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"Nanofibers: A Comprehensive Exploration Of Their Benefits, Roles, Applications, Types And Methodological Approaches"

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ABSTRACT

Nanofibers provide flexible surface functionalities, porosity, and a broad region of surface changing 3D topography. It treats wound healing, pain management, infectious diseases, diseases of the gastrointestinal tract, neurological diseases, and problems of the cardiovascular system. Electrospinning, is one of the method used to create the nanofibers. Different polymers are used in the production of nanofibers, depending on their intended application.. It examines the types, histories, benefits, drawbacks, and polymers employed in nanofiber technology. Additionally, a summary of the types of polymers employed in the creation of nanofibers was provided. The review article mostly discusses the types of electrospinning as a fabrication method and the applications of nanofibers.

Keywords: Electerospinning, Nanofibers, Wound healing, polymers.

INTRODUCTION:

Nanofibers, a type of one-dimensional (1D) nanomaterial, are well-known for their numerous applications in both science and industry. Compared to other regularly used base materials, nanofibers possess superior mechanical properties and a diameter a thousand times smaller than human hair. They also have a lot of porosity, changing surface functions, and surface variable 3D topography**[1]**. Nanofibers can be produced using a variety of materials. The nanofibers are categorized based on the polymers**[2** The next goals is to improve control over the alignment of the nanofibers during deposition. It is feasible to use nanofibers in biomedical applications such as filters, in vivo models, scaffolods for tissue engineering, wound dressings, and nanomedicine.

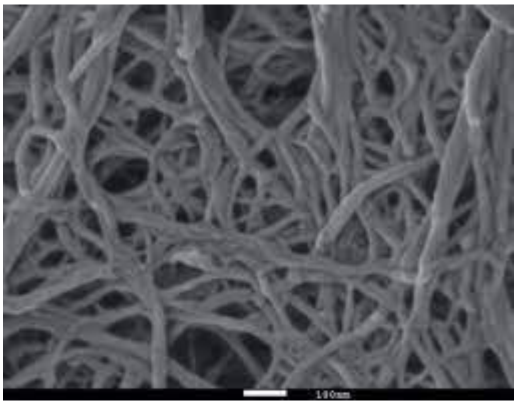


Fig 1: Nanofibers

Nanofibers lessen the toxicity and side effects, facilitate easier alternate administrations, because are used in tissue engineering. The physical properties must be taken into account in order to mimic the nanoscale properties of human tissues. There are numerous uses for nanofibers in drug delivery systems and medical equipment. They are used to prevent, diagnose, or cure disorders. Applications for nanofiber medical devices includes wound healing.

HISTORY:

The first nanofibers were made via electrospinning almost 400 years ago. William Gilbert invented the process of electrospinning approximately 1600. The ongoing electrospinning research has boosted competitiveness amongst laboratory-scale equipment. The market was reopened with a variety of spinning and collecting electrode accessories. Numerous companies have developed innovative production methods based on conventional electrospinning in an effort to overcome low productivity **[4]**.

TYPES:

Nanoscience and nanotechnology have created several different types of nanoparticles during the last 20 years, including nanofibers, nanorods, nanowires, and nanosheet nanomaterials. According to this categorization, nanomaterials of 100 nm are called nanofibers. The size, shape, and content of the nanofibers and nanofibrils are classified **[7]**.

Inorganic nanofibers:

Electrospinning has been used to manufacture a number of inorganic nanofibers, which are then calcined **[8]**. Inorganic nanofibers have been produced by photocatalysis. **[9,10]**.

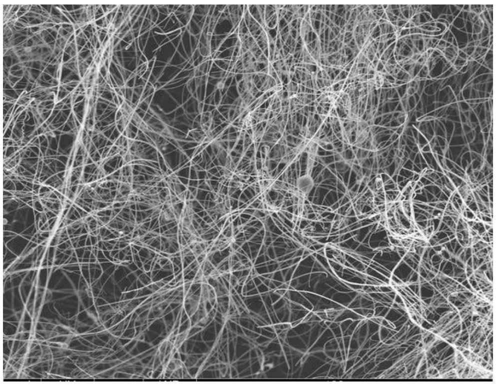


Fig 2: Inorganic nanofibers

Carbon nanofibers:

Carbon nanofibers (CNFs), a type of one-dimensional (1D) nanomaterial, are mostly carbon-based. **[11,12].** Ideal cylindrical nanofibers coated with graphene layers are called carbon nanotubes. Cone, cup, or plate-shaped graphene layers are stacked to create cylindrical carbon nanofibers that are electrospun or vapor-grown **[13].**

