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Review

A review on nanotechnological aspects in medicinal textile

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Abstract: Nanoscience and Technology has become popular and touched almost every branch of science and technology. Textile engineering is also not exception. Various nanoparticles are being used in smart textiles and technical textile products. Medical textile is an important area and have much opportunities for innovation and discoveries. Therefore, nanomaterials are used in medical textiles to have exotic properties. Herein we have discussed several methods for the characterization of materials at nanoscale. The common spectroscopic techniques like UV-Visible spectroscopy and microscopic techniques like scanning electron microscopy and transmission electron microscope routinely used in material characterization are discussed in detail. In the last section of the article we discussed various applications of nanomaterials in modern medical textile. The nanomaterials are used in surgical gowns, sanitary napkins, UV protection appliances, antimicrobial coating, sutures etc. Some advanced nanomaterials can be used in disease diagnosis, flame retardants, efficient drug delivery systems etc.

Keywords: Nano-textile; flame retardant; drug delivery; polymeric nanoparticles; sanitary napkins

1. Nanoscience at a glance

Since dawn to dusk we require various types of materials for our routine life. Actually everything in the world can be broadly classified into two main groups i.e. energy and matter. The energy part can be experienced whereas the matter part can be directly touched and visualized except some gases. According to famous Equation developed by Einstein energy and matter are interconvertible into each other. The material science deals with the various types of materials used in daily life. If we observe around us we quickly realize that the materials are changing continuously according to particular time and period. The change in material is visualized in all discipline from accommodation, clothing, war weapons, communication systems, transportation and also in the food stuff [1–9]. Thus, the presence of a particular

material is the reflection of the time. Nature has created various types of materials which human is using directly or indirectly. Some of the materials produced in the nature are directly used whereas some materials are developed by efforts of human either by processing or by combing different materials found in the nature. Sometimes the materials are just engineered for different purposes i.e., structural modification is done for example surgical blade is having different structure than the scalpel etc. But it is clear that the use of a particular type of material is the reflection of that particular period for instance the earlier man used stones as weapons and consequently the period is known as stone age, then gold age, copper age, iron age, plastic age and now stepped into Nano age.

Today nanomaterials are used in various disciples of science and technology for different purposes. Here it is important to note that though today the word 'Nano' become very popular among the researchers and academicians, the nanomaterials were in existence much earlier. In fact, nature itself generates several materials at nanoscale. The number of naturally occurring nanomaterials exceeds far than the synthesized nanomaterials. The materials at nanoscale can be synthesized by various techniques [10–21]. If we go back, we find that the first relationship between human life and properties of materials at nanoscale was established in Ayurveda which is an ancient system of medicine developed in Indian subcontinent about 5000 years ago and supposed to be originated from Atharvaveda. In Ayurveda several Bhasma are used which are nothing but metals in Nano-form with therapeutic importance. Then, in different civilization and periods materials at nanoscale were used for instance Lycurgus cup and of the cathedrals contains materials at nanoscale much earlier than the modern nanotechnology. American physicist Nobel laureate Richard Feynman is considered to be father of modern nanotechnology. In his speech under the title, 'There is plenty of room at the bottom' delivered on 29th December 1959, he explained the phenomenon of nanotechnology to the researchers of modern period. Later on Japanese scientist Taniguchi coined the term Nano which means dwarf or small. Actually dwarf is a vague term and then the researched come to the conclusion for the single definition of nanoscience and technology. According to the definition, 'Any material whose any dimensions lies in the range of 1 nm to 100nm and its at least one property is different from that of bulk is said to be nanomaterial' [22–25]. Thus, we realize that the properties of materials at nanoscale differs from that of bulk. There are several reasons for the deviation of the properties of materials at nanoscale. As nanomaterials are extremely small in size, its mass is too small and hence gravitational force becomes ineffective, the electrostatic force of attraction or repulsion becomes significant on nanoscale, van der Waal's force of attraction become important at nanoscale, due to availability of higher number of atoms on the surface, surface energy increases and surface remains in the stretched state. Due to several factors the properties of materials at nanoscale become different than that of bulk. In fact, the properties of bulk materials are the average properties of as observed at nanoscale.

2. Synthesis of nanomaterials

We have discussed the nanoscale phenomenon and science at nanoscale. Due to the change in properties at nanoscale, nanomaterials possess different physical,

chemical and biological properties than their bulk counterparts. Therefore, the nanomaterials with exotic properties can be used for various purposes where the bulk counterparts cannot be used. Hence, it becomes essential to synthesize and engineer the materials at nanoscale. As we have discussed the dimensions at nanoscale, it is simple to understand that bulk materials can be broken into fine particles in the Nano regime. This phenomenon is very much similar to the domestic grinding where the larger materials are broken into fine particles. This phenomenon is scientifically known as top down process. But this process requires very costly instruments like Ball milling etc. Also, the nanomaterials synthesized through this process are non-uniform in size and suffers from several defects [26–31]. The size and shape of the materials to be synthesized at nanoscale cannot be monitored. Therefore, there was a real need to develop some alternative process which can overcome these hurdles. The attempts were made then the researchers and soon new method was developed, where the particles smaller than are grown and their growth is restricted once they reach Nano regime. This is known as bottom up process. Today bottom up process for the synthesis of nanomaterials become very popular among the researchers. In the earlier days the bottom up synthesis required various chemicals for synthesis of materials at nanoscale. Such chemicals may be hazardous and even many times costly. Therefore, to overcome this researcher turned towards biological route of synthesis of nanomaterials. At the dawn of biological route of synthesis of nanomaterials, micro-organisms were used. The micro-organisms could successfully synthesize various nanomaterials. But the maintenance of micro-organism [32–41]. Thus, the researchers turned towards the synthesis of nanomaterials using plant parts and plant their extracts. Rai Dhirendra Prasad is scientist and veterinary doctor from Bihar Veterinary College, Patna, India. He is a visionary scientist and gave sight for the use of Indian cow urine for synthesis of materials at nanoscale. So far Prasad et.al. could successfully synthesis silver, gold, cadmium, copper oxide, cobalt oxide and palladium nanomaterials using Indian cow urine. The synthesized nanomaterials could show biological and catalytically activity. To the best of our knowledge, information and belief this is most economical and environmental friendly route to synthesize transition metal and transition metal oxide nanomaterials.

Once the material is synthesized it becomes very essential to determine its properties which is popularly known as characterization of nanomaterials. The characterization of nanomaterials involves examinations of their physical, chemical, structural and morphological properties at nanoscales typically ranging from 1nm to 100nm. This is crucial for understanding of their behavior, performance and potential applications.

3. Characterization of nanomaterials

Today with the advancement of science and technology there are numerous techniques available which can be used to reveal the physical, chemical, structural and morphological properties of the materials at nanoscale. The modern characterization techniques involved can be broadly categorized into two groups such as (1) Spectroscopic techniques and (2) Microscopic techniques [42–51]. In this section we will take an overview of the classification of modern characterization techniques. The

modern characterization techniques can be divided into different groups based upon (1) Instrumental Methods of Analysis, (2) Information what we gain from the characterization techniques, (3) Entity Characterized and Possible Characterization Techniques. These techniques are shown in tabular form in the **Tables 1–3**. It is not possible to discuss, all the characterization techniques involved in nanomaterials characterizations. Hence, we would try to focus on some important characterization techniques routinely involved in material characterizations [52–61]. We will try to discuss in detail UV-Visible, XRD, Microscopic Techniques like SEM, TEM etc.

Table 1. Instrumental methods of analysis based upon physical property [62–95].

Sr. No.	Physical properties	Instrumental methods based upon physical property
1	Absorption of Radiation (Determination of absorption of radiations involve several steps and techniques depending upon types of radiations being studied)	Spectrophotometry X-Ray, UV, Visible, IR, colorimetric Photometry Radiography Neutron Activated Analysis Atomic Absorption Calorimetry Thermo-luminescence dosimetry Nuclear Magnetic Resonance Electron Spin Resonance Spectroscopy (ESR)
2	Emission of Radiation (Emission of radiation is the phenomenon in which energy is released from a source in the form of electromagnetic waves)	Emission Spectroscopy X-Ray, UV, Visible Inductively Coupled Plasma Optical Emission Spectroscopy Flame photometry
3	Rotation of Radiation (Also known as optical rotation. Optical rotation occurs when linearly polarized light passes through certain materials)	Polarimetry Ellipsometry Faraday Rotation Circular Dichroism Spectroscopy Optical Rotatory Dispersion Optical Rotatory Dispersion Optical Rotatory Sensors Dispersion
4	Diffraction of Radiation (Electromagnetic waves spread out as they encounter an obstacle)	X-Ray Electron Diffraction Method Light Diffraction Neutron Diffraction Acoustic Diffraction
5	Reflection of Radiation (It is the process in which electromagnetic radiations bounce after they strike the surface)	Refractometer Interferometry X-ray Reflection Technique Acoustic Reflection Technique Optical Reflection Measurement Neutron Reflection Techniques Electron Reflection Techniques
6	Scattering of Radiation (Electromagnetic waves or particles are redirected or deflected from the original path when they interact with the matter)	Turbidimetry Nephelometry Raman Spectroscopy Dynamic Light Scattering Static Light Scattering Particle Scattering Technique Raman and Inelastic Scattering Techniques X-Ray and Neutron Scattering Techniques

Table 1. (*Continued*).

Sr. No.	Physical properties	Instrumental methods based upon physical property
7	Electrical Potential (It is the amount of electrical potential energy per unit charge)	Potentiometry Chronopotentiometry Kelvin Probe Voltmeter Electrostatic Voltmeter Electrochemical Techniques Numerical Modeling Electrostatic Field Mapping
8	Electrical conductance (It is measurement of material's ability to conduct electricity)	Conductivity Impedance Spectroscopy Four Probe Method Two Probe Method Electrochemical Methods Kelvin Probe
9	Electrical Current (Flow of electric current through a conductor)	Polarography Ammeter Shunt Resistance Half Effect Clamp Meter Current Transformers Half Effect Sensors Amperometric Titration
10	Thermal Properties (It is the characteristic of the material that describe response to the heat)	Thermal Conductivity Dilatometry Calorimetry Thermal Gravimetric Analysis Differential Scanning Calorimetry Thermomechanical Analysis Enthalpy Methods
11	Mass to charge ratio (It is the ratio of ion's mass to the charge)	Mass Spectroscopy Ionization Acceleration Deflection Detection Data Analysis

Herein we are trying to enlist the characterization and information, which was get after analysis in tabular form. After these the commonly used characterization techniques are discussed in detail as presented in **Table 2**, which provides the information regarding various characterization techniques and the main information obtained from them [96].

Table 2. Modern characterization techniques for analysis of nanomaterials and textiles [97–99].

Sr.No.	Abbreviation	Characterization techniques	Main information (utility)
1	XRD	X-Ray Diffraction	Crystal structure, Phase identification, Stress and Deformation, Quantitative Analysis, Orientation and Texture, Crystallite size and Strain, etc.
2	XAS	X-Ray Absorption Spectroscopy	X-ray absorption co-efficient, Elemental identification, Quantitative Analysis, Local Structural Distortions, Chemical State of Species, Co-ordination Geometry, Interatomic Distances, Chemical Speciation, Electronic Structure, Debye-Waller factors, and non-crystalline NPs
3	SAXS	Small Angle X-Ray Scattering	Particle Size, Size distribution, Shape and Morphology, Porosity and Surface Area, Inter-particle Interactions, Growth Kinetics

Table 2. (*Continued*).

