extend the usability of active smart textiles.

Washability and Durability

- Ensuring that electronic components can withstand washing and everyday wear and tear.

Data Security and Privacy

- Addressing concerns related to data security and privacy when wearable technology collects and transmits personal information.

Integration with AI

- Integration of artificial intelligence (AI) and machine learning algorithms to enhance the capabilities of active smart textiles.

4.3. CONDUCTIVE FIBRES

- Conductive fibers are textile materials that possess electrical conductivity, allowing them to conduct electrical signals and power.
- They play a critical role in wearable technology, enabling the integration of electronic components into textiles.

Importance in Wearable Technology

- Conductive fibers serve as the foundation for creating flexible and functional electronic circuits within wearable garments.
- They enable the seamless integration of sensors, LEDs, and other electronic components into clothing.
- Conductive polymer-based electrochromic fabrics show promising applications in new intelligent displays, flexible smart wearables, and military camouflage, thanks to their flexibility, light weight, high degree of controllability, and wide range of color change.

- The textile structures which can conduct electricity are called conductive textiles. It may be either made using conductive fibres or by depositing conductive layers onto non-conductive textiles.
- A conductive fabric can conduct electricity and made with metal strands woven into the construction of the textile. It can be inhibited the static charge generated on fabric, to avoid uncomfortable feelings and electrical shocks also.

4.3.1. TYPES OF CONDUCTIVE FIBERS

Metallic Conductive Fibers

- Made from metal or metal-coated materials like silver, copper, or gold.
- Offer high electrical conductivity but can be less flexible than other types.

Carbon-Based Conductive Fibers

- Utilize carbon nanotubes, graphene, or carbon-coated materials.
- Known for their flexibility, lightweight, and suitability for e-textiles.

Polymeric Conductive Fibers

- Use conductive polymers like polypyrrole or PEDOT:PSS.
- Combine electrical conductivity with flexibility and comfort.

4.3.2. APPLICATIONS OF CONDUCTIVE FIBERS IN WEARABLE TECHNOLOGY

Wearable Sensors

- Conductive fibers are used to create sensors for measuring temperature, humidity, pressure, and more.
- They enable the integration of sensors directly into clothing for health monitoring and environmental sensing.

Heating Elements

- Conductive fibers with resistance properties can generate heat when an electrical current passes through them.
- Used in heated clothing for cold weather or medical applications.

Lighting and Displays

- LEDs and OLEDs can be embedded in fabrics using conductive fibers.
- This allows for illuminated textiles and even flexible displays on clothing.

Energy Harvesting

- Conductive fibers can capture energy from motion or sunlight and convert it into electrical power.
- Used in self-powered wearable devices.

4.3.3. CHALLENGES AND FUTURE DIRECTIONS

Durability

- Ensuring that conductive fibers remain functional after repeated bending, washing, and wear.

Scalability

- Developing cost-effective manufacturing methods for large-scale production of conductive fibers.

Compatibility

- Integrating conductive fibers with standard textile manufacturing processes.

Biocompatibility

- Addressing concerns related to skin irritation and allergies when using conductive fibers in wearable technology.

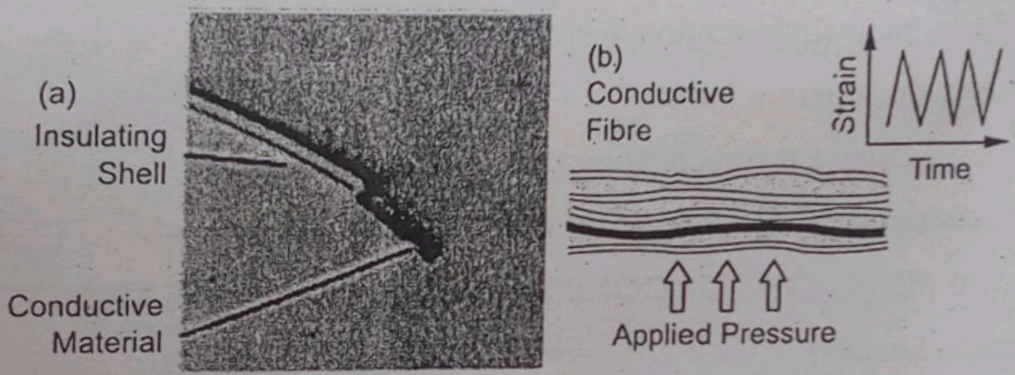


Fig. 4.2.

4.3.4. METHODS OF PRODUCING CONDUCTIVE TEXTILES ARE SUMMARIZED AS FOLLOWS

- Adding carbon or metals in different forms such as wires, fibres or particles.
- Using inherently conductive polymers.
- Coating with conductive substances.

4.3.5. TYPES OF CONDUCTIVE TEXTILES:

Generally, four kinds of conductive textile as follow:

1. Anti-static textiles
2. EM shielding textiles
3. E-textiles
4. Functional coatings

4.3.5.1. Anti-static textiles:

Static electricity can the build-up of electric charge on the surface of objects. Which can be caused many problems for textile materials, manufacturing and handling the product.

In dry textile process, fibres and fabrics can tend to generate electro-static charges from friction.

When fibres and fabrics are moving at high speeds on different surfaces, (like: conveyer belts, transport bands, driving cords, etc) causing fibres and yarns to repel each other.

These static charges can be produced electrical shocks and caused the ignition of flammable substances. Two techniques are known to prevent static electricity in textiles.

One is to create a conducting surface and another is to produce a hydrophilic surface. In these ways antistatic textiles are produced to avoid the potential hazards caused by static charge or, electricity.

4.3.5.2. EM shielding

- Electro Magnetic shielding (EMs) is the process of restricting the diffusion of electromagnetic fields into a space. In this process, electrically or magnetically conductive barrier is used.
- Shielding is common technique for protecting electrical equipment and human beings from the radiating electro-magnetic fields. This barrier can be rigid or flexible.
- When an EM beam passes through an object, the electro-magnetic beam interacts with molecules of the object and this interaction may take place as absorption, reflection, polarization, refraction, diffraction through the object.
- EM Shielding textiles materials can be found in the form of woven, knitted, and nonwoven fabric also.
- The major components of these fabrics are fibres and yarns. To achieve an effective shielding behaviour, these fibres should be electrically conductive.
- Conductive yarns can be made by blending conductive fibres with conventional staple fibres, twisting conductive or insulator filaments together.
- For example, conductive metallic yarn (such as: silver, copper, etc.) can be wrapped with insulating textile materials to create hybrid yarns. Which could be integrated into woven or knitted structures.
- Hybrid yarns or metallic fibre can be integrated into these designs as warp. Electromagnetic shielding effectiveness of the fabric decreased with the increase in fabric openness.

4.3.5.3. E-textiles

- Electrically conductive fibres and yarns have attracted great interest because of their distinguished features including reasonable electrical conductivity, flexibility, electrostatic discharge, and EM interference protection.
- Conductive textile fibres are the primary component for wearable smart textiles introduced particularly for different applications such as sensors, electromagnetic interference shielding, electrostatic discharge, and data transfer in clothing.
- Therefore, the demand for electrically conductive fibres and yarns is ever-growing.