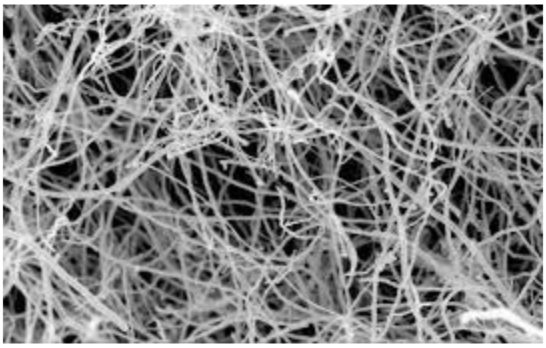


Fig3: carbon nanofibers

Polymer based nanofibers:

Numerous products and services, including clothing, fishing nets, surgical masks, heart valve replacements, air conditioner filters, cigarettes, and vascular grafts, use polymer-based fibers. The spinneret design and collecting mechanism were improved to generate nanofibers. Polymer melt electrospinning must be carried out in a vacuum **[15]**. Splintered nanofibers are only being investigated .**[16]**.

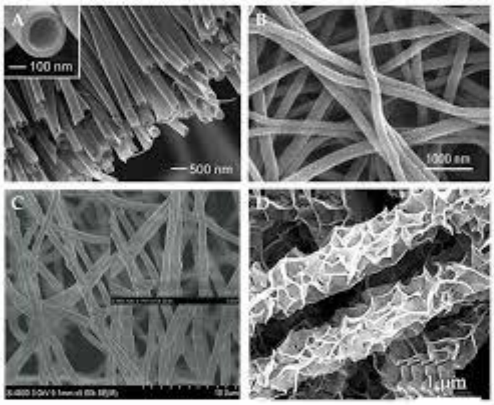


Fig 4: Polymer based nanofibers

Composite nanofibers:

Composite nanofibers are frequently made by fusing together several phases of various elements or chemical structures. This nanofibers have microscopic activity, amazing conductivity. This nanofibers has found applications in various industries due to its exceptional physical and chemical qualities. **[27].** With the help of electrospun can produce these nanofibers. Composite nanofibers are done by several techniques. **[24]**.

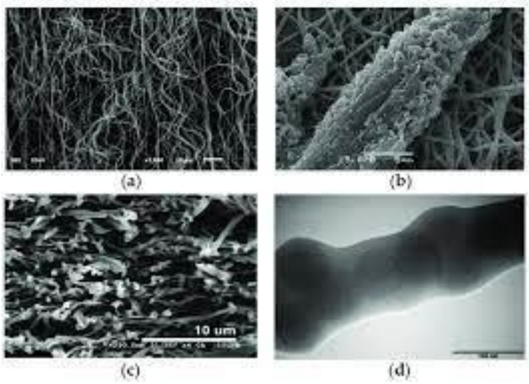


Fig 5: composite nanofibers

POLYMERS:

Natural polymers are mostly utilized in nanofiber technology; many other polymers, such as synthetic polymers , can only be synthesized. Elastomers are typically produced by polymers having high extension properties in ambient circumstances. Synthetic fibers, namely polyester and nylon, can efficiently be used. Plastic resins that are sold commercially. They improve mechanical qualities and processability **[37]**.

ROLE OF POLYMERS:

Polymers, both natural and manmade, mixes of polymers, and other composite materials can be spun into nanofibers. Choosing the right polymer is essential to creating nanofibers with characteristics unique to a given use. For biomedical applications, the ideal polymer should have mild hydrophilicity, mechanical strength, biodegradability, and safety. The polymers used to fabricate nanofibers can come from either synthetic or natural sources, and each has its own advantages and disadvantages **[17]**. In regenerative medicine, the application of scaffolds for tissue engineering, dressings for wounds, and vascular grafts are produced. **[18]**

TYPES:

Natural:

Transdermal medication delivery may be investigated with nanofibers manufactured from both natural and synthetic polymers. When it comes to nanofibers, natural polymers are chosen over synthetic polymers because of their superior qualities. The most popular method for electrospinning to make nanofibers are polysaccharides and proteins **[19]**.