Sr.No.	Abbreviation	Characterization techniques	Main information (utility)
4	XPS	X-ray photoelectron Spectroscopy	Electronic structure, Elemental composition, Depth profiling, Chemical Bonding, Quantitative Analysis, Oxidation States, Ligand Binding, Surface Sensitivity, etc.
5	FT-IR	Fourier Transform Infrared Spectroscopy	Surface Composition, Ligand Binding, Chemical compositions, Functional Group Analysis, Chemical Bonding, Quantitative Analysis, Structural Analysis etc.
6	NMR	Nuclear Magnetic Resonance Spectroscopy	Ligand Density and Arrangements, Electronic Core Structure, Chemical shift, Relaxation Times, Spin-Spin Coupling Integration, NOE, Atomic Composition, The Influence of Ligands on NP shape, NP size
7	BET	Brunauer Emmett Teller	Surface Area, Monolayer Adsorption, Multilayer Adsorption, Pore Volume, Pore Size Distribution, Specific Surface Area
8	TGA	Thermogravimetric Analysis	Mass and Composition of Stabilizers, Thermal Analysis, Decomposition Kinetics, Moisture Content, Oxidative Stability, Evaporation and Desorption, etc.
9	LEIS	Low Energy Ion Scattering	Thickness and Chemical Composition of Self-Assembled Monolayers of NPs, Elemental Composition, Surface Stability, Isotopic Composition, Surface Structure, Chemical Bonding, Depth Profiling, Surface Sensitivity, etc.
10	UV-Visible spectroscopy	Ultra-violet Visible Spectroscopy	Electronic Transition, Absorption Spectra, Identification of Functional Groups, Optical Properties, Size, Concentration, and Agglomeration State, Hints at Nanoparticles Shape, Quantitative Analysis, Detection Limit, etc.
11	PL Spectroscopy	Photoluminescence spectroscopy	Optical Properties, Relation to Structural Features such as Defects, Size, Emission spectra, Energy Band Structure, Dopant and Defect States, Quantum Yield, Lifetime and Decay Dynamics, Composition, etc.
12	DLS	Dynamic Light Scattering	Hydrodynamic Size, Particle Size Distribution, Temperature and Solvent Effect, Dynamic Effect, Aggregation and Agglomeration Effect, Poly-dispersity Effect, Concentration Effect, Detection of Agglomeration etc.
13	NTA	Nanoparticle Tracking Analysis	Nanoparticles Size Distribution, Temperature and Environment Effect, Dynamic Behaviour, Aggregation and Agglomeration, Concentration, Mobility etc.
14	DCA	Direct Coupling Analysis	Nanoparticles Size and Their Distribution, Protein Structure Prediction, Biological Insights, Protein Engineering, Co-Evolutionary Signals, Functional Insights, Long Range Interactions, Residue-Residue Contact etc.
15	ICP-MS	Inductively Coupled Plasma Mass Spectroscopy	Elemental Composition, Size, Size Distribution, NP Concentration, Elemental Composition, Trace Element Analysis, Isotopic Analysis, Matrix Effect and Interferences, High Throughput, Quantitative Analysis, Multi-element Analysis etc.
16	SIMS, ToF-SIMS, MALDI	Sputtering Ion Mass Spectroscopy	Chemical Information on Functional Groups Especially Surface Sensitivity, Elemental and Molecular Composition, Depth Profiling, Isotopic Analysis, Spatial Resolution, Surface Contamination, Surface Chemistry, Material Characterization, Molecular Orientation, and Conformation, Surface Topography, MALDI for Nanoparticle Size
17	VSM	Vibrating Sample Magnetometer	Magnetic Properties of Nanomaterials, Magnetic Moment, Magnetic Hysteresis, Magnetic Field Dependence, Curie Temperature, Sample Properties etc.

Table 2. (*Continued*).

Sr.No.	Abbreviation	Characterization techniques	Main information (utility)
18	Contact Angle	Contact Angle	Determination of Hydrophobic Characters of Thin Films, Wettability, Surface Energy, Surface Roughness, Surface Modification, Adhesion and Spreading, Surface cleanliness and contamination, Surface Heterogeneity etc.
19	FMR	Ferromagnetic Resonance Spectroscopy	Nanoparticle Size and Distribution, Shape, Crystallographic Imperfections, Surface Composition, M value, Magnetic Anisotropic Constant, Demagnetization Fields. It is widely used to determine magnetic anisotropy, magnetic domain structure, spin dynamics in materials.
20	XMCD	X-Ray Magnetic Circular Dichroism	Site symmetry and magnetic moments of transition metal ions in ferro and ferri magnetic materials element-specific
21	CLSM	Confocal Laser Scanning Microscope	Imaging, Ultrafine Morphology,
22	BAM	Brewster Angle Microscope	Gas-liquid Interface Imaging
23	APM	Atomic Probe Microscopy	Three Dimensional Imaging, Surface Topography, Surface Roughness and Texture, Surface Friction and Adhesion, Nano-mechanical Properties, Chemical composition and Interactions etc.
24	MFM	Magnetic Force Microscopy	Magnetic Material Analysis, Magnetic Field Measurement, Magnetic Domain Imaging, Surface Mapping, Magnetic Interactions etc.
25	LEED	Low Energy Electron Diffraction	Surface/Adsorbate bonding, Crystalline Structure Determination, Surface Morphology, Surface Symmetry, Surface Reconstruction, Surface Defects and Ordering, Dynamic Surface Processing etc.
26	AEM	Auger Electron Microscopy	Chemical Surface Analysis, Elemental Composition, Depth Profiling, Quantitative Analysis, Spatial Resolution, Surface Sensitivity, Chemical State Analysis, etc.
27	CFM	Chemical Force Microscopy	Chemical/Surface Analysis, Used in Material Sciences, Biological Sciences, Nanotechnology, Surface Chemistry and Molecular Interactions
28	FIM	Field Ion Microscopy	Chemical Profile/ Atomic spacing, Surface Topography, Surface Dynamics, Defect Analysis, Chemical Composition, Crystallographic Information, Atomic Resolution Imaging etc.
29	UPS	Ultraviolet Photoemission Spectroscopy	Surface Analysis, Electronic Band Structure, Work Function, Chemical Composition, Surface Sensitivity, Fermi level Position etc.
30	AAS	Atomic Absorption Spectroscopy	Chemical Analysis, Elemental Identification, Quantitative Analysis, Sensitivity, Selectivity, Accuracy and Precision, Sample Matrix Compatibility etc.
31	ICPMS	Inductively Coupled Plasma Mass Microscopy	Elemental Analysis, Sensitivity, Selectivity, Isotopic Analysis, Speed and Throughput, Accuracy and Precision etc.
32	SANS	Small Angle Neutran Scattering	Surface Characterization, Size and Shape of Particle, Polymer Conformations and Dynamics, Inter-particles Interactions, Phase Separation and Domain Structure, Internal Structure Porosity etc.
33	CL	Cathodoluminescence	Characteristic Emission, Elemental Composition, Defects and Impurities, Microstructural Analysis, Dopant Distribution, Opto-electronic Properties.
34	Nano-calorimetry	Nano-calorimetry	Latent Heat of Fusion, Heat Capacity, Chemical Kinetics, Thermal Conductivity, Calorimetric Imaging, Energetics of Nanomaterials, Phase Transitions etc.
35	Sears Method	Sears Method	Colloidal size, Specific Surface Area, Dynamic Structure Factors, Phase Diagram and Phase Transition, Collective Excitation, Dynamic Heterogeneity etc.
36	FS	Fluorescent Spectroscopy	Elemental Analysis, Identification of Molecules, Energy Transfer, Dynamics and Kinetics, Environmental Sensing and Structural Information etc.

Table 2. (*Continued*).

Sr.No.	Abbreviation	Characterization techniques	Main information (utility)
37	LSPR	Localized Surface Plasmon Resonance	Nano-sized Particle Analysis, Enhanced Optical Properties, Sensing of Environmental Parameters, Detection of Molecular Binding Events, Refractive Index Sensing, Surface Chemistry and Functionalization etc.
38	Rutherford Backscattering	Rutherford Backscattering	Quantitative Elemental Analysis, Elemental Composition, Depth Profiling, Surface Roughness, Material Identification, Isotopic Analysis, Thickness Measurement, etc.
39	TEM	Transmission Electron Microscopy	NP size, Monodispersed shape, Aggregation State, Defect and Localize Quantify Nanoparticles in Matrices, Study Growth Kinetics, Microstructure characterization, Electron Diffraction Pattern, Nanoparticle Analysis, Elemental Analysis, Crystallography, etc.
40	HR-TEM	High-Resolution Transmission Electron Microscopy	All Information by Conventional TEM and also on the Crystal Structure of a Single Particle. It is used to Distinguish Between Monocrystalline, Polycrystalline, and Amorphous, Atomic Scale Imaging, Lattice Parameter Determination, Defect Analysis, Crystallography etc.
41	Liquid TEM	Liquid Transmission Electron Microscopy	Depict Nanoparticle Growth in Real-time, Study Growth Mechanism, Single Particle Motion, and Super-lattice formation, Surface Chemistry and Catalysis, Environmental and Biological Imaging, Electrochemical Processes, Bio-molecular Dynamics and Interactions, Real Time Observations of Dynamic Processes
42	Cryo-TEM	Cryo Transmission Electron Microscopy	Study Complex Growth Mechanisms, and Aggregation Pathways, Good for Molecular Biology and Colloidal Chemistry to Avoid the Presence of Artifacts or Destroyed Samples, High Resolution Imaging, Drug Delivery System, Virus Structure Assembly, Membrane Biology, Structural Biology, High resolution Imaging etc.
43	ED	Electron Diffraction	Crystal Structure, Lattice Parameter, Study Order, and Disorder Transformation, Long-Range Order Parameters, Crystallographic information, Phase Identification, Texture Analysis, Grain Size and Microstructure, Strain Analysis and Thin Film Analysis etc.
44	STEM	Scanning Transmission Electron Microscopy	Combined with HAADF, and EDX for Morphology Study, Crystal Structure, and Elemental Composition, Study the Atomic Structure of Hetero-interface, Atomic Structure, Chemical Composition, Strain Mapping, Electronic Structure, Magnetic Properties, Nano-structure Characterization etc.
45	Aberration-corrected STEM, TEM	Aberration corrected Scanning Transmission Electron Microscopy	Atomic structure of NP clusters, especially bimetallic ones, as a function of composition, alloy, homogeneity, phase segregation
46	EELS	Electron Energy Loss Spectroscopy	Type and Quantity of Atoms Present, Chemical States of Atoms, Collective Interaction of Atoms with Neighbors, Bulk Plasma Resonance, Energy Loss Measurement, Core and Valence Electrons Interactions, Chemical Composition, Chemical Bonding and Coordination, Optical and Electrical Properties etc.
46	Electron tomography	Electron tomography	Realistic 3D article visualization, snapshots, video, and quantitative information down to atomic scale, Structural Dynamics and Conformational Changes, Co-relative imaging, Subcellular and Structural Organelles.
47	SEM-HRSEM, T-SE-EDX	Scanning Electron Microscopy- High-Resolution Scanning Electron Microscope	Morphology, Dispersion of Nanoparticles in cells and other Matrices/ Supports, Surface Morphology, surface Analysis and Metrology, Pore Structure and Porosity, Surface Modification and Nanostructure, Chemical Mapping, Elemental Composition, Microstructure Analysis, Precision in the Lateral Dimension of Nanoparticles, Quick Examination-Elemental Composition

Table 2. (*Continued*).

Sr.No.	Abbreviation	Characterization techniques	Main information (utility)
48	EBSD	Electron Backscattered Diffraction Microscopy	Structure, Crystal Orientation, and Phase of Matrices in SEM. Examine Microstructure, Phase Identification, Deformation and Recrystallization, Microstructural Characterization, Texture Analysis, Grain Boundary Characterization, Reveal Texture, Defects, Grain Morphology, Deformation etc.
49	AFM	Atomic Force Microscope	Nanoparticle Size and Shape in 3D mode, Evaluate the Degree of Covering of a Surface with Nanoparticle Morphology, Dispersion of Nanoparticles in Cell and other Matrices/ Supports, Surface Topography, Surface Roughness and Texture, Electrical and Magnetic Properties, Nano-manipulation and Nanolithography, Molecular Recognition and Interactions, Friction and Adhesion, Mechanical Properties, Precision in the Lateral Dimension of Nanoparticles, Quick Examination- Elemental Composition
50	MFM	Magnetic Force Microscopy	Standard AFM Imaging Together with the Information of Magnetic Moments of Single NPs. Magnetic contrast, Material Characterization, Surface Topography, Sample Magnetization, Magnetic Properties Characterization, Magnetic Field Mapping, Study Magnetic NPs in the Interior of cells. Discriminate from Non-magnetic NPs
51	GATS	Gravimetric Absorbency Testing System	Fiber orientation angle and distribution of fiber orientation (for non-woven fabric) Pore size and porosity Absorbency, Thickness, Basis weight, Stiffness, Tensile strength, Bursting strength Elements of Tear strength, Air permeability Comparative analysis, Wrinkle Properties, Retention Capacity, Rate of Absorption, Absorption Capacity, Surface tension effect,

Table 3. Analytical techniques for medical textiles at nanoscale [100–138].

Entity to be characterized	Possible characterization techniques
Size (structural properties)	TEM, XRD, DLS, NTA, SAXS, HRTEM, SEM, AFM, EXAFM, FMR, DCS, ICP-MS, UV-Vis, MALDI, NMR, TRPS, EPLS, Magnetic susceptibility
Shape	TEM, HRTEM, AFM, EPLS, FMR, 3D-tomography
Elemental chemical composition	XRD, XPS, ICP-MS, ICP-OES, SEM-EDX, NMR, MFM, LEIS
Crystal structure	XRD, EXAFS, HRTEM, STEM, electron diffraction
Size distribution	DCS, DLS, SAXS, NTA, ICP-MS, FMR, DTA, TRPS, SEM, Superparamagnetic Reflexometry
Magnetic properties	SQUID, VSM, MFM, FMR, XMCD, Magnetic Susceptibility
Optical properties	UV-Visible spectroscopy, Photoluminescence spectroscopy, EELS-STEM
Detection of Nanoparticles	TEM, SEM, STEM, EBSD, Magnetic Susceptibility
Structural defects	HRTEM, EBSD
Dispersion of nanoparticles in matrices	SEM, AFM, TEM
3D visualization	3D topography, AFM, SEM
Single-particle properties	SP-ICP-MS, UV-Vis, RMM-MEMS, PTA, DCS, TRPS
Density	DCS, RMM-MEMS
Agglomeration state	Zeta potential, DLS, DCS, UV-Visible spectroscopy, SEM, Cryo-TEM, TEM
Concentration	ICP-MS, UV-Visible, RMM-MEMS, PTA, DCS, TRPS
Surface charges	Zeta potential, EPM
Surface area, specific surface area	BET, liquid NMR

Table 3. (*Continued*).