- The development of novel conductive fibres becomes crucial with technological improvement in wearable electronics such as wearable displays, solar cells, actuators, data managing devices, and biomedical sensors.
- E-textiles play a critical role in selecting the conductivity of smart textile electronics.
- Textile applications such as lighting, considerable current is necessary and low ohmic fibres are preferred. On another hand, for certain sensing or heating applications lower conductivity would work better.
- So, it requires fibres exhibiting lower electrical conductivity. E-textiles need flexible and mechanically stable conducting materials to ensure electronic capabilities in apparel.

4.3.5.4. Functional coatings

- For many applications, functional coating is the material interfaces and surfaces that provide beneficial functionality over their intrinsic bulk characteristics.
- Hence, coatings provide a versatile method of modifying textiles with conductive properties. Subsequently, the textile fabric acts as a supporting structure or carrier material for the conductive finish.
- Conventional methods such as dip coating or roll coating are typically used to apply bulk coatings in the form of a saturation or lamination that covers the entire "surface" of the textile.
- However, as will be presented herein, the advent of nano-technology in textile research, the development of novel process techniques, and the advancement of inks and coating formulations affords the opportunity to apply coatings to increasingly finer structures.

4.3.6. PROPERTIES OF CONDUCTIVE TEXTILES

Physical properties

- Low weight,
- High strength,
- Flexibility,
- Durability,
- Elasticity,
- Heat insulation,
- Water absorbency,
- Dyeability,
- Drape,
- Soft handling,

4.3.7. FABRICATION TECHNIQUES FOR CONDUCTIVE FIBERS

Coating and Deposition

- Involves coating or depositing conductive materials onto regular textile fibers.
- Methods include sputtering, chemical vapor deposition, and electroplating.

Incorporation during Fiber Production

- Conductive materials are blended with polymer solutions before fiber spinning.
- This method results in conductive fibers throughout the entire structure.

Printing and Dyeing

- Conductive inks or dyes are applied to textiles using techniques like screen printing or inkjet printing.
- Suitable for adding conductive patterns to existing fabrics.

Yarn and Thread Formation

- Conductive fibers can be fabricated by twisting or spinning conductive materials into yarn or threads.
- This approach creates highly flexible conductive elements.

4.4. TREATED CONDUCTIVE FIBERS

- Treated conductive fibers refer to textile fibers that have undergone specific treatments or coatings to enhance their electrical conductivity.
- These fibers are crucial components in wearable technologies, enabling the integration of electronic functionalities into textiles.

Importance in Wearable Technology

- Treated conductive fibers offer the advantage of improved conductivity and durability, making them essential for creating reliable and functional electronic circuits in wearable devices.

Types of Treated Conductive Fibers

Metal-Coated Conductive Fibers

- These fibers are typically made of non-conductive materials like nylon or polyester, which are then coated with a thin layer of metal such as silver or copper.
- The metal coating enhances conductivity and provides flexibility.

Chemical Treatment

- Conductive fibers can be chemically treated using solutions containing conductive nanoparticles or polymers.
- Chemical treatments can improve conductivity while maintaining fiber flexibility.

Doping

- Doping involves introducing conductive additives or dopants into the fiber's polymer matrix.
- Common dopants include graphene, carbon nanotubes, and conductive polymers. Fabrication and Treatment Techniques for Conductive Fibers

Electroless Plating

- Involves immersing fibers in a solution containing metal ions, which adhere to the fiber's surface through a chemical reaction.
- This process results in a uniform metal coating that enhances conductivity.

Physical Vapor Deposition (PVD)

- PVD methods, such as sputtering or evaporation, allow for precise control over the metal coating thickness.
- Ideal for creating thin, conductive layers on fibers.

Chemical Vapor Deposition (CVD)

- Chemical vapor deposition can be used to grow conductive materials directly on the fiber's surface.
- It ensures good adhesion and uniformity.

D. Polymer Blending

- Conductive polymers or nanoparticles can be blended with the fiber's polymer during spinning or extrusion.
- This approach ensures conductivity throughout the fiber.

Chemical Treatments

- Fibers can be soaked or coated with solutions containing conductive materials or additives.
- The treatment process can be customized to achieve the desired level of conductivity.

Applications of Treated Conductive Fibers in Wearable Technology

Flexible Circuits

- Treated conductive fibers enable the creation of flexible and washable circuits integrated into clothing.
- These circuits can connect sensors, LEDs, and other electronic components.

Biometric Monitoring

- Wearable devices with biometric sensors, such as ECG or EMG sensors, benefit from the enhanced conductivity of treated fibers.
- They ensure accurate and reliable data collection.

Wearable Antennas

- Treated conductive fibers can be used to create antennas for communication in smart garments.
- This enables wireless connectivity in wearable technology.

Heating Garments

- In heated clothing, such as heated jackets or gloves, treated conductive fibers are used to distribute heat evenly.
- They offer comfort and warmth in cold environments.

Challenges

Durability and Washability

- Ensuring that treated conductive fibers maintain their conductivity and functionality after repeated wash cycles and wear.

Cost-Effectiveness

- Developing cost-effective methods for treating fibers on a large scale while maintaining quality.

Customization

- Offering customizable treatments to meet specific conductivity and flexibility requirements for different wearable applications.

Sustainability

- Exploring sustainable materials and treatment processes to reduce the environmental impact.

4.5. CONDUCTIVE FABRICS

- Conductive fabrics are textile materials that are woven or coated with conductive elements, such as metal threads or conductive polymers.
- They serve as a fundamental building block for integrating electronics into wearable technology.
- Conductive fabrics enable the creation of flexible and wearable circuits, sensors, and interfaces within clothing and accessories.
- They bridge the gap between traditional textiles and electronic components, making wearable technology comfortable and functional.

Types of Conductive Fabrics

Metallic Conductive Fabrics

- These fabrics contain metal threads or fibers, such as silver, copper, or gold.

- ❖ Known for their high electrical conductivity but can be less flexible than other types.

Textile-Based Conductive Fabrics

- ❖ Made by weaving or coating regular textile fibers with conductive coatings.
- ❖ Offer a balance between conductivity and flexibility, making them ideal for e-textiles.

Polymeric Conductive Fabrics

- ❖ Incorporate conductive polymers or conductive coatings on textile substrates.
- ❖ Known for their flexibility and lightweight properties.

Fabrication Techniques for Conductive Fabrics

Weaving and Knitting

- ❖ Conductive fabrics can be woven or knitted using conductive yarns or fibers alongside regular textile fibers.
- ❖ This method allows for the creation of conductive patterns and traces within the fabric.

Coating and Printing

- ❖ Regular fabrics can be coated or printed with conductive materials like conductive inks or metal nanoparticles.
- ❖ Suitable for adding conductive elements to existing textiles.

Laminating

- ❖ Conductive layers can be laminated onto textiles, creating a conductive surface.
- ❖ This technique provides flexibility while ensuring good conductivity.

Direct Incorporation

- ❖ Conductive materials can be directly incorporated into the fabric during the textile production process.
- ❖ The resulting fabric contains conductive elements uniformly distributed throughout.

Applications of Conductive Fabrics in Wearable Technology

Wearable Sensors

- ❖ Conductive fabrics are used to create sensor arrays for measuring temperature, pressure, humidity, and more.
- ❖ They enable non-invasive health monitoring and environmental sensing.

Smart Garments

- ❖ Clothing and accessories made with conductive fabrics can include integrated LED displays, touch-sensitive areas, or heating elements.

- Smart garments enhance user experience and comfort.

Flexible Circuits

- Conductive fabrics serve as the substrate for creating flexible and washable circuits.
- They connect electronic components like microcontrollers, sensors, and power sources.

E-Textiles

- Conductive fabrics are the foundation of electronic textiles (e-textiles).
- E-textiles encompass a wide range of applications, from heated clothing to interactive fashion.

Challenges

Durability

- Ensuring that conductive fabrics remain functional after repeated bending, washing, and wear.

Integration Complexity

- Developing techniques for seamlessly integrating conductive fabrics with electronic components.

Cost-Efficiency

- Exploring cost-effective production methods for conductive fabrics to promote wider adoption.

Customization

- Offering customizable solutions to meet the specific needs of different wearable technology applications.

4.6. CONDUCTIVE INKS

Conductive inks are specialized inks that contain conductive materials like silver, copper, or graphene.

- They are essential components in the fabrication of flexible and wearable electronic circuits and sensors.
- Conductive inks offer a versatile and cost-effective means to create conductive traces, patterns, and components on flexible substrates, such as textiles, for wearable applications.

Types of Conductive Inks

1. Metal-based Inks

(*a*) **Silver (Ag) inks:** Widely used due to high conductivity and excellent compatibility with various substrates.

(*b*) **Copper (Cu) Inks:** Increasingly popular due to cost-effectiveness compared to silver, but with slightly lower conductivity.

(*c*) **Gold (Au) Inks:** Expensive but offers excellent stability and conductivity.

2. Carbon-based Inks

(*a*) **Carbon nanotubes (CNTs) Inks:** Provide good electrical conductivity and mechanical flexibility.

(*b*) **Graphene Inks:** Offer excellent electrical properties and can be produced from graphite or chemical vapor deposition.

(*c*) **Conductive Polymers:** Provide flexibility and compatibility with organic substrates.

Fabrication Techniques for Conductive Inks

Screen Printing

- Screen printing is a common technique for applying conductive inks to textiles.
- It involves forcing ink through a stencil onto the fabric, creating conductive patterns.

Inkjet Printing

- Inkjet printers can deposit conductive inks with precision onto various substrates.
- Ideal for creating detailed and customized conductive patterns.

Spray Coating

- Conductive inks can be sprayed onto substrates using specialized equipment.
- This method is suitable for large-area applications.

3D Printing

- 3D printing technology can be adapted to print conductive traces and structures directly onto wearable components.
- Allows for complex and customized designs.

Applications of Conductive Inks in Wearable Technology

Flexible Circuits

- Conductive inks enable the creation of flexible and stretchable circuits on textiles or other flexible substrates.
- These circuits connect electronic components, facilitating data processing and power distribution.

Sensors

- Wearable sensors for monitoring physiological parameters, such as heart rate and temperature, often utilize conductive inks for electrode placement.
- They ensure accurate and reliable data collection.

LED Displays

- Conductive inks can be used to print LED displays onto textiles.
- Smart clothing with integrated displays can convey information or change appearance dynamically.

Energy Harvesting

- Wearable devices can incorporate energy-harvesting components, such as flexible solar cells.
- Conductive inks are used to create conductive traces for efficient power transfer. Challenges:

Adhesion and Durability

- Ensuring that conductive ink patterns adhere well to flexible substrates and remain functional after wear and washing.

Material Selection

- Continued research into the development of eco-friendly and sustainable conductive ink materials.

Precision Printing

- Advancements in printing technologies for finer and more precise conductive patterns.

Cost-Effective Production

- Exploring cost-effective methods for large-scale production of conductive ink-based wearable components.

4.7. CASE STUDY SMART FABRIC FOR MONITORING BIOLOGICAL PARAMETERS

Applications of Smart Fabrics in Healthcare

(*i*) Remote Patient Monitoring:

Smart fabrics allow continuous monitoring of patients' vital signs outside the hospital, providing early warning of any deterioration.

(*ii*) Elderly Care

Smart fabrics are used in garments for the elderly to monitor falls, detect changes in posture, and ensure their safety.

(*iii*) Sports and Fitness

Athletes use smart fabrics to track performance metrics, manage exertion levels, and prevent injuries.

(*iv*) Sleep Monitoring

Smart fabrics embedded in sleepwear monitor sleep patterns, helping diagnose sleep disorders and improve sleep quality.

- Merging electronics with textiles has become an emerging trend since textiles hold magnificent wearing comfort and user-friendliness compared with conventional wearable bioelectronics.
- Smart textiles can be effectively integrated into our daily wearing to convert on-body biomechanical, biochemical, and body heat energy into electrical signals for long-term, realtime monitoring of physiological states, showing compelling medical and economic benefits.
- The current progress in self-powered biomonitoring textiles along three pathways: biomechanical, body heat, and biochemical energy conversion.
- Finally, it also presents promising directions and challenges in the field, as well as insights into future development.
- The smart textiles for self-powered biomonitoring, which could contribute to revolutionizing our traditional healthcare into a personalized model.