Entity to be characterized	Possible characterization techniques
Ligand binding/ composition/ density/ arrangement/ mass, surface composition	XPS, FTIR, NMR, SIMS, FMR, TGA, SANS
Growth kinetics	SAXS, NMR, TEM, cryo-TEM, liquid-TEM
Chemical state -oxidation state	XAS, EELS, XPS, Mossbauer

3.1. UV-visible spectroscopy

UV-visible spectroscopy as shown in **Figure 1** is used for the measurement of the intensity of absorption in near ultraviolet and visible radiation by a sample. Ultraviolet and visible radiation ranges in wavelength from 200 nm to 800 nm and are energetic enough to promote outer electrons in an atom to higher energy levels. UV-visible spectroscopy is useful for qualitative and quantitative analysis of sample. Moreover, UV-visible spectroscopy can also be used to determine the band gap of semiconductors. This band gap can be calculated by the Equation:

$$\Delta Eg = \frac{1240}{\lambda_{max}} \quad (1)$$

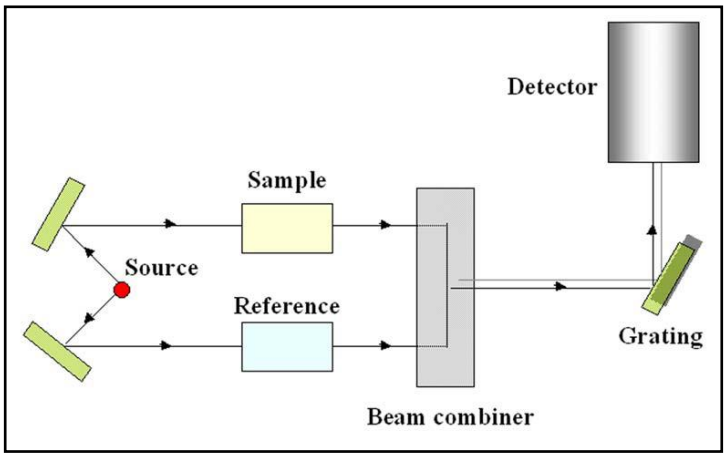

Figure 1. A pictorial representation of the principle of UV-Vis Spectrophotometer [139].

As UV radiations are associated with high energy, it produces a change in the electronic energy of the molecule. The relationship between the energy absorbed in an electron transition and frequency (υ), wavelength (λ) and wave number ($\bar{\upsilon}$) of radiation producing the transition can be explained as,

$$\Delta E = h\upsilon = \frac{hc}{\lambda} = hc\bar{\upsilon} \quad (2)$$

where h is plank's constant, c is velocity of light and ΔE is energy absorbed in electronic transition in a molecule from low of energy state (ground state) to a high energy state (excited state).

The amount of energy absorbed depends upon energy difference between the ground state and excited state; smaller the difference, the longer the wavelength of absorption. The principal characteristic of an absorption band are its position and intensity. The position of an absorption band corresponds to the wavelength of radiation whose energy is equal to the required for an electronic transition. The

intensity of absorption highly depends on two factors viz. the probability of interaction between the radiation energy and the electronic system as well as the difference between ground state and excited state [112–121]. The intensity of absorption can be derived from Beer-Lambert's law given as,

Beer Lambert's law: "When a bean of monochromatic light is passed through homogeneous absorbing medium then the rate of decrease of intensity of radiation with the thickness of absorbing medium is directly proportional to the intensity of radiation as well as concentration of solution."

$$-\frac{dI}{dx}\alpha Ic$$

$$-\frac{dI}{dx} = kIc$$

$$-\frac{dI}{I} = kdxc$$

Integrating above Equation we get:

$$-\int_{Io}^{I}\frac{dI}{I} = kc\int_{0}^{x}dx$$

$$-log_e\left[\frac{I}{Io}\right] = kcx$$

$$log_e\left[\frac{I}{Io}\right] = -kcx$$

$$I = Ioe^{-kcx} \quad (3)$$

Above Equation is known as Beer—Lambert's Equation.

The metallic nanomaterials are known to exhibit characteristic colour. The absorption of electromagnetic radiation by metallic nanoparticles originates from coherent oscillation of valence band electrons induced by an interaction with electromagnetic field. These resonances are known as surface plasmon that occurs only with nanomaterials. The noble metal colloidal solutions are showing the phenomenon of Surface Plasmon Resonance; thus UV-visible spectroscopy is a powerful tool for its characterization.

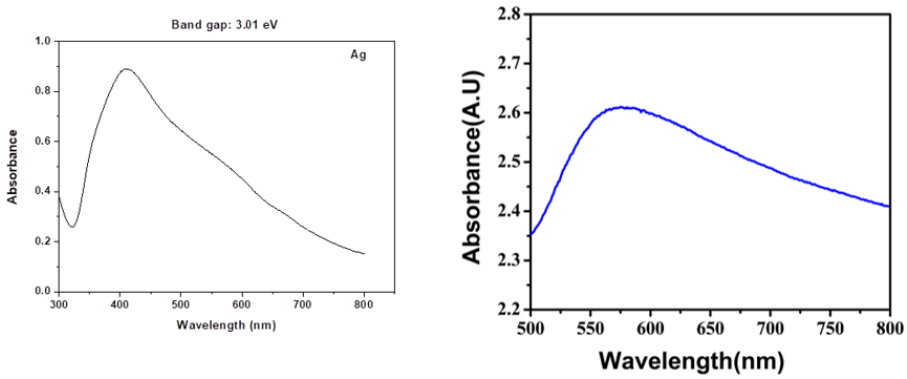

Figure 2. UV-Visible Absorption Spectra of Silver (Left) and Gold (Right) Nanoparticle.

UV-Visible spectroscopy is an important technique for chemical analysis of noble metallic nanomaterials. In this research work, this technique has been used to get an idea about the formation of nanomaterials. Also this technique can be used to

reveal rate of formation of nanoparticles [134]. The UV-Visible spectra of Ag and Au Nanomaterials are shown as below in **Figure 2**. The absorption spectrum is the characteristic of nanomaterials. The absorption spectrum depends upon size of nanomaterials also.

3.2. X-Ray diffraction (XRD)

In material research researchers and scientists have to determine the chemical composition and crystalline constitution of materials. The chemical composition of some materials can be determined through chemical analysis too. But during chemical analysis the compound cannot be recovered. Also chemical composition of every compound could not be successfully determined. Therefore, there was a real need to develop some alternative technique of analysis. Thus, researchers turned towards the physical technique for the analysis. To date x-ray diffraction is one of the most important available non-destructive and accurate laboratory technique which can provide information about the chemical composition, crystal structure, crystal orientation, crystallite size, lattice strain, phase composition, preferred orientation of powder, solid and liquid samples and layer thickness [122–131]. Several materials are made up of tiny crystallites. The chemical composition and structure of these tiny crystallites are called phase. The materials can be single phase or multiple phase mixture. The materials can contain crystallite and non-crystalline compositions at the same time. When the sample is exposed to x-ray diffraction pattern, different crystallite structures give different x-ray pattern. Phase identification can be performed by comparing the diffraction pattern. Therefore, with the help of comprehensive data base is maintained by ICDD the phase of the compound can be determined successfully. The X-rays were discovered in 1895 by German physicist Wilhelm Conrad Rontgen72. They were so called X-rays because their nature was unknown at that time. Actually, X-rays are invisible, highly penetrating electromagnetic radiations of much shorter wavelengths than visible light. X-rays are electromagnetic radiations with a wavelength of the order of 10–10 m. Van Lave demonstrated in 1912 that X-rays could be diffracted by crystal. Later, in year 1935 Le Galley first constructed an X-ray powder diffractometer73. After this invention, metallurgists and mineralogists use X-ray powder diffractometers primarily to study structural imperfections. X-rays scatter or fluorescence as a result of interaction with electrons in the materials to which they are irradiated. This phenomenon can provide information about the detail structure of an object and also provides information about its constituents. X-ray diffraction study has been widely in metallurgy and material sciences.

X-ray powder diffraction is the rapid analytical technique primarily used for identification of the proper phase and crystalline material. The analyzed material is finely ground, homogenized and average bulk composition is determined. They are typically generated by bombarding a metal with high-energy electrons. The high-energy electrons must penetrate through the outer electron shells and interacts with the inner shell. If more than a critical amount of energy is transferred to an inner-shell electron, that electron is ejected i.e., it escapes the attractive field of the nucleus, leaving the hole in the inner shell and generating an ionized atom. The ionized atom can return almost to its lowest energy (ground state) by filling in the missing electron with one from the outer shells. It is this transmission that is accompanied by the

emission of an X-ray or Auger electron. It is the transition which is accompanied by the emission of an X-Ray or Auger electron. The wavelength λ of characteristic line giving rise to a particular transition is given by Mosely's law:

$1 / \lambda = c (Z - \sigma)2$

The emission of X-Raya with different target materials is depicted as below in **Table 4**.

Table 4. X-Ray emission with different target materials.

Sr. No.	Target Metal	Λ of Kα Radiation
1	Mo	0.71A˚
2	Cu	1.54A˚
3	Co	1.79A˚
4	Fe	1.94A˚
5	Cr	2.29A˚

The principle of working of XRD 'the elastic scattering of the X-rays from structure that have long range order'. The x-rays get diffracted by a crystal because the wavelength of x-rays is similar to the inter atomic spacing in the crystal. X-ray diffraction is based on constructive interference of monochromatic X-rays and a crystalline sample. British physicist Sir W.H. Braggs and W.L. Braggs developed a theory in 1913 to explain why cleavage faces of crystals appear to reflect X-ray only at a certain angle of the incident (θ). This Equation is called Bragg's law and is given as:

$$2d \sin \theta = n\lambda \quad (4)$$

where, d is the distance between the two atomic layers in crystal and λ is the wavelength of the incident X-ray beam, and n is an integer that indicates the order of reflection. This law relates wavelength of electromagnetic radiation to the diffraction angle and the lattice spacing in a crystalline sample. These diffracted X-rays are then detected, processed and counted. By scanning the sample through the range of 2 θ angle, all possible diffraction directions of the lattice should be attained due to random orientation of the powdered material.

The applications of XRD can be enlisted as below:

- Identification of fine grained minerals such as clays and mixed layer clays that cannot be easily determined through optical instruments.
- Characterization of crystalline materials.
- Determination of purity of the sample.
- Determination of modal amounts of minerals.
- The thin films can be characterized.
- Determination of the thickness, roughness and density of the thin film using. glancing incidence X-ray reflectivity measurement.
- Measurement of super-lattice in multilayer epitaxial; structure.
- Determination of dislocation density and quality of the film by rocking curve measurement.
- Determining lattice mismatch between film and substrate and to inferring stress and strain.

- Strength of the technique:
- XRD units are widely available and easy to operate. It does not require very elaborate training.
- This is non-destructive method of analysis. This means the sample can be further used for other purposes.
- Minimal sample preparation is required.
- Powerful and rapid technique for identification of unknown material.
- Data interpretation is simple and straightforward.
- In most cases it provides an unambiguous mineral determination
- This a relatively rapid technique for structure and composition determination
- Limitations.
- This technique requires tenths of a gram of sample which must be ground into fine powder.
- There must be access to standard reference files of inorganic compounds. In absence of standard reference file, comparison of the XRD pattern would not be possible.
- Homogeneous and single phase material is best for identification of an unknown.
- In case of mixture of the materials, the materials having at least 2% amount can only be determined.
- The unit cell determinations, indexing of patterns for non-isometric crystal systems is complicated.

The XRD pattern can confirm the structure and crystallinity of nanomaterials. Also the size of the synthesized nanomaterials can be calculated by XRD pattern. Herein we furnish the XRD pattern of Ag, ZnO and composite nanomaterial in **Figure 3** as shown below.

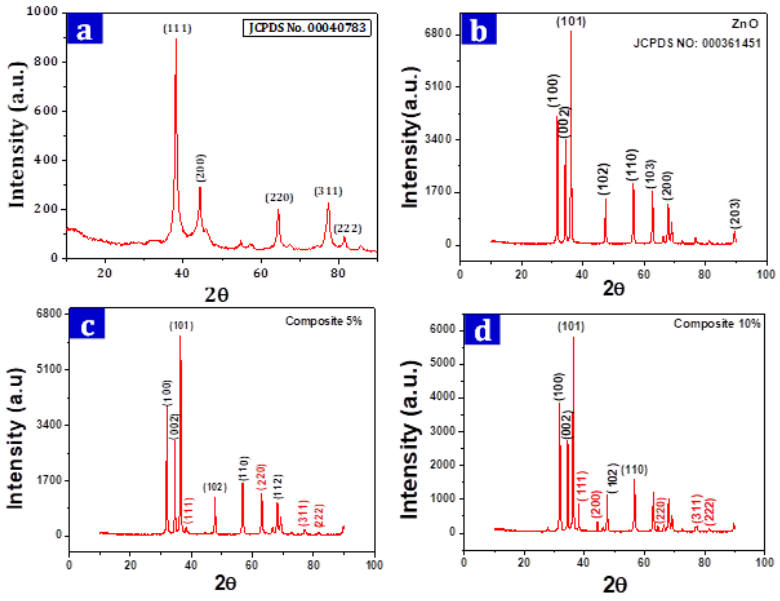

Figure 3. XRD pattern of ZnO, Ag and ZnO + Ag composite nanoparticle (ES Engineered Science).

3.3. Scanning electron microscopy

SEM as shown in **Figure 4** is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons [132–138]. The electrons interact with the atoms in the sample, producing various signals that can be detected and that contain information about the sample's surface topography and composition. The electron beam scans in a raster scan pattern, and the beam's position is combined with the detected signal to produce an image.

Scanning electron microscopy is extremely useful for direct observations of surface because they offer better resolution and depth of field than optical microscopes. The SEM shows very detailed 3-D images at much higher magnification than is possible with a light microscope. The image created without light waves are rendered black and white. In a very brief way SEM works under vacuum in a column where an electron gun emits a beam of high energy electrons. The two major components of SEM are the electron column and control console. The electron column consists of an electron gun and two or more electron lenses, which influences the path of electrons travelling down an evacuated tube.

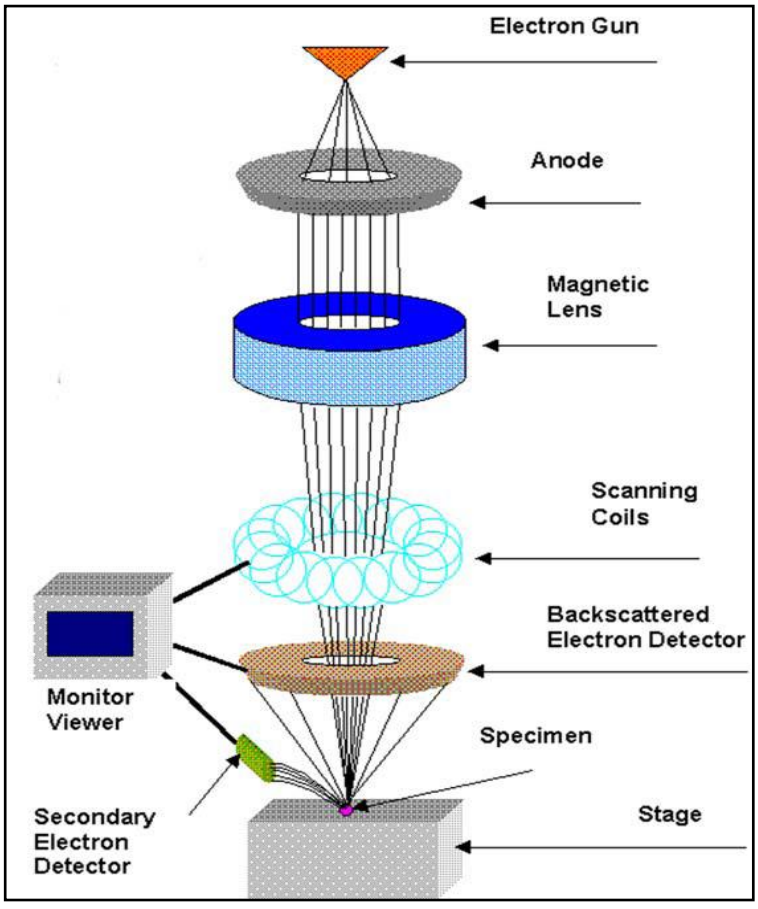

Figure 4. Schematic showing the working of a scanning electron microscope [139].

Instrumentation: A SEM consists of an electron gun that produces the electrons, an anode at high voltage that accelerates the electrons, a system of electromagnetic lenses that focuses the beam of electrons onto the samples, scanning coils that facilitate the scanning of electron beam over the sample surface, the sample chamber where the

sample is located, and detectors that measures the signals generated due to the interaction of the electrons with sample and this is shown in **Figure 5**. All these components are housed within the vacuum chamber.

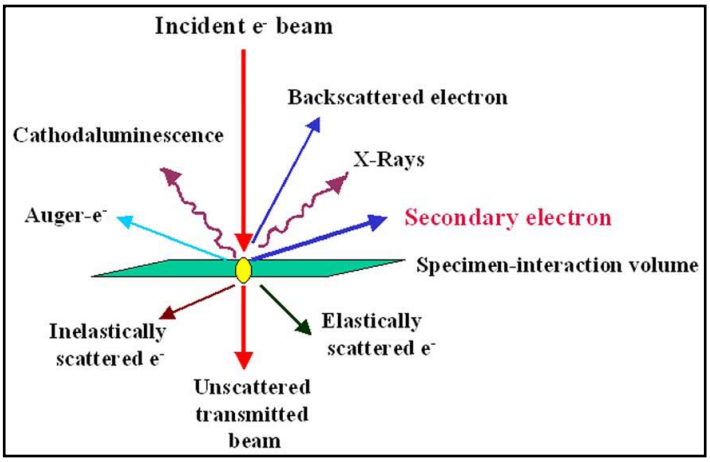

Figure 5. A cartoon showing the possible effects after sample-electron beam interaction [139].

These are two types of electron source or electron gun; the first thermionic and the second field emission guns. A thermionic electron relies on electrons emitted from heated wire or a filament. The filament is usually a bent tungsten wire that functions as a cathode. The bent portion is heated up when an electric current passes through the filament. The outer orbital electrons of the tungsten atoms are emitted when they gain sufficient thermal energy to overcome the energy barrier that prohibits the electrons from escaping. The higher the temperature more is the number of electrons emitted. Tungsten is usually chosen as filament because it can withstand high temperature without melting. However, thermionic electron guns have relatively low brightness. Whereas the field emission electron gun relies on electrons emitted from a sharp tip upon the application of a high electric field. It does not involve heating of a filament. Instead, when a high electric field is applied to the tip, quantum mechanical tunneling takes place. Typically, the field emission gun has two anodes. The first anode (at 0–5 kV) serves to extract the electrons from the tip while second anode (at 1–50 kV) serves to accelerate the electrons and this determines the energy of electrons travelling down the column of SEM. The field emission gun has higher brightness.

As electrons are streaming out of electron guns, they form a spray pattern. In order to control the profile of this electron beam into a finely adjusted focused beam, electromagnetic lenses are used. When an electron with charge q and velocity v travels in a region with a magnetic field B it experiences a force given by,

$$F = q.VxB \tag{5}$$

Here it should be noted that since the direction of force acting is perpendicular to the direction of the velocity, therefore the Lorentz force acting on the electrons has no effect on the speed of electrons. The only effect the magnetic field has is on the electron which changes the direction of motion of electrons.

The magnetic profile generated by a typical electromagnet used in SEM is highly non-uniform. The magnetic field of electromagnetic lens can be considered to be made up of two independent components viz. the vertical axis component (Hz) and

horizontal radial component (Hr). The radial component causes the electron travelling in 2-direction to move in a helical manner with respect to the central axis. The axial component causes the electron to move closer to the central axis, i.e., the effect of axial component is to reduce the diameter of the helical path of the electrons. As a result, the electron beam spirals down the column as it passes through the electromagnetic lens. The resultant effect is that the electron beam becomes finely focused and can be scanned over the sample for imaging purposes.

The scanning of the electron beam over surface of sample is achieved by deflecting the beam using an applied electrostatic or magnetic field. Typically, a deflection yoke consists of four radially oriented coils arranged so that the magnetic field is perpendicular to the axis of the system. The magnetic field generated by these coils can be controlled by the amount of electric current passing through these coils. By programming these coils, one can readily focus the electron beam over the sample surface.

The typical accelerating voltage used in SEM is of the order of a few thousand volts. With an energetic beam of electrons scanning over the sample surface, a number of phenomenon occur due to interactions between the electrons and sample atoms. For example; the incident electron can collide with the electron of the atoms or atomic nuclei. Energetic incident electrons can collide with the electrons of sample and knock them out of their usual orbits. These electrons are known as secondary electrons. During the process, the incident electron loses little energy and continues to generate more secondary electrons as it travels further into the sample. A single incident electron will generate a shower of thousands of secondary electrons until the secondary electron loses its energy. Since large number of secondary electrons is generated, the detection of secondary electron is the most common mode of operation for SEM sample imaging. Secondary electrons are having low energy so that secondary electrons generated deep in the sample are unable to travel to the surface and leave the sample. As a result, the secondary electrons detected are primarily from region close to the sample surface (<10 nm). Thus, SEM imaging would produce good topographical information for the sample. Sample preparation for Scanning Electron Microscopy (SEM) involves several critical steps to ensure high-quality imaging. For biological samples, the process typically starts with fixation using chemical fixatives to preserve the structure, followed by dehydration using a series of increasing concentrations of ethanol or acetone. The sample is then dried, often through critical point drying to prevent structural collapse. The dried sample is mounted on an SEM stub using conductive adhesives and, if non-conductive, coated with a thin layer of conductive material like gold or platinum. Final checks under a light microscope ensure proper preparation before loading the sample into the SEM chamber. Proper preparation is essential to obtain clear, detailed images without artifacts.

Sometimes, an incident electron collides with the nucleus of a sample atom, causing the electron to bounce back. Such electrons are referred to as backscattered electrons. Since the atomic nucleus is more massive than electron, the back scattered electrons has high velocity and are characterized by their high energy of a few KeV. High density samples will generally create more back scattered electrons, and hence back scattered electrons can be utilized to identify difference in the densities of the sample. The production of back scattered electrons is directly proportional to the

atomic number of the atoms in the sample. Therefore, the regions with atoms of higher atomic number would appear brighter than regions with atoms of lower atomic number. Thus besides providing the information of topography back scattered electrons provides valuable information on the density and elemental distribution in the sample [137,138]. SEM image of synthesized nanomaterials are shown as below in **Figure 6**.

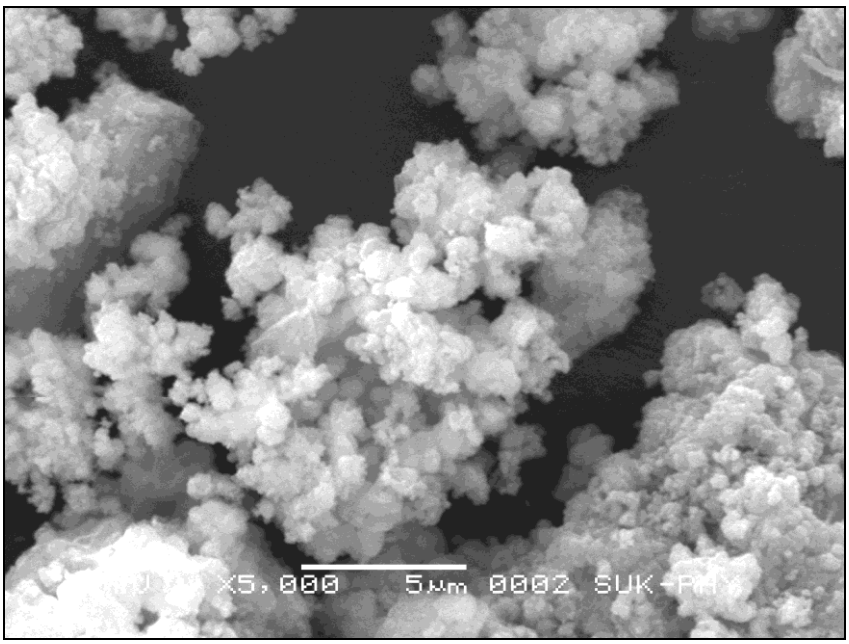

Figure 6. SEM image of synthesized silver nanomaterials (Adapted from JALCOM).

3.4. Transmission electron microscope

A Transmission Electron Microscope (TEM) is a powerful tool used to visualize the ultrastructure of materials at very high magnifications and resolutions. Unlike conventional light microscopes, which use visible light to illuminate specimens, TEMs use a beam of electrons.

Electron Source: In a Transmission Electron Microscope (TEM), the electron source is a crucial component responsible for generating a beam of high-energy electrons. There are primarily two types of electron sources used in TEM:

Thermionic Electron Source: This type of electron source relies on the principle of thermionic emission, where electrons are emitted from a heated filament. The filament, typically made of tungsten or other refractory metals, is heated to a high temperature, causing electrons to escape from its surface. These emitted electrons are then accelerated and focused to form a beam by electromagnetic lenses. Thermionic electron sources are widely used in conventional TEM instruments.

Field Emission Electron Source: Field emission electron sources operate on a different principle known as field emission, where electrons are emitted from a sharp metal tip under the influence of a strong electric field. Field emission sources can produce electron beams with much higher brightness and coherence compared to thermionic sources, resulting in improved spatial resolution and imaging capabilities in TEM. However, they require sophisticated vacuum systems and precise control of electric fields.