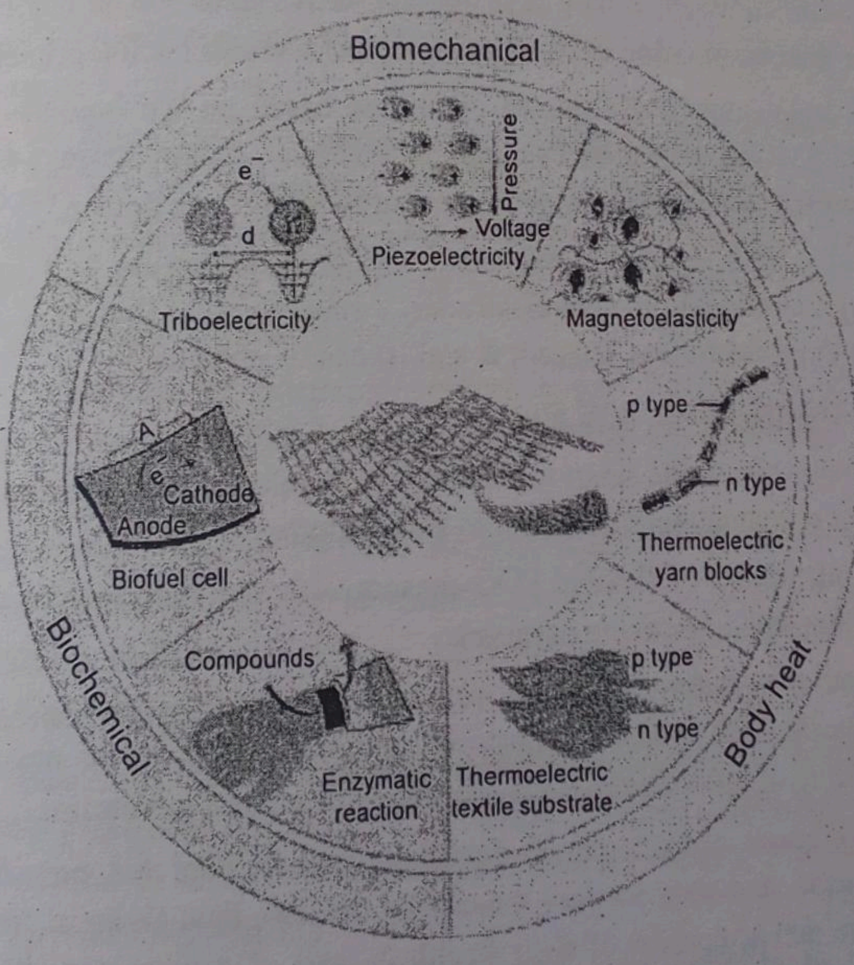


Fig. 4.3.

- Self-powered biomonitoring textiles via biomechanical, body heat, and biochemical energy conversion are discussed in this work.
- Platform technologies, including piezoelectric nanogenerators (PENGs), triboelectric nanogenerators (TENGs), and magnetoelastic generators (MEGs) for biomechanical energy conversion, thermoelectric generators (TEGs) for boy heat energy conversion,

and biofuel cells (BFCs) for biochemical energy conversion, are systematically introduced and discussed in a textile form.

- Working in a self-powered manner with greatly improved wearing comfort, the smart biomonitoring textiles pave a compelling road to personalized healthcare.

4.7.1. SMART FABRIC FOR MONITORING BIOLOGICAL PARAMETERS - ECG

- Devices that monitor physiological activities such as heart activity or electrocardiogram (ECG, also called EKG)], brain activity/electroencephalogram], muscle activity/electromyography , and other health indicators such as skin temperature , respiration, breathing, sweating rate, etc. have tremendous advantages in monitoring health.
- ECG is the process of recording the electrical activity of the heart, one of the most important physiological signals, which contains a treasure trove of information about the heart condition and heart-related diseases, such as arrhythmia, cardiac arrest, premature atrial contraction, premature ventricular contraction, congestive heart failure and coronary artery disease.
- Recently, wearable ECG devices that enable us to continuously monitor heart activity are being developed as textile-based devices.
- As textiles are an indispensable part of our life, this is quite convenient for handling.

4.7.1.1. Overview of the ECG Signal

- The appropriate and affordable heart activity monitoring devices to know the status at any time and detect disorders at an early stage.
- ECG is one of the most widely used vital signal sensing and health monitoring methods which contains important information to diagnose cardiovascular diseases and examine their development.
- ECG is a medical diagnosis activity for the heart, performed by placing two or more electrodes on the skin.
- The heart pumps blood throughout the body, and during this time an electrical signal is generated. The heart contains upper and lower parts, the upper chambers are called atria, and the lower chambers ventricles; each part consists of a right and left chamber.
- During normal blood circulation, the right atrium receives deoxygenated blood returning from the body and the left atrium receives oxygenated blood from the lungs. Similarly, the left ventricle receives oxygenated blood from the left atrium and pumps it through the aorta and then out to the rest of the body, whereas the right ventricle receives blood from the right atrium and pumps it through the pulmonary arteries to the lungs, where it picks up oxygen and drops off carbon dioxide.
- Atria contract (depolarize) to pump blood to the ventricle and relax (repolarize) to receive blood and in a similar manner, the ventricles also contract during blood pumping and relax while receiving blood from the atria.

- During this heart activity, the blood circulates in our body and the heart generates electrical currents due to the polarization and depolarization of the atria and ventricles which can be measured on the skin using ECG.
- The sinoatrial node, which is the natural pacemaker of the heart located at the right atrium, is the origin of the electrical activity of the cardiac system. Conducting pathways take the impulse to different parts of the heart to regulate heartbeats.
- The full morphological structure of the ECG signal contains the P wave, T wave, and QRS complex as shown in Figure , where the P wave represents the depolarization of the atrium, the QRS complex is generated by the depolarization of the ventricles, and the T wave results in the re-polarization, i.e., relaxation of the ventricles.

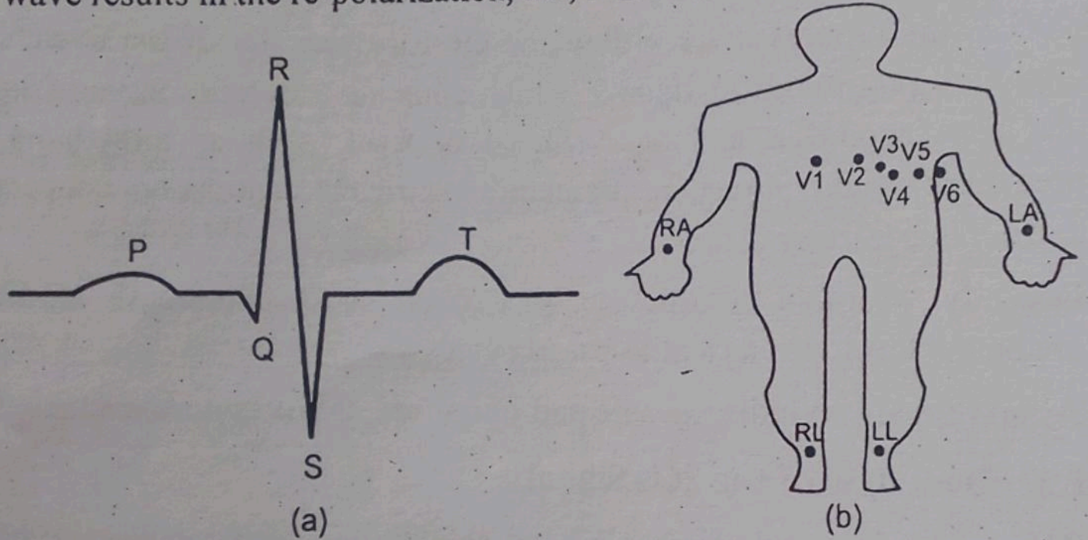


Fig. 4.4. (a) Typical normal ECG signal with major components from Lead I configuration; (b) electrode placement for standard clinical ECG measurement, where V is the voltage, RA is the right arm, LA is the left arm, RL is the right leg, and LL is the left leg electrodes.