Both types of electron sources have their advantages and limitations. Thermionic sources are relatively simpler and more robust, making them suitable for routine TEM applications. Field emission sources, on the other hand, offer superior performance for advanced TEM techniques such as high-resolution imaging, electron energy-loss spectroscopy (EELS), and electron diffraction.

Thus, the electron source in a TEM serves as the foundation for generating the electron beam used to interrogate specimens and produce high-resolution images of their internal structure. The choice between thermionic and field emission sources depends on the specific requirements of the application and the desired performance characteristics of the microscope

- Condenser System: In a Transmission Electron Microscope (TEM), the condenser system is a critical component responsible for shaping and converging the electron beam before it interacts with the specimen. The condenser system typically consists of several elements that work together to control the beam's properties. Here is some of the key components and their functions:
- Condenser Lens: The condenser lens focuses the electron beam emitted by the electron source onto the specimen. It is typically a magnetic lens that uses electromagnetic fields to bend and focus the electrons. The condenser lens ensures that the electron beam is well-collimated and directed towards the specimen with high intensity.
- Condenser Aperture: The condenser aperture is a small aperture or aperture system located near the condenser lens. It controls the size and shape of the electron beam that passes through it. By adjusting the aperture size, users can control the convergence angle of the beam, which affects the depth of focus and the spatial resolution of the microscope.
- Condenser Stigmator: The condenser stigmator is a set of electromagnetic coils used to correct astigmatism in the electron beam. Astigmatism can occur due to imperfections in the condenser lens or misalignment of the optical system, leading to distorted images. The condenser stigmator allows users to adjust the beam's focus in different directions to compensate for astigmatism and improve image quality.
- Condenser Deflector: Some TEM systems may include a condenser deflector, which is used to move the electron beam across the specimen surface. This feature allows users to perform scanning TEM (STEM) imaging, where the beam is raster-scanned across the specimen to generate high-resolution images and perform spectroscopic analysis.

Thus, the condenser system in a TEM plays a crucial role in preparing the electron beam for interaction with the specimen. By controlling the beam's convergence, focus, and astigmatism, the condenser system contributes to the overall performance and imaging capabilities of the microscope. Adjustments to the condenser system are often made by the microscope operator to optimize imaging conditions for specific samples and applications

- Specimen: The sample to be examined is usually very thin (less than 100 nanometers) and must be prepared carefully to withstand the vacuum inside the microscope and the bombardment of electrons.

In Transmission Electron Microscopy (TEM), preparing the specimen is a crucial step to ensure high-quality imaging and accurate analysis. The specimen must be ultra-thin to allow electrons to pass through, and it must also be stable under the high vacuum conditions inside the microscope. Here's an overview of the specimen formation process in TEM:

- Sample Selection: The first step is selecting the appropriate sample for analysis. This could be a thin section of a material, a biological specimen, a nanoparticle, or a thin film, depending on the research question or application.
- Sample Preparation: Mechanical Thinning: For bulk materials, the sample is usually mechanically thinned using techniques such as grinding, polishing, or ultramicrotomy. This process gradually reduces the thickness of the sample until it reaches the desired thinness.
- Ion Milling or Focused Ion Beam (FIB) Milling: In some cases, particularly for semiconductor devices or complex structures, ion milling or FIB milling may be used to precisely mill the sample to the desired thickness. These techniques allow for more controlled thinning and can produce extremely thin specimens with nanometer-scale precision. Cryogenic Techniques: Biological specimens or materials sensitive to high-energy electron beams may require cryogenic techniques for preservation. Cryo-ultramicrotomy or cryo-FIB milling can be used to prepare frozen-hydrated samples for TEM analysis.
- Support Substrate: The ultra-thin specimen is typically supported on a TEM grid, which is a thin metal or carbon support substrate with a mesh-like structure. The specimen is deposited onto the grid using techniques such as pipetting, spraying, or transferring from a thin sectioning grid.
- Staining or Contrast Enhancement: In some cases, staining or contrast enhancement techniques may be employed to enhance the visibility of specific features in the specimen. This could involve using heavy metal stains or specialized contrast agents to highlight certain structures or components.
- Drying and Stabilization: The prepared specimen is then dried and stabilized to ensure it remains intact and stable under the high vacuum conditions inside the TEM chamber. This may involve air-drying, freeze-drying, or chemical fixation depending on the nature of the sample.
- Transfer to TEM: Once prepared, the specimen is carefully transferred to the TEM chamber using specialized handling tools and techniques to avoid contamination or damage. The TEM chamber is then evacuated to create a high vacuum environment suitable for electron microscopy.
- Imaging and Analysis: With the specimen loaded into the TEM, imaging and analysis can begin. The electron beam passes through the ultra-thin specimen, interacting with its atomic structure and producing high-resolution images that reveal detailed information about its composition, morphology, and properties.

Thus, specimen formation in TEM is a meticulous process that requires careful preparation and handling to ensure the quality and integrity of the sample for analysis. Proper specimen preparation is essential for obtaining meaningful and accurate results in TEM imaging and analysis

- Objective Lens: The electron beam passes through the specimen, and the objective lens collects and focuses the transmitted electrons onto a fluorescent screen or a detector.

In a Transmission Electron Microscope (TEM), the objective lens is a crucial component responsible for collecting and focusing the electrons transmitted through the specimen. It plays a fundamental role in forming the high-resolution images that are characteristic of TEM. Here's an overview of the objective lens and its function:

- Position and Function: The objective lens is located below the specimen holder and is positioned close to the specimen. Its primary function is to collect the electrons that pass through the specimen and focus them onto an imaging plane, where they form an image that can be observed and recorded.
- Electromagnetic Design: The objective lens typically consists of one or more magnetic coils arranged around the optical axis of the microscope. These coils generate a magnetic field that acts on the electrons passing through the specimen, bending their trajectories and focusing them onto the imaging plane.
- Adjustable Parameters: The objective lens may have adjustable parameters such as focus, astigmatism correction, and aperture size. These parameters can be adjusted by the microscope operator to optimize imaging conditions for different specimens and desired imaging modes.
- Magnification and Resolution: The objective lens plays a critical role in determining the magnification and resolution of the TEM images. By controlling the convergence and focusing of the electron beam, the objective lens determines the spatial resolution of the microscope, which is typically on the order of nanometers or even sub-nanometers in modern TEM instruments.
- Imaging Modes: The objective lens is essential for various imaging modes in TEM, including bright-field imaging, dark-field imaging, and high-resolution imaging techniques such as lattice imaging and high-angle annular dark-field (HAADF) imaging. The configuration and settings of the objective lens can be adjusted to optimize imaging for different modes and applications.

Thus, the objective lens in a TEM is a critical component that plays a central role in forming high-resolution images of specimens. Its design, configuration, and performance characteristics have a significant impact on the quality and capabilities of the microscope for imaging and analysis in various scientific and technological fields.

- Image Formation: The transmitted electrons interact with the specimen, undergoing scattering, diffraction, and absorption. These interactions form the basis of contrast in the resulting image.

In a Transmission Electron Microscope (TEM), image formation is a complex process that involves the interaction of electrons with the specimen and subsequent detection of the transmitted electrons to generate an image. Here's a detailed breakdown of the steps involved in image formation in TEM:

- Electron Source and Beam Formation: The process begins with the generation of a beam of high-energy electrons by the electron source, which could be a thermionic emitter or a field emitter. This electron beam is then focused and

shaped by electromagnetic lenses in the condenser system to form a coherent and convergent beam.

- Specimen Interaction: The focused electron beam passes through the ultra-thin specimen, which is typically mounted on a TEM grid. As the electrons interact with the atoms in the specimen, they undergo various interactions, including scattering, diffraction, and absorption.
- Elastic Scattering (Direct Transmission): Some of the electrons in the beam pass directly through the specimen without interacting significantly with the atoms. This process, known as elastic scattering or direct transmission, contributes to the formation of the bright areas in the TEM image.
- Inelastic Scattering (Secondary Electrons): Other electrons in the beam undergo inelastic scattering interactions with the specimen atoms, resulting in the emission of secondary electrons. These secondary electrons can also contribute to image formation, particularly in techniques such as scanning transmission electron microscopy (STEM).
- Diffraction: When the electron beam interacts with the crystal lattice of the specimen, it undergoes diffraction, resulting in the formation of a diffraction pattern. This pattern contains information about the crystal structure of the specimen and can be used to analyze its composition and orientation.
- Image Formation: The transmitted electrons, along with any secondary electrons and diffraction patterns, are collected and focused by the objective lens onto an imaging plane, typically a fluorescent screen or a digital detector. The distribution of electrons on the imaging plane forms an image that represents the spatial distribution of electron density within the specimen.
- Detection and Visualization: The image formed on the detector can be visualized directly through the eyepieces or recorded digitally for further analysis. Modern TEMs often use digital detectors capable of capturing high-resolution images and performing advanced techniques such as electron energy-loss spectroscopy (EELS) and electron diffraction.

By analyzing the resulting images, researchers can study the morphology, crystal structure, defects, and composition of materials at the atomic and nanometer scales, making TEM a powerful tool in various scientific and technological fields.

- Projector System: The image formed by the objective lens is magnified and projected onto a screen or a detector. In TEM, the process of image formation primarily involves the collection and focusing of transmitted electrons by the objective lens onto an imaging plane, typically a fluorescent screen or a digital detector.

Once the electron beam passes through the specimen and interacts with it, the objective lens collects and focuses the transmitted electrons to form an image. This image is then magnified and projected onto the imaging plane, where it can be visualized or recorded for analysis.

The objective lens, as well as any intermediate lenses, play a crucial role in this process by controlling the convergence and focusing of the electron beam to achieve the desired magnification and resolution. The resulting image on the imaging plane

represents the spatial distribution of electron density within the specimen, providing detailed information about its internal structure.

- Detector: In a Transmission Electron Microscope (TEM), the detector is a crucial component responsible for capturing and recording the images formed by the transmitted electrons. The detector plays a fundamental role in converting the electron signal into a digital or visual representation that can be analyzed and interpreted by researchers. Here's an overview of the detector in TEM:
- Types of Detectors: There are several types of detectors used in TEM, each with its own advantages and capabilities. Some common types include:
- Fluorescent Screen: In traditional TEMs, a fluorescent screen coated with a phosphorescent material may be used as a detector. When electrons strike the screen, they cause it to emit visible light, which can be observed directly through the eyepieces or captured by a camera for imaging.
- Photographic Film: In older TEM instruments, photographic film was commonly used as a detector. The film captures the pattern of electrons transmitted through the specimen, which can be developed and examined to produce images.
- Digital Cameras: Modern TEMs often use digital cameras as detectors. These cameras can capture high-resolution images of the electron beam as it interacts with the specimen. The images are then digitized and stored electronically for analysis and processing.
- Scintillator-Photomultiplier Detector: In some TEM configurations, a scintillator material is used to convert the electron signal into visible light, which is then detected by a photomultiplier tube (PMT) or a charge-coupled device (CCD) camera.
- Performance Characteristics: The performance of the detector in TEM is critical for achieving high-quality imaging and analysis. Important characteristics of a detector include its sensitivity, spatial resolution, dynamic range, signal-to-noise ratio, and speed of data acquisition.
- Specialized Detectors: Some TEM systems may include specialized detectors for specific imaging techniques or applications. For example, energy-dispersive X-ray spectroscopy (EDS) detectors can be integrated into TEMs to analyze the elemental composition of specimens, while electron energy-loss spectroscopy (EELS) detectors can measure the energy lost by electrons as they pass through the specimen.
- Data Acquisition and Processing: The detector in TEM captures the images formed by the transmitted electrons, which are then processed and analyzed using dedicated software tools. This may involve tasks such as image alignment, contrast enhancement, filtering, and quantitative analysis of features within the specimen.

Overall, the detector in TEM is a critical component that enables researchers to visualize and analyze the internal structure of specimens at the atomic and nanometer scales. Advances in detector technology continue to improve the capabilities and performance of TEM for a wide range of scientific and technological applications.

The resulting image provides detailed information about the internal structure of the specimen, including features such as crystal structure, defects, and morphology, at

the nanometer scale. TEM is widely used in various fields, including materials science, biology, nanotechnology, and semiconductor research, among others.

TEM is a microscopic technique in which a beam of the electron is transmitted through an ultra-thin specimen, interacting with the specimen as it passes through. The working principle of TEM is very much similar to the light microscope. The prime difference between light microscope and electron microscope is that, in case of light microscope, light rays are used to focus and produce image whereas in case of TEM, electron beams are used to focus on the specimen and to produce image. Electrons are having shorter wavelength as compared with light. The mechanism of a light microscope is that an increase in resolution power decreases the wavelength of light, but in TEM when electrons are illuminated, the specimen, the resolution power increases increasing the wavelength of the electron transmission. The working principle of TEM can be depicted as under:

The working principle of a Transmission Electron Microscope (TEM) is based on the interaction of a beam of electrons with a thin specimen.

Electron Generation: Electrons are generated by an electron gun through thermionic emission or field emission. In thermionic emission, electrons are released from a heated filament, while in field emission, electrons are emitted from a sharp metal tip under the influence of a strong electric field.

Beam Formation and Focusing: The emitted electrons are accelerated and focused into a coherent beam using electromagnetic lenses. These lenses function similarly to optical lenses but use electromagnetic fields to control the trajectory of electrons.

Specimen Preparation: The specimen to be analyzed is typically very thin (on the order of tens to hundreds of nanometers) and must be prepared using specialized techniques such as ultra-microtomy or focused ion beam milling. This thinness is crucial to allow electrons to penetrate through the sample.

Transmission through Specimen: The focused electron beam passes through the thin specimen. As the electrons traverse the material, they interact with its atoms through various processes, including scattering, diffraction, and absorption.

Interaction with Specimen: The interactions of electrons with the atoms in the specimen lead to the formation of an image. The degree of interaction depends on factors such as the atomic number of the elements in the specimen, the thickness of the sample, and the energy of the incident electrons.

Image Formation: After passing through the specimen, the transmitted electrons carry information about its internal structure. This information is collected and magnified by electromagnetic lenses to form an image on a fluorescent screen or a digital detector.

Detection and Visualization: The image formed on the detector can be visualized directly or recorded digitally for further analysis. Modern TEMs often use digital detectors that can capture high-resolution images and even perform advanced techniques such as electron energy-loss spectroscopy (EELS) and electron diffraction.

By analyzing the resulting images, researchers can study the morphology, crystal structure, defects, and composition of materials at the atomic and nanometer scales, making TEM an indispensable tool in various scientific and engineering fields

An image is formed from the interaction of the electrons transmitted through the specimen; the image is magnified and focused onto the imaging device such as a fluorescent screen. In TEM analysis, a thin specimen is illuminated with electrons in which the electron intensity is uniform over the illuminated area. As the electrons travel through the specimen, they are either scattered by a variety of processes or they may remain unaffected by the specimen. The result is that a non-uniform distribution of electrons emerging from the surface of the specimen contains all the structural and chemical information about the specimen. An electron microscope is constructed to display this non-uniform distribution of electrons in two different ways viz. angular distribution of scattering that can be viewed in the form of scattering patterns, and spatial distribution of scattering that can be observed as contrast in images of the specimen. The advantages of this arrangement are the possibility of directly viewing the area from which the diffraction pattern arises. The basic components of the transmission electron microscope are shown in **Figure 7**.

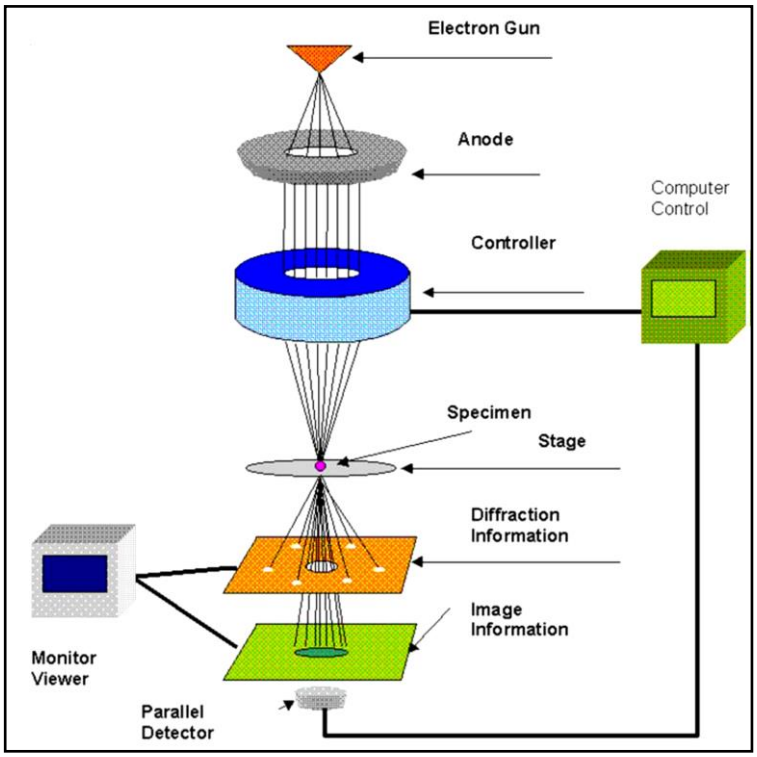

Figure 7. A pictorial representation of the transmission electron microscope [139].

A technical explanation of a typical TEM working is as follows:

The vital source i.e., an electron gun produces a stream of monochromatic electrons.

TEM works with voltage electron beam. Here a focused beam of electrons instead of light is used to image.

The magnification power is over 2 million times better than that of light microscope.

TEM uses electron beam for resolution.

The stream is focused to a small, thin coherent beam by the use of condenser lenses 1 and 2. The first lens is usually controlled by a spot size knob that largely

determines the spot size and the second lens is usually controlled by the intensity or brightness knob that changes the size of the spot on the sample. The second lens usually controlled by the intensity or brightness knob actually changes the size of the spot on the sample.

The beam is restricted by the condenser aperture, knocking out high-angle electrons.

The beam strikes the specimen and part of it are transmitted.

The transmitted portion is focused on the objective lens.

Optical objective and selected area metal apertures can restrict the beam, the objective aperture enhancing contrast by blocking out high-angle diffracted electrons, and the selected area aperture enabling the user to examine the periodic diffraction of electrons by the ordered arrangement of atoms in the sample. Sample preparation for Transmission Electron Microscopy (TEM) requires meticulous steps to produce ultra-thin samples suitable for electron transmission. Biological specimens are typically fixed using chemical fixatives like glutaraldehyde, followed by staining with heavy metals such as osmium tetroxide to enhance contrast. The sample is then dehydrated through a graded series of ethanol or acetone solutions and embedded in a resin to stabilize the structure. Ultra-thin sections, typically around 70–90 nm thick, are cut using an ultra-microtome and collected on a copper grid. For materials science samples, thinning can be achieved through techniques like ion milling or mechanical polishing. The final step often involves additional staining or coating to improve electron contrast before the sample is examined in the TEM.

The photographic image is recorded from the electron after it has passed through a thin sample of the specimen under study.

The image is passed down the column through the intermediate and projector lenses.

The image strikes the phosphorus image screen and light is generated, allowing the user to see the image. The darker area of the image represents those areas of the sample that fewer electrons were transmitted through 77. The TEM images of synthesized Silver Nanomaterials are shown as below in **Figure 8**.

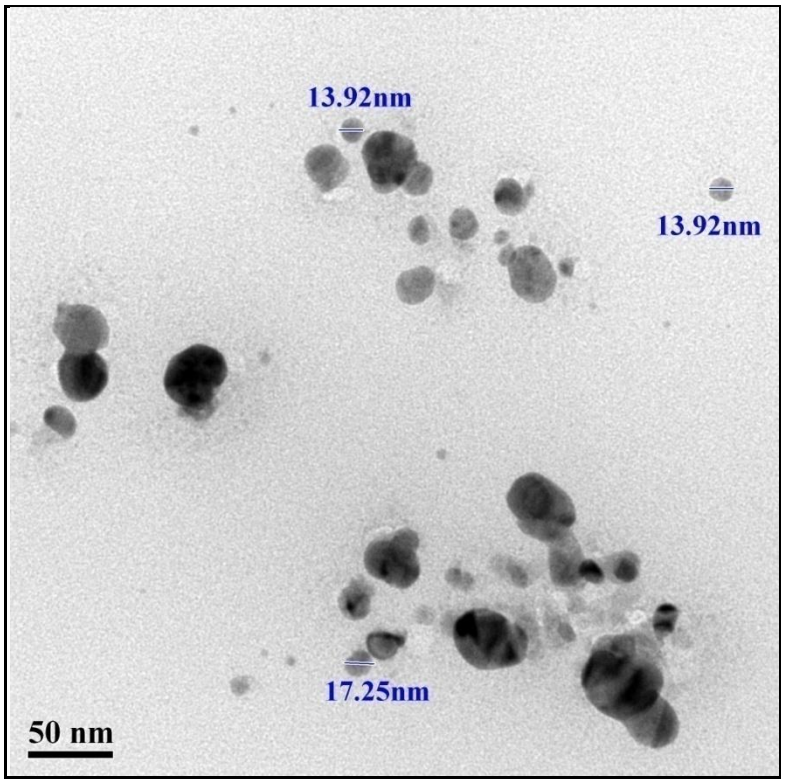

Figure 8. TEM Image of silver NP showing size of nanoparticles.

4. Applications of nanomaterials in medical textiles

The potential of the materials at nanoscale is well understood by the group of researchers and scientists from every branch of technology are trying to get benefit from the materials at nanoscale. Textile industry is one of the leading industry globally. The researchers working in textile also took an effort to use nanomaterials in it. Technical textile is an important branch of textile. The Medical textile can be considered as the subgroup of technical textile that focuses on fiber based products used in health management. The use of textiles in medicine can be traced back. The bandage is the common example of non-woven material used in health care. The medical textile products can be organized into three basic categories i.e., patient specific, general patient management and procedure specific. The medical textile products can be used in dressing, implants, surgical sutures, diapers, menstrual pads, wipes and barrier fabrics. The recently spread pandemic Covid-19 created higher demand for the products of medical textiles. The natural fiber has been used in medical applications since long time and with advancement in technology splits and bandages are becoming important. The medical textile covers vast area of applications such as wound care, disease management, preventive clothing etc. Apart from these, there are several applications such as tissue engineering, anti-microbial dressing, surgical suture thread, anti-viral textiles, medical gowns, surgical masks, PPE kits, Pressure infusion bags, inflatable tourniquets, blood pressure cuffs, medical isolated gown, medical beds, shoe covers, implants, draping clothing, smart textiles, odor control materials, drug delivery systems, compression garments.

4.1. Anti-microbial textile

Antimicrobial textiles are fabrics that have been treated or engineered to inhibit the growth of microorganisms, such as bacteria, fungi, and viruses, on their surface. Here are some key points about antimicrobial textiles:

Functionality: Antimicrobial textiles are designed to reduce or prevent the growth and proliferation of microorganisms on the fabric surface. This helps in controlling odors, maintaining hygiene, and reducing the risk of infections associated with contact with contaminated surfaces.

Treatment Methods: Antimicrobial properties can be imparted to textiles through various methods, including chemical treatments, coatings, or incorporating antimicrobial agents directly into the fibers during manufacturing. Common antimicrobial agents used in textile treatments include silver nanoparticles, quaternary ammonium compounds, and zinc pyrithione.

Applications: Antimicrobial textiles find a wide range of applications in industries such as healthcare, hospitality, sports and outdoor gear, apparel, and home textiles. In healthcare settings, antimicrobial fabrics are used in hospital gowns, bed linens, wound dressings, and other medical textiles to help reduce the risk of healthcare-associated infections.

Benefits: The use of antimicrobial textiles offers several benefits, including improved hygiene, extended product lifespan (due to reduced microbial degradation), reduced odor formation, and enhanced comfort for the wearer. In healthcare settings, antimicrobial textiles can contribute to infection prevention and control efforts.

Considerations: While antimicrobial textiles can be beneficial, there are some considerations to keep in mind. These include the durability and longevity of antimicrobial treatments, potential environmental impact, safety concerns related to certain antimicrobial agents, and the development of microbial resistance over time.

Regulations and Standards: In some regions, antimicrobial textiles may be subject to regulations and standards to ensure their safety and efficacy. Manufacturers may need to comply with relevant guidelines and testing protocols to demonstrate the antimicrobial properties of their products.

The antimicrobial properties of Gold nanomaterials against different microorganisms and the resulting zone of inhibition is given as under in **Table 5**.

Table 5. Zone of inhibitions in mm of synthesized sample against various microorganisms (Current Research in Green and Sustainable Chemistry).

Micro organisms	**25 µg/mL**	**50 µg/mL**	**75 µg/mL**	**100 µg/mL**	**control + ve(Streptomycin)**
	Zone of inhibition in mm				
Aspergillus niger	14	14	15	15	19
Fusarium solani	12	12	12	12	17
Proteus vulgaris	10	11	11	12	13
Pseudomonas aeruginasa	14	14	15	14	20
Staphylococcus aureus	15	16	15	14	21
Salmonella typhimurium	16	12	11	17	15

Overall, antimicrobial textiles play an important role in promoting hygiene and reducing the transmission of harmful microorganisms in various environments. As research and technology continue to advance, there is ongoing innovation in the development of antimicrobial textile solutions to address evolving needs and challenges.

Mode of action of silver nanoparticles

Though several mechanisms have been proposed, the anti-microbial activity of silver nanoparticle is not fully understood. Silver nanoparticles are considered to be a slow release source of silver ions which reacts with thiol groups of proteins and interfere with DNA replication. Also silver is supposed to generate free radicals, which damage the bacterial membrane. In addition, it is suggested that antibacterial activity can also occur through direct contact between nanoparticle and bacterial cell causing structural damage to their cell wall.