- The quality of the ECG signal is essential for precise and accurate heart activity monitoring. Any ECG device, whether clinical or portable, contains three essential components: the electrodes which are placed over the skin to capture the ionic currents generated from the heart and convert them into electrical current, the interconnections or wires taking out the acquired signal to the processing unit, and the processing unit which is used to filter unwanted signals and amplify the signal to help identify and interpret the signal.
- Of these, the electrodes are the main components that affect the quality of the acquired signal. Conventionally, ECG is recorded by placing the electrodes on the skin, usually around the chest and on the limbs.
- The standard clinical ECG acquisition employs a 12-lead system that contains 10 electrodes with six electrodes fixed around the chest labeled V1 to V6 and four electrodes attached to the limbs.

- Among the limb electrodes, three electrodes are used to generate three bipolar limb leads (Leads I, II, and III, which record the voltage difference between two limb electrodes).
- Lead I refer to the voltage between the left arm and right arm electrodes, Lead II refers to the voltage between the left leg and right arm electrodes, and Lead III refers to the voltage between the left leg and left arm electrodes.
- Unipolar limb leads, which are also called augmented leads, are derived from the same three electrodes used for the bipolar leads.
- Augmented vector left (aVL) lead is recorded by placing a positive electrode on the left arm and the negative pole is a combination of the right arm electrode and the left leg electrode, while the augmented vector right (aVR) lead uses a positive electrode on the right arm and a negative pole which is a combination of the left arm electrode and the left leg electrode.
- In the same way, the aVF lead uses a positive electrode on the left leg and the negative pole is a combination of the right arm electrode and the left arm electrode.
- The augmented leads can be computed based on the bipolar ones. Here, the fourth electrode is used to provide a ground reference, usually through active circuits. Figure b shows the standard electrode placement in the 12-lead system.
- Usually, ECG measurements using textile electrodes use only two or three electrodes, though in the case of two electrodes, a single bipolar limb lead can be obtained, while with three electrodes, Leads I, II and III can be obtained.

4.7.1.2. Textile-Based ECG Electrodes

- Wearable electronic smart textiles can be developed by using the textile fabric itself as a sensor or embedding the sensor in textile clothes.
- The integration of flexible ECG sensors with everyday textiles will be convenient for handling and cost-saving purposes.
- Instead of attaching a separate electrode like a disposable Ag/AgCl electrode, making the textile itself a sensing electrode is more interesting for monitoring the health and wellbeing of individuals demanding long-term heart monitoring.
- Textile-based sensors could contribute possibilities for providing more affordable, accessible, and easy-to-wear measuring devices, thus giving a greater potential to users to take active control of their health as part of a preventive lifestyle which brings a reduction in healthcare cost by the early detection of health problems.
- However, conventional textile products that are found in everyday garments are intrinsically electrically non-conductive and hence cannot be directly used for bio-sensing applications.
- Sensing or data transmission via the textile material requires the textile to be electrically conductive. Textiles can be made electrically conductive by integrating metals, carbon

materials, or conductive polymers into the textile structure through several techniques at different stages (fibers, yarns, or fabrics)

- Wearable textile electrodes for continuous health monitoring products, as part of standard clothing, are needed to satisfy several requirements. The most important requirement is that they should have adequate electrical conductivity.
- Sufficient electrical conductivity is necessary to detect even small amplitudes in the electrophysiological signals of the heart. High electrical conductivity results in lower skin–electrode impedance which is very essential during ECG measurements to acquire high signal quality.
- Additionally, as part of standard clothes, textile electrodes should have a good visual appearance taking into account fashion aspects, and at the same time be comfortable for the wearer.
- Furthermore, the conductive textiles should allow standard maintenance such as washing and ironing. In addition, the electrodes should be easy to wear and use, and should be as lightweight as possible, though should not hinder the users' movement and daily activity.
- Apart from the electrodes, the signal recording also needs interconnections and data processing and possibly an antenna, which should also be integrated (completely or partly) into the garment. After data processing, the result may then in turn be used to display information on the health status of the wearer, either to the user or to the concerned people such as their physician.
- All these parameters of wearable sensors make designing such products very challenging as many conflicting requirements must be considered during product development.
- Depending on the coupling between the electrode and the skin, textile-based dry electrodes can be categorized into two types:

  (*i*) contact electrodes and

  (*ii*) non-contact electrodes.

  In contact electrodes, the direct physical coupling is established between the skin and the electrode. Electrodes are required to have continuous conformal contact with the skin of the wearer to allow consistent signal detection and to minimize artifacts and noise, i.e., unwanted signals.
- When electrodes are directly attached to the skin, they should be biocompatible not to cause any negative impact on the skin of the user, whereas in non-contact electrodes, there is no physical contact to the skin and the electrodes are rather separated from the skin by a dielectric material or air.
- In a non-contact system, the electrodes should be kept at a fixed distance from the skin for optimal operation.

- These sensors function by the principle of sensing the electric field created by the displacement currents in the body through the coupling of charges between the patient's skin and the electrode and are called capacitively coupled electrodes.
- Non-contact electrodes are especially important when contact electrodes damage the skin like in newborns. Most electrodes used are contact electrodes and provide better signal quality.
- These textile-based electrodes can be developed by integrating yarns or wires to the textile structure or applying conducting compounds onto the textile fabric surface. In the following section, the methods to make textile electrodes for ECG applications have been covered in detail.

4.7.1.3. Metal Integrated Textile Electrodes

The earlier forms of electrically conductive textiles are made by integrating metal yarns into textiles. Metal yarns are different from metal wires, as they consist of metal fibers or filaments that are processed as standard textile fibers (cotton or polyester) to create a yarn.

They were first developed to discharge static electricity. The metal fibers are produced either through a bundle-drawing process or shaved off the edge of thin metal sheeting, leading to very thin metal filaments (diameters ranging from 1 to 80 micron). Metal fabric electrodes can then be developed by integrating metal yarns made up of these metal fibers such as stainless steel during the manufacturing stage (weaving, knitting, or nonwoven).