Ag, TiO_2 and ZnO NPs can be utilized to impart antibacterial and fungicidal properties to textiles. Ag NPs have large surface areas that increase their contact with bacteria and fungi. The antiseptic mechanism of Ag NPs is based on reacting with proteins in these organisms and adversely affecting their cellular function and inhibiting cell growth. They also reduce respiration, limiting the activity of the basal metabolism of the electron transfer system, and substrate transport into the cell membrane. When Ag NPs contact with moisture or bacteria, they adhere to the cell wall and membrane.63 While the Ag NPs in their metallic state are inert, they ionize in the presence of moisture. The Ag^+ ions are reactive and they diffuse through the cell wall and membrane into cytoplasm. Ag^+ ions bind to sulphur containing proteins on the cell membrane to structurally change the cell wall. The changes result in the release of the cellular components to extracellular fluid due to the changes in the osmotic pressure. Additionally, the Ag^+ ions bind to phosphate containing proteins to condense DNA, leading to a reaction with thiol group proteins to cause cell death. They also suppress the function of enzymes and inhibit the cell to produce ATP. Ag NPs slow down the growth and multiplication of bacteria and fungi that are involved in odor creation and itchiness. For example, Ag NPs can be applied to socks to prevent the growth of bacteria and fungi. The antimicrobial efficacy of Ag additives depends on the concentration, surface area, and the release rate of the Ag^+ ions.66–68 Ag-containing textiles can release dissolved and particulate Ag (20%–30%) into washing liquid in the first cycle. In fabrics comprising Ag metal, oxidation from Ag(0) to Ag(I) is required for releasing Ag+ ions in solution. Ion release from Ag NPs is a cooperative oxidation process involving dissolved oxygen and protons to produce peroxide intermediates and complete reactive dissolution. The presence of oxygen is essential for the release of dissolved Ag through the surface oxidation of Ag NPs. The ion release rates increase as the temperature is increased and as the pH is decreased. For example, Ag NPs (2 $mg \cdot L^{-1}$) after 24 h incubation in air-saturated solution released 0.3 mg L^{-1} dissolved Ag at pH 5.68, 0.6 mg L^{-1} at pH 4.0 and 0.1 mg L^{-1} at pH 8.0. Additionally, the change in ionic strength has negligible effect on the release kinetics. TiO_2 NPs can also be utilized to impart textiles with antibacterial properties. Upon illumination with light with energy higher than its bandgap (3.2 eV), TiO_2 as a photocatalyst has the ability to have its electrons jump from the valence band to the

conduction band. The electron and electric hole pairs form on the surface of the photocatalyst, where the electrons and oxygen form O^{2-} and the positive electric holes and water create hydroxyl radicals. The unstable substances on the surface of the photocatalyst are oxidized into CO_2 and water. Through this mechanism, the photocatalyst decompose organic matters including odor molecules, bacteria, and viruses. The catalytic activity of TiO_2 NPs has been utilized in textiles to provide antibacterial properties. The photocatalytic activity might be improved by creating TiO_2/SiO_2 nanocomposites or Au-doped TiO_2 nanocomposites in cotton fabrics with self-cleaning properties. Furthermore, ZnO behaves similar to TiO_2 to produce antibacterial properties.76 ZnO NPs (21–25 nm) have been synthesized in reverse micelle cores of polystyrene (PS) and polyacrylic acid. ZnO NPs coated onto textiles showed self-cleaning properties in the presence of gram-negative E. coli and aerobic gram-positive S. aureus. Additionally, SiO_2 and Ag NPs with core-corona structure were electrostatically assembled onto cotton surfaces with high packing density to impart antibacterial properties to fabrics. The coronas of NPs can be loaded with antibacterial moieties such as quaternary ammonia salts as well as metal coatings on cotton fabrics. Discussions focusing on self-cleaning and antimicrobial nanomaterials in textiles can be found elsewhere.

4.2. UV-protection

UV protection using nanoparticles in textiles is an innovative approach to enhance the sun protection properties of fabrics. Nanoparticles, typically metal oxides such as zinc oxide (ZnO) and titanium dioxide (TiO_2), are incorporated into the textile fibers or applied as coatings on the fabric surface. Here's how this process works and its benefits:

UV Absorption: Nanoparticles such as ZnO and TiO_2 have the ability to absorb and scatter UV radiation. When incorporated into textiles, these nanoparticles can intercept and absorb UV rays, preventing them from reaching the skin beneath the fabric.

Broad Spectrum Protection: ZnO and TiO_2 nanoparticles offer broad-spectrum protection, meaning they can effectively block both UVA and UVB radiation. This helps to reduce the risk of sunburn, premature skin aging, and skin cancer caused by prolonged exposure to sunlight.

Uniform Distribution: Nanoparticles can be dispersed evenly throughout the textile matrix, ensuring uniform UV protection across the fabric surface. This distribution helps to maintain consistent sun protection properties even after repeated washing or stretching of the fabric.

Transparency and Comfort: Compared to traditional UV-blocking additives, nanoparticles can provide UV protection without significantly altering the appearance or texture of the fabric. Fabrics treated with nanoparticles remain lightweight, breathable, and comfortable to wear, making them suitable for a wide range of clothing and outdoor applications.

Durable and Long-lasting: Nanoparticles are resistant to degradation by UV radiation and exposure to environmental factors, ensuring long-lasting UV protection

for the lifetime of the garment. This durability makes nanoparticle-treated textiles ideal for outdoor apparel, swimwear, sportswear, and other sun-protective clothing.

Environmentally Friendly: ZnO and TiO_2 nanoparticles are generally considered safe and environmentally friendly when used in textile applications. They are non-toxic, biocompatible, and do not release harmful chemicals into the environment during use or disposal.

Thus, overall, UV protection using nanoparticles in textiles offers an effective, versatile, and sustainable solution for mitigating the harmful effects of solar radiation on the skin. By incorporating nanoparticles into fabrics, manufacturers can create sun-protective clothing that helps to promote skin health and reduce the risk of sun-related skin damage and diseases Technically, inorganic UV blockers are far more preferable to organic UV blockers as they behave like chemically stable and non-toxic under constant exposure to high temperatures and UV. It is said that, semiconductor oxides such as TiO_2, ZnO, SiO_2 and Al_2O_3 are usually Inorganic UV blockers. Among these semiconductor oxides, titanium dioxide (TiO_2) [15–20] and zinc oxide (ZnO) [21] are commonly used. It was observed that, nano-sized titanium dioxide and zinc oxide were more efficient at absorbing and scattering UV radiation than the traditional size and performs better to obstruct UV radiation. The main reason behind this, nanoparticles has a larger surface area per unit mass and volume than the conventional materials, which leads to the increase of the effectiveness of blocking UV radiation.

4.3. Sanitary napkins

Menstruation, commonly referred to as a period, is a natural biological process that occurs in people with female reproductive systems. Here's an overview:

Definition: Menstruation is the monthly shedding of the uterine lining (endometrium) that occurs in the absence of pregnancy. It is characterized by vaginal bleeding, which typically lasts for a few days to a week.

Menstrual Cycle: Menstruation is part of the menstrual cycle, which is controlled by hormonal changes in the body. The menstrual cycle typically lasts about 28 days, although it can vary from person to person. The cycle is divided into several phases, including the follicular phase, ovulation, and the luteal phase, leading up to menstruation.

Menstrual Flow: During menstruation, the uterus sheds its lining along with blood and tissue through the vagina. The flow of menstrual blood can vary in color, consistency, and volume from person to person and from one menstrual period to another.

Menstrual Symptoms: Many people experience symptoms before or during menstruation, collectively known as premenstrual syndrome (PMS) or premenstrual dysphoric disorder (PMDD). Common symptoms include mood swings, bloating, breast tenderness, headaches, and cramps.

Hygiene and Management: During menstruation, proper hygiene practices, such as using menstrual hygiene products like pads, tampons, menstrual cups, or period underwear, are essential to manage menstrual flow and prevent leaks. It's also important to change these products regularly to maintain cleanliness and prevent infections.

Menstrual Health: Menstrual health is an important aspect of overall reproductive health. Issues such as irregular periods, heavy bleeding (menorrhagia), painful periods (dysmenorrhea), and absence of periods (amenorrhea) may indicate underlying health conditions that require medical attention.

Social and Cultural Perspectives: Menstruation is often surrounded by social and cultural beliefs, taboos, and stigmas in various societies. Efforts to promote menstrual equity, education, and access to menstrual hygiene products aim to address these issues and ensure that menstruating individuals can manage their periods with dignity and without barriers.

Understanding menstruation is essential for individuals with menstrual cycles, as well as for healthcare providers, policymakers, and society as a whole, to support menstrual health and well-being.

Gravimetric absorbency testing is particularly relevant for sanitary napkins, as it helps in assessing their effectiveness in managing menstrual flow. Here's how gravimetric absorbency testing contributes to the evaluation of sanitary napkins:

Absorption Capacity: Gravimetric testing measures the amount of liquid a sanitary napkin can absorb before reaching saturation. This is crucial in determining the overall effectiveness of the napkin in managing menstrual flow throughout the day or night.

Rate of Absorption: It's important for sanitary napkins to quickly absorb menstrual fluid to prevent leaks and maintain comfort. Gravimetric testing helps in assessing how rapidly the napkin absorbs liquid, providing insights into its performance during real-world use.

Retention Capacity: Once absorbed, the menstrual fluid should be securely retained within the napkin to prevent leaks and ensure dryness. Gravimetric testing helps in evaluating the napkin's ability to retain absorbed fluid under pressure, such as when the wearer moves or sits.

Surface Dryness: Gravimetric testing can also provide information about the surface dryness of the napkin after absorption. A napkin that quickly absorbs fluid and keeps the surface dry enhances comfort and reduces the risk of skin irritation.

Comparative Analysis: By testing different types or brands of sanitary napkins, gravimetric testing allows for comparative analysis of their absorbency performance. This helps consumers and manufacturers make informed decisions about product selection and improvement.

Overall, gravimetric absorbency testing is an essential tool for evaluating the performance of sanitary napkins and ensuring that they meet the needs and expectations of users in terms of comfort, protection, and reliability during menstruation.

On an average women lose 65 to 80 mL of fluid in a period. The essential properties of sanitary napkin is as below:

Protection against leakage.

Comfortable to wear and stay in a place.

Hygienic and environmentally friendly.

Odorless.

Sanitary napkins are a member of disposable hygiene products those belong to technical textiles as they contain functional textile materials. Sanitary napkins have a

big market [1] because almost the half of the world population consists of women and every woman have menstrual bleeding during their fertile periods [1,2]. The sanitary napkin market will maintain its size until new techniques, which are easier to use, accessible, hygienic and more comfortable, will be emerged. Sanitary napkins are produced as layered structures as they have to fulfill different properties such as absorption, leakage prevention, comfort etc. at the same time. These layers contain textile and film structures. The uppermost layer which contacts with the body is the top sheet. The material of top sheet can be polyethylene film or polypropylene spun bond nonwoven fabric. An acquisition-distribution layer (ADL) is under the top sheet and it distributes the menstrual fluid along the sanitary napkin and transfers it to the absorbent layer below. ADL can be made of air laid wood pulp nonwovens or multicomponent structures composed of wood pulp and man-made fibers. Absorbent layer is usually made of wood pulp and superabsorbent polymer. It can be produced by air laid technology and with different configurations. The bottom layer namely back sheet is usually an impermeable film. The ADL and absorbent layers are made up of nonwoven fabrics. It is advantageous to use nonwoven fabrics as they are easy and fast to produce, they absorb high amount of fluid and they provide comfort to the user.

The most common material used for commercial sanitary pads is superabsorbent polymer (SAP). This material was first utilized for sanitary pad and diaper manufacture in high-income countries (Japan and the US) in the 1970s. The challenges regarding SAP are that it is expensive, and the production is more technical, requiring a high level of capital and complex machinery. In contrast to SAP, natural plant fibers are cellulose-based and attract water which make them highly absorbent. The structure of plant fibers changes dimensions with changing moisture content because the cell wall contains hydroxyl and other oxygen containing groups that attract moisture through hydrogen bonding. Moisture swells the cell wall, and the fiber expands until the cell wall is saturated with water. Beyond this saturation point, moisture exists as free water in the void structure and does not contribute to further expansion. Superabsorbent polymer can absorb up to 200-fold of its own weight of water [17]. Cotton fibers, from cotton plants, typically hold water up to 24–27-fold their own weight [140]. Linen fibers, which are obtained from the flax plant, have less absorbency than cotton fibers [141]. Cotton terry cloth, where cotton fibers are woven in loops, is more absorbent than standard cotton. The surface area of the loops is designed to absorb liquids and the ability of absorption is driven by fabric weight, thickness, and pile yarn twist [142]. Hemp or industrial hemp is a natural fiber from a variety of the Cannabis sativa plant. Hemp has Int. J. Environ. Res. Public Health 2021, 18, 9766 3 of 8 antibacterial properties and good absorbency [21,22]. Hemp is more water absorbent than cotton [143]. Bamboo fiber or bamboo textile is another highly absorbent material. Bamboo fiber is also more absorbent than cotton [24]. A study in cloth diapers, comparing bamboo diapers, cotton diapers and blended fabrics found that pure bamboo has the strongest antibacterial activity and a bamboo cotton blend had greater absorption capacity than pure cotton [25]. The cross-section of the bamboo fiber is filled with numerous micro-holes and micro-gaps. Bamboo fibers' cellulose composition consists of crystalline and hierarchal structures which differs from the other natural materials. Bamboo is also found to contain a unique anti-bacterial and bacteriostasis bio-agent called 'Bamboo Kun'. This feature of bamboo fiber makes it

useful for sanitary products, as it will not gather as much bacteria as other alternatives, when worn for extended periods. Bamboo fiber appears to be an excellent alternative to SAPs, as it is highly absorbent, biodegradable and has excellent ventilation and several anti-bacterial properties. However, processing of bamboo fiber and sealing it into a sanitary pad is expensive, which in turn increases the user cost. In view of that, direct usage of bamboo wadding fabric instead of bamboo fibers was investigated in this current study. Bamboo wadding fabric has been used previously only inside quilts and children's coat.