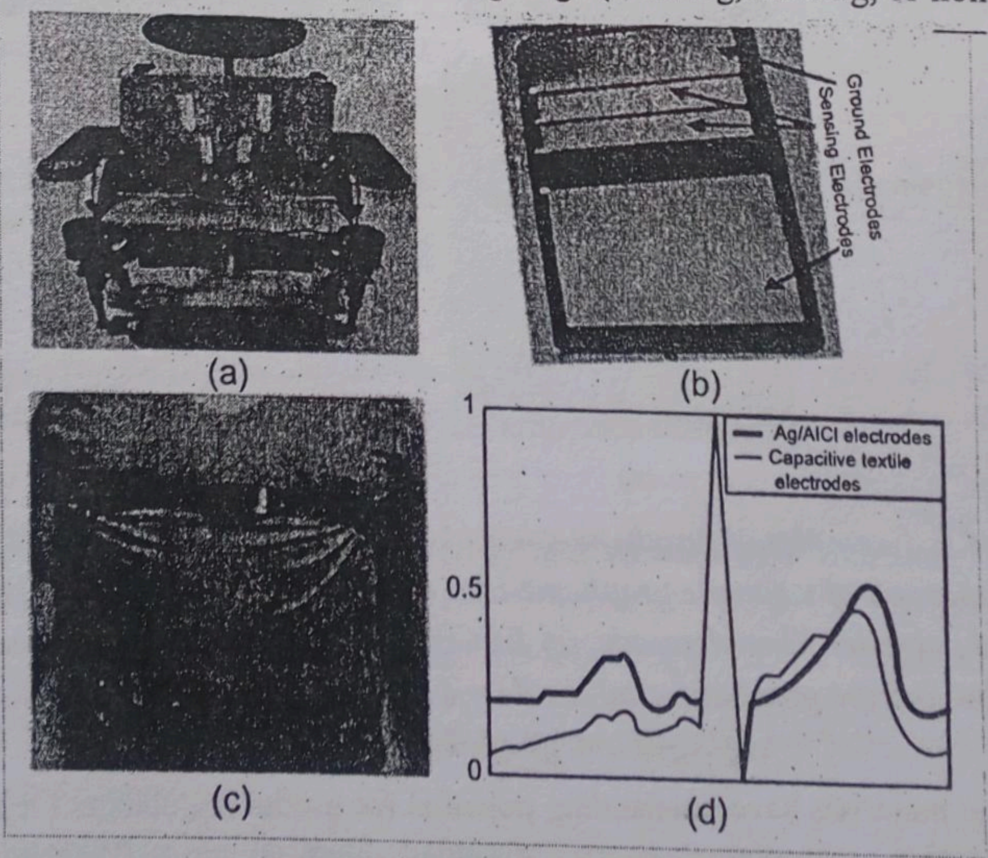


Fig. 4.5.

Metal integrated textile-based ECG non-contact electrodes have been developed. The metal threads in this can be silver, copper, or stainless steel, but also other metal wires are employed to develop conductive textiles.

These non-contact electrodes can be integrated into clothing, a chair, a wheelchair, a hospital bed, and a stretcher, or other seats. Some examples of non-contact textile ECG sensors.

Metal-coated conductive textile materials are attractive for biopotential monitoring due to their high conductivity; however, they have certain limitations. Some metals are prone to corrosion, especially under conditions such as humidity, metals such as stainless steel have a high density which affects the fabric weight and softness, and metallic-coated fabrics have poor abrasion resistance. Some examples of metal-coated textile-based ECG electrodes are shown in Figure 4.5 (*a*) - (*c*), Figure 4.5 (*d*) presents a comparison of ECG signals collected using Ag/AgCl and silver-coated textile electrodes, and results revealed that major peaks are visible in both signals.

4.7.1.4. Carbon-Coated Textile Electrodes

As the interest in conductive textiles increases, alternative methods are being investigated to produce suitable products for wearable smart textiles. Carbon materials have been used in the development of electrically conductive polymer composites and textiles.

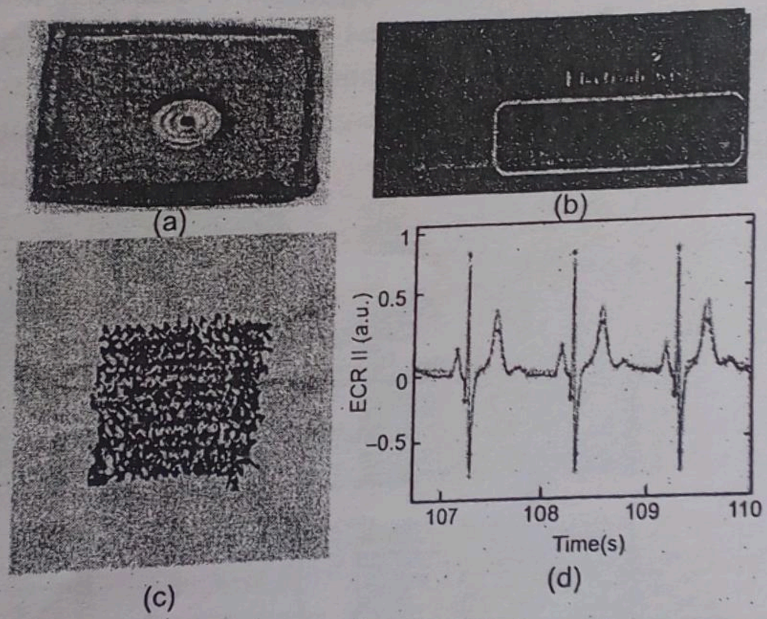


Fig. 4.6. Examples of graphene-coated textile ECG electrodes and resulting signals: (a) photograph of a sample grapheme-clad nylon fabric for ECG electrode, (b) graphene-coated polyester fiber electrode, (c) ECG signals recorded from conventional Ag/AgCl electrodes and the graphene-clad textile with wristband, and (d) filtered ECG signals from Ag/AgCl and graphene-clad textile electrodes

Carbon materials have outstanding potential for producing conductive textiles due to low cost, corrosion resistance, flexibility, excellent electrical properties, and high aspect ratio (length-to-width ratio). Carbon-based materials such as carbon fibers, carbon nanotubes (CNT), and chemically modified graphite and graphene (GN) have been used in the development of conductive textiles for biopotential monitoring. The graphene-clad conductive textile sensing electrodes which are washable.

A wearable smart medical garment for ECG monitoring was developed by stitching the electrodes on an elastic wristband and neckband. The test results revealed that these signal qualities collected by the dry electrodes were comparable with conventional Ag/AgCl electrodes. ECG monitoring feasibility was evaluated by using a tight-fitting elastic sport shirt, where small silver discs created the electrical contact of the p-electrodes and wires.

The contact impedance between the patch electrode and the skin was low (70.0 kΩ), whereas the contact impedance of Ag/AgCl electrodes was 118.7 kΩ. This was due to the carbon paste which covered the skin and provided a conformal contact with the silver discs in the t-shirt, which helps to provide excellent ECG signal quality at different conditions comparable with conventional gelled electrodes. Figure 4.6 (*a*), (*b*) present textile ECG electrodes and Figure 4.6 (*c*), (*d*) show a comparison of ECG signals collected using textile and Ag/AgCl electrodes from .

In the cross-correlation of the entire waveform in Figure 4.6 (*c*) was 88%, the cross-correlation in Figure 4.6 (*d*) showed an almost perfect overlap of signals.