4.4. Surgical gowns

Gravimetric absorbency testing also plays a role in assessing the effectiveness of surgical gowns, albeit in a slightly different context compared to absorbent products like sanitary napkins. Here's how gravimetric testing contributes to the evaluation of surgical gowns:

Liquid Barrier Performance: Surgical gowns are designed to provide a barrier against fluids such as blood, bodily fluids, and other contaminants during medical procedures. Gravimetric testing helps in evaluating the gown's ability to repel liquids and prevent them from penetrating through the fabric.

Fluid Resistance: In addition to providing a barrier, surgical gowns should resist fluid penetration under varying levels of pressure. Gravimetric testing assesses the gown's resistance to liquid penetration, which is crucial for protecting healthcare workers from exposure to potentially infectious materials.

Durability: Gravimetric testing can also provide insights into the durability of surgical gowns under simulated usage conditions. This includes assessing how well the gown maintains its liquid barrier properties after repeated use, laundering, or exposure to other stress factors.

Comparative Analysis: Similar to other applications, gravimetric testing allows for comparative analysis of different types or brands of surgical gowns. This helps healthcare facilities select gowns that offer the optimal balance of protection, comfort, and cost-effectiveness.

Overall, gravimetric absorbency testing is an important tool for evaluating the performance of surgical gowns in terms of fluid resistance and barrier properties. By ensuring that gowns meet or exceed relevant standards and requirements, gravimetric testing helps protect healthcare workers and patients during medical procedures.

Surgical gowns as personal protective garments which are designed for acting as physical barriers between sterile and non-sterile zones especially for being able to keep the viral agents away from the patients and also keep the blood related pathogens away from the health personnel in order to create a safe operation environment and to minimize the risks for both parties.

The major uses of gowns are twofold. First, gowns are used in surgery and while performing invasive procedures, both to decrease the transmission of skin flora from the healthcare staff and to protect the staff against contact with potentially infective material, such as blood. Second, gowns are used when caring for patients with certain infectious disease to aid in preventing cross-transmission.

Surgical garments using to protect the patient and the surgical team during surgery must have a number of features. Pore size in the surgical garment, liquid repellency - liquid-tightness, air permeability and the other properties need to be analyzed. Liquid repellent feature of surgical clothes is very important to prevent the growth of bacteria in moist environments. Fluid repellent surgical clothes is sufficient only in the absence of moisture and fluid such as eye surgery and micro-surgery. If surgery is necessary in patients with problems such as Hepatitis B, Hepatitis C or HIV must be used liquid repellent fabric for surgical gown, during the course of an operation, to prevent contamination of the patient.

Air permeability of surgical clothes varies according to its raw material. Surgical gowns that allow moisture to evaporate are more suitable to provide the heat balance of the body easily. Surgical gowns that are made from fabric with better air permeability and water vapor transfer rate, have the ability to provide a wider comfort.

If surgical gown does not allow enough evaporation and transfer, can cause discomfort to disrupt the balance of the body. Materials used in surgical gowns must prevent the penetration of bacteria and viruses by linking liquids. But the same material must allow water vapor to escape to ensure protection of body's heat balance.

Nowadays two categories of materials are used to manufacture surgical gowns: Reusable and single-use material. Reusable surgical gowns are manufactured from woven fabrics and are subjected to washing and sterilization process before each use. But disposable surgical gowns are manufactured from nonwoven fabrics and are designed for a single use.

With modern technology, it is possible to obtain surgical gowns and drapes using many different materials. The choice of using single-use or reusable gowns must be taken into consideration rules relating to the barrier and comfort properties of gowns, safety of patient and staff and the risk of bacterial contamination.

4.5. Biocompatible coatings

Nanoparticles can be used to create biocompatible coatings on medical textiles, enhancing their performance and functionality. These coatings may improve properties such as water repellency, stain resistance, and durability while maintaining biocompatibility with the skin.

4.6. Diagnostic textiles

Nanoparticles can be functionalized with biomolecules or antibodies to create diagnostic textiles for detecting specific biomarkers or pathogens. By integrating nanoparticles into textiles, wearable diagnostic devices can be developed for monitoring health parameters, such as glucose levels, pH, or biomarker concentrations, in real time.

Diagnostic textiles are a fascinating intersection of textile technology and medical diagnostics. They involve the integration of functional materials and sensors into textiles to monitor physiological parameters, detect diseases, or provide therapeutic functionalities. Let's see how they work and some examples:

Integration of Functional Materials: Diagnostic textiles incorporate materials with specific properties, such as conductive fibers, nanoparticles, or biomolecules, into the fabric. These materials can interact with biological samples or physiological signals.

Sensing Mechanisms: The functional materials integrated into the textile can serve as sensors to detect various biological signals, such as temperature, humidity, pH, or specific biomarkers indicative of health conditions.

Signal Transmission and Processing: Once the sensors detect signals, such as changes in temperature or biomarker concentrations, the data needs to be transmitted and processed. This can be achieved through embedded electronics or wireless communication systems integrated into the textile.

Monitoring and Analysis: The data collected by the sensors can be monitored in real-time or stored for later analysis. This information can provide valuable insights into an individual's health status, allowing for early detection of diseases or monitoring of chronic conditions.

Examples of diagnostic textiles include:

Smart Garments: Clothing embedded with sensors to monitor vital signs like heart rate, respiration rate, or body temperature. These garments can be particularly useful for athletes, patients with chronic conditions, or elderly individuals living independently.

Wound Dressings: Textiles incorporated with sensors or antimicrobial agents to monitor wound healing or detect infections. These dressings can provide real-time feedback on the condition of the wound and alert healthcare providers to any complications.

Biomedical Implants: Textiles used as implantable devices for drug delivery, tissue engineering, or monitoring physiological parameters inside the body. These implants can be designed to degrade over time or to be biocompatible with the surrounding tissues.

Environmental Monitoring Textiles: Fabrics embedded with sensors to detect environmental pollutants, toxins, or pathogens. These textiles can be used in protective clothing for workers in hazardous environments or for monitoring air and water quality in public spaces.

Overall, diagnostic textiles offer a non-invasive, comfortable, and potentially cost-effective way to monitor health parameters and improve healthcare outcomes. They represent a promising area of research and innovation at the intersection of textiles, electronics, and medicine

4.7. Therapeutic textiles

Nanoparticles with unique properties, such as magnetic nanoparticles or nanoparticles with photo thermal properties, can be incorporated into textiles for therapeutic applications. For example, magnetic nanoparticles embedded in textiles can be used for targeted hyperthermia treatment of cancerous tumors, while photothermal nanoparticles can be employed for localized heating therapy.

Therapeutic textiles are specialized fabrics designed to provide various health benefits and promote well-being through their interaction with the body. These textiles

often incorporate functional materials or technologies that offer therapeutic properties. Here we will discuss some common types of therapeutic textiles and their applications.

Compression Garments: These garments exert pressure on specific areas of the body to improve circulation, reduce swelling, and alleviate symptoms associated with conditions like lymphedema, varicose veins, or deep vein thrombosis. Compression garments are commonly used in medical settings and sports performance.

Far-Infrared Emitting Textiles: Far-infrared (FIR) emitting textiles contain fibers or coatings that emit FIR radiation when exposed to body heat. FIR radiation is believed to improve blood circulation, enhance tissue oxygenation, and promote relaxation. These textiles are used in clothing, bedding, and accessories for therapeutic purposes such as pain relief and stress reduction.

Antimicrobial Textiles: Antimicrobial textiles are treated with substances that inhibit the growth of bacteria, fungi, or other microorganisms. They are used in healthcare settings, personal protective equipment, and everyday clothing to reduce the risk of infections and maintain hygiene.

Moisture-Wicking Fabrics: Moisture-wicking fabrics are engineered to transport moisture away from the skin to the outer surface of the fabric, where it can evaporate more easily. These textiles help regulate body temperature, keep the skin dry, and prevent discomfort and irritation caused by sweating.

Aromatherapy Textiles: Aromatherapy textiles are infused with essential oils or microencapsulated fragrance molecules that are released upon contact with the skin or through mechanical stimulation (e.g., rubbing or pressure). These textiles can provide therapeutic benefits such as stress relief, relaxation, and mood enhancement.

Biomechanical Textiles: Biomechanical textiles are designed to support specific body movements or postures to prevent injuries, alleviate pain, or promote rehabilitation. Examples include orthopedic braces, support belts, and athletic tape.

Photochromic and Thermochromic Textiles: These textiles change color in response to light (photochromic) or temperature (thermochromic), offering visual feedback on environmental conditions or body temperature changes. They can be used for monitoring purposes or as a form of therapy for conditions like Raynaud's disease.

Therapeutic textiles continue to evolve with advances in material science, textile engineering, and medical research. They offer a non-invasive, comfortable, and often cost-effective approach to improving health and well-being, both in clinical settings and everyday life.

4.8. Barrier textiles

Nanoparticles can be used to create barrier textiles with enhanced properties, such as impermeability to fluids and airborne particles. By coating or embedding nanoparticles into textile fibers, medical textiles can be engineered to provide protection against biological and chemical hazards in healthcare settings.

Barrier textiles are fabrics designed to provide a physical barrier against external agents such as liquids, chemicals, microorganisms, or particles. These textiles are engineered to prevent the penetration or transfer of substances, thereby protecting the wearer or the environment. Here are some common types of barrier textiles and their applications:

Waterproof Textiles: Waterproof fabrics are treated or coated with substances that repel water, preventing it from penetrating the material. These textiles are used in rainwear, outdoor gear, medical garments, and protective clothing to keep the wearer dry and comfortable in wet conditions.

Chemical Protective Clothing: Chemical barrier textiles are designed to resist penetration by hazardous chemicals, acids, solvents, and other corrosive substances. They are used in industrial settings, laboratories, and emergency response situations to protect workers from chemical exposure and skin contact.

Medical Barrier Textiles: Medical barrier textiles are used in healthcare settings to prevent the transmission of infectious agents such as bacteria, viruses, and bloodborne pathogens. These textiles include surgical gowns, drapes, masks, gloves, and other personal protective equipment (PPE) worn by healthcare professionals to minimize the risk of contamination and infection transmission.

Particle Barrier Textiles: Particle barrier textiles are engineered to block the penetration of airborne particles, dust, pollen, and other allergens. They are used in respiratory protection equipment, cleanroom garments, filtration systems, and environmental control applications to maintain air quality and protect individuals from respiratory hazards.

Radiation Shielding Textiles: Radiation barrier textiles are designed to attenuate or block ionizing radiation from sources such as X-rays, gamma rays, and radioactive particles. They are used in medical imaging, nuclear medicine, radiation therapy, and nuclear industry applications to protect workers and patients from radiation exposure.

Fire-Resistant Textiles: Fire barrier textiles are treated with flame-retardant chemicals or made from inherently fire-resistant fibers to prevent ignition, inhibit flame spread, and minimize heat transfer. They are used in protective clothing for firefighters, industrial workers, and military personnel, as well as in home furnishings and building materials to enhance fire safety.

Insect Repellent Textiles: Insect barrier textiles are treated with insect repellent chemicals or infused with insecticidal substances to deter mosquitoes, ticks, and other biting insects. They are used in outdoor apparel, camping gear, and mosquito nets to reduce the risk of insect-borne diseases such as malaria, Zika virus, and Lyme disease.

Barrier textiles play a critical role in protecting human health, safety, and comfort across a wide range of industries and applications. Their development and use continue to advance with innovations in material science, textile engineering, and regulatory standards for safety and performance.

5. Summary

The novel properties of NPs have been exploited in a wide range of potential applications in medicine, cosmetics, renewable energies, environmental remediation and biomedical devices. Among them silver and copper nanoparticles have attracted increasing interest due to their unique physical, chemical and biological properties compared to their macro-scaled counterparts. These metallic NPs have distinct physico-chemical properties including a high electrical and thermal conductivity, surface enhanced Raman scattering, chemical stability, catalytic activity and non-linear optical behavior. These properties make them of potential value in consumer

products like ink, microelectronics and medical imaging. A primary interest in the idea of nanoscience comes from its associations with biology. The size of the nanoparticle is comparable to the size of the biomolecules such as DNA, enzymes, antibodies, and polysaccharides. Noble metal nanoparticles like gold and silver are found to be bio-compatible. Therefore, they find various medicinal applications.

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