4.7.1.5. Conductive Polymer-Coated Textile Electrodes

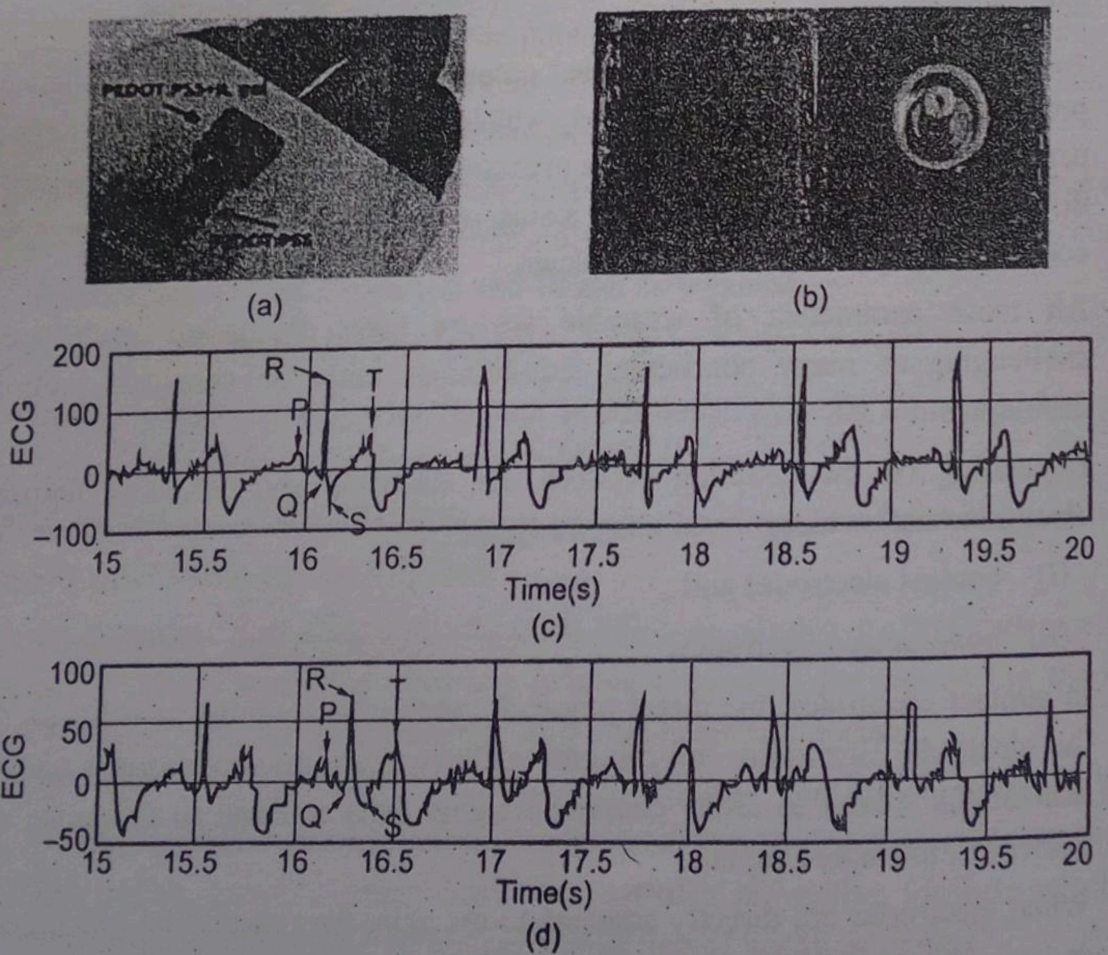


Fig. 4.7. Conductive polymer-coated textile electrodes: (a) PEDOT:PSS and ionic liquid gel-coated polyester textile electrode; (b) PEDOT:PSS-coated textile electrode (c) ECG signal collected from PEDOT:PSS-coated textile electrode before washing; and (d) after 50 washing cycle. The ECG signals collected using textile electrodes show 25.5 dB SNR before washing and 10.3 dB SNR after 50 washing cycles.

Recently conductive polymers have received much attention as they allow for the creation of lightweight and flexible conductive materials, such as textiles coated with a conductive polymer. These materials, owing to their flexibility, durability, ease of manufacturing, and application, are considered promising for wearable health care applications. Moreover, conductive polymer-based conductive textiles are expected to allow for the creation of more comfortable textile electrodes for ECG applications. Recently, a lot of work on conductive polymer-based textile electrodes has been reported, owing to their promising electrical conductivity, ease of use, and low process cost

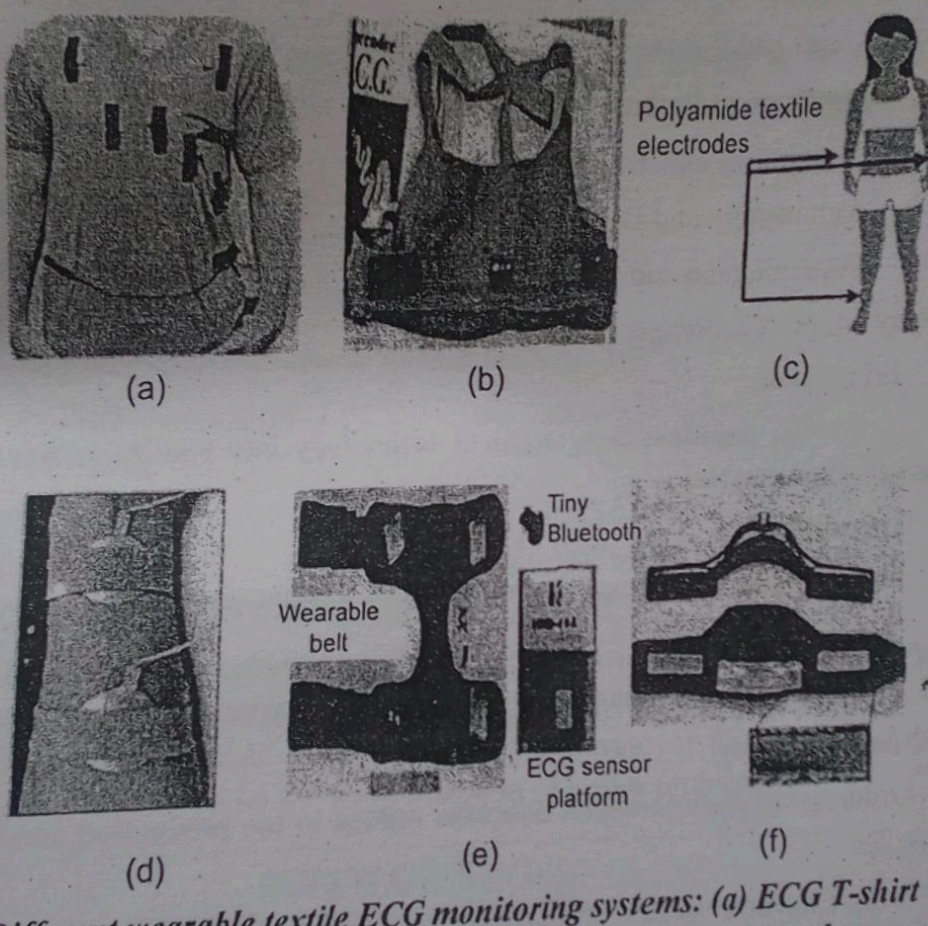


Fig. 4.8. Different wearable textile ECG monitoring systems: (a) ECG T-shirt with active electrodes and connectors (b) PEDOT:PSS-coated polyamide electrodes sewn into bras, (c) electrode placement for ECG measurement where plastic clamps were used to fix the electrodes onto the wrist (d) ECG sensing wristband with printed and flexible electrodes (e) wearable chest belt with silver-coated nylon woven electrodes and Bluetooth module (f) ECG belt with wetting pad (above) and the embroidered electrodes (below)

4.7.2. SMART FABRIC FOR MONITORING BIOLOGICAL PARAMETERS - RESPIRATION

- Respiration monitoring involves tracking the rate and depth of a person's breathing.
- It is essential for assessing lung health, sleep quality, and stress levels.
- To monitor breathing pattern by a body-conducted sound sensor placed on the neck.
- The sensors used are namely air-coupled microphone and acceleration sensor.

- Wearable devices use various sensors, such as strain gauges or piezoelectric sensors, to measure chest or abdominal movements during breathing.
- Respiration monitoring is vital for sleep apnea diagnosis, stress management, and athletic performance optimization.
- Wearables can detect breathing abnormalities and provide feedback for relaxation and stress reduction.

4.7.2.6. Technology Behind Wearable ECG and Respiration Monitoring

Sensors

- Wearable devices employ specialized sensors for ECG and respiration monitoring.
- ECG sensors detect electrical signals from the heart, while respiration sensors measure chest or abdominal movements.

Data Processing

- Data collected by wearable sensors are processed and analyzed in real time by microcontrollers or connected smartphones.
- Algorithms can identify irregularities and patterns indicative of specific conditions.

Communication

- Wearable devices may use Bluetooth or other wireless technologies to transmit data to smartphones or cloud-based platforms for remote monitoring.

4.7.2.7. Challenges and Future Directions

Accuracy

Ensuring the accuracy and reliability of ECG and respiration measurements in wearable devices.

Battery Life

Developing energy-efficient solutions to extend the battery life of wearables, as continuous monitoring can be power-intensive.

Data Security

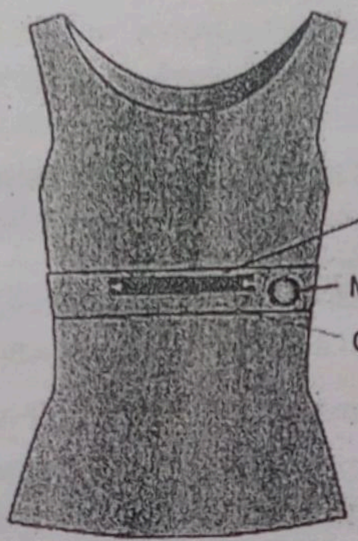
Addressing concerns related to the privacy and security of health data collected and transmitted by wearables.

Integration

Integrating ECG and respiration monitoring seamlessly into everyday wearables for user comfort and convenience.

- ECG and respiration monitoring in wearable devices provide valuable insights into heart health, respiratory function, and overall well-being.
- These technologies enable early detection of irregularities, personalized health management, and improved performance.

- As technology continues to advance and challenges are addressed, wearable ECG and respiration monitors will play a pivotal role in preventive healthcare and health optimization.



TWO MARK QUESTIONS WITH ANSWERS

1. ***Define Smart Textiles.***

Smart Textiles are defined as textile products such as fibers, filaments, and yarn which are woven, knitted or non-woven which can interact with the environment or wearer. The combination of textile with electronics which is all known as etextiles can be applicable to the development of smart material.

"Smart textiles are the fabrics that have been developed with new technologies that provide added value to the wearer"

2. ***What are the types of Smart Textiles?***

   1. Passive smart materials
   2. Active smart material
   3. Very smart materials
   4. Materials with AI

3. ***What is Passive Smart Textile?***

These textiles are not actively respond to stimuli but have unique properties.

Examples include fabrics with UV protection, flame resistance, or water repellency.

4. ***Define Active Smart Textiles.***

Active Smart textiles can sense and respond to external stimuli. Active smart textiles are those that adapt and change their functionality in response to changes in the external environment or in response to a user input. These materials may change shape, store and regulate heat, and be applied to a wide range of flexible applications. Examples include fabrics with embedded.

5. *What are the components of Smart Textiles?*
   - Sensors
   - Actuators
   - Microelectronics
6. *Write the applications of Smart Textiles.*
   - Healthcare
   - Fashion
   - Sports and Fitness
   - Military and Defense
   - Automotive and Transportation
   - Architecture and Design
   - Entertainment and Gaming
7. *What are the Challenges in Smart textile?*

Integration

Achieving seamless integration of technology into textiles without compromising comfort and aesthetics.

Durability

Ensuring that smart textiles can withstand washing and everyday wear and tear.

Power Supply

Developing efficient and long-lasting power sources for electronic components.

Sustainability

Addressing environmental concerns related to the production and disposal of smart textiles.

8. *List the Characteristics of Passive Smart Textile.*

Passive smart textiles do not contain electronic components like sensors or actuators but excel in other areas.

These textiles exhibit properties such as UV resistance, flame resistance, and water repellency.

9. *Mention the types of Passive Smart Textile.*
   - UV-Protective Textiles
   - Flame-Resistant Textiles
   - Water-Repellent Textiles
10. *What is Conductive fibers ?*

Conductive fibers are textile materials that possess electrical conductivity, allowing them to conduct electrical signals and power.

11. ***What are the types of conductive fibers ?***

(i) Metallic Conductive Fibers (ii) Carbon-Based Conductive Fibers

(iii) Polymeric Conductive Fibers

12. ***What is the purpose of Conductive ink?***

Conductive inks are specialized inks that contain conductive materials like silver, copper, or graphene.

They are essential components in the fabrication of flexible and wearable electronic circuits and sensors.

Conductive inks offer a versatile and cost-effective means to create conductive traces, patterns, and components on flexible substrates, such as textiles, for wearable applications.

13. ***List the types of Conductive Ink.***

- Metal-based Inks
- Carbon-based Inks

14. ***What are the fabrication techniques for conductive inks?***

- Screen Print
- Inkjet Printing
- Spray Coating
- 3D Printing

15. ***What are the advantages of Textile based ECG sensor?***

Textile-based sensors could contribute possibilities for providing more affordable, accessible, and easy-to-wear measuring devices, thus giving a greater potential to users to take active control of their health as part of a preventive lifestyle which brings a reduction in healthcare cost by the early detection of health problems.

REVIEW QUESTIONS

1. Explain Passive smart textile in detail
2. Explain Active smart textile in detail
3. Describe about the applications of Smart Textiles.
4. Describe about the four different types of Smart conductive textiles in detail.
5. Explain in detail about the properties of Conductive textiles.
6. Explain in detail about smart fabric for monitoring biological parameters with neat diagrams.
7. Explain in detail about ECG Respiration system in Smart textile with neat sketches.
8. Explain in detail about conductive fibres.
9. Explain in detail about the conductive inks.
10. Describe the applications of Smart textile in healthcare.

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