It is possible to create nanofibers from electrospun polysaccharides that contain cellulose, alginate, and chitosan derivatives and use them as a delivery system. Chitosan is made up of the linear co-polymers. To encapsulate the fungus, hybrid electrospun nanofibers were created by mixing cellulose acetate and polyvinyl alcohol **[33]**.

Semi synthetic polymers:

They are processed to recover their useful forms. Semi-synthetic polymers originate from cellulose, a naturally occurring polymer. Semi-synthetic polymers are sometimes known as thermoplastic polymers **[36]**.

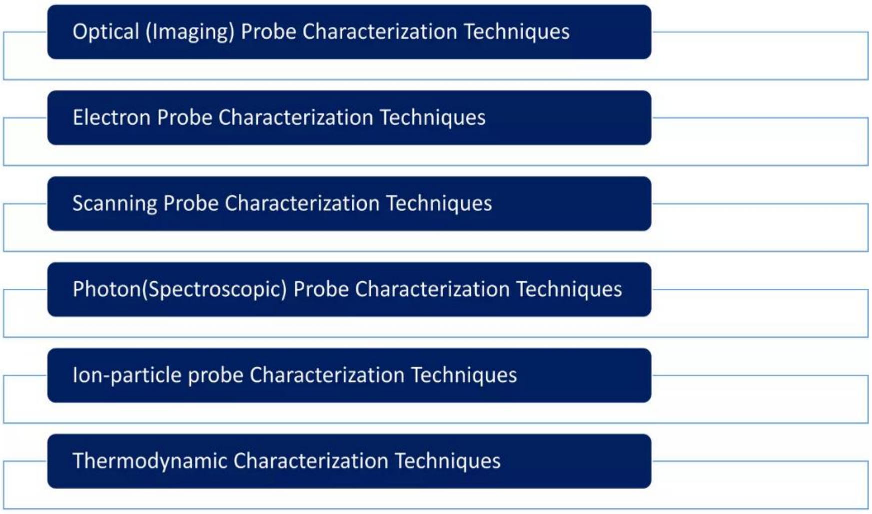
The process of preparing cellulose is called acetylation; cellulose diacetate is made with sulfuric acid and acetic anhydride. Usually, this stuff is utilized to create film spectacles that resemble threads. Examples of semi-synthetic polymers are cellulose nitrate and gun cotton, among others **[37,38]**.

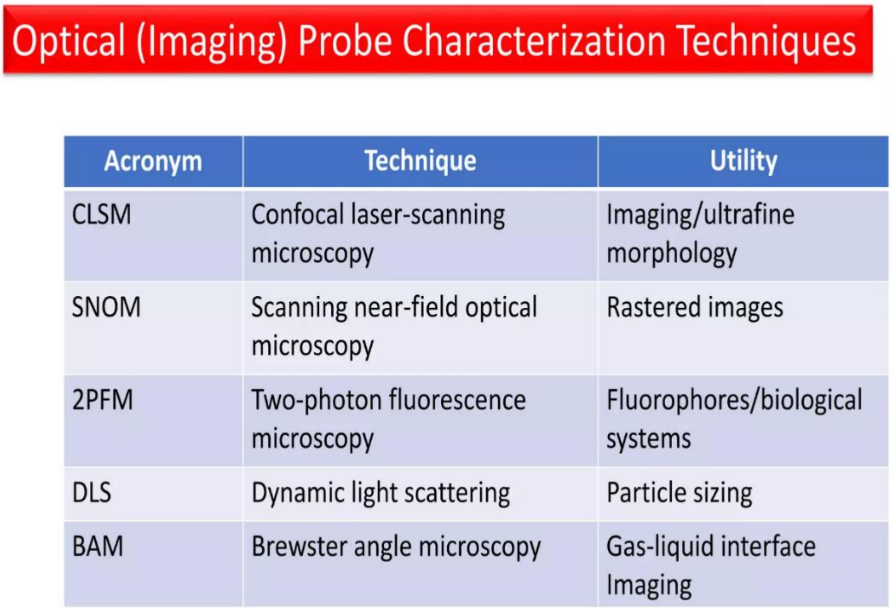
Synthetic polymers:

The majority of materials are utilized in the production of nanofibers are polylactic acid, polyvinylpyrrolidone, PCL and its co-polymers, PEO, and PVA.

Polyethylene oxide is frequently utilized by drug delivery and tissue engineering applications. Most nanofiber compositions are made up of polycaprolactone, polylactic acid, and polyvinylpyrrolidone **[43]**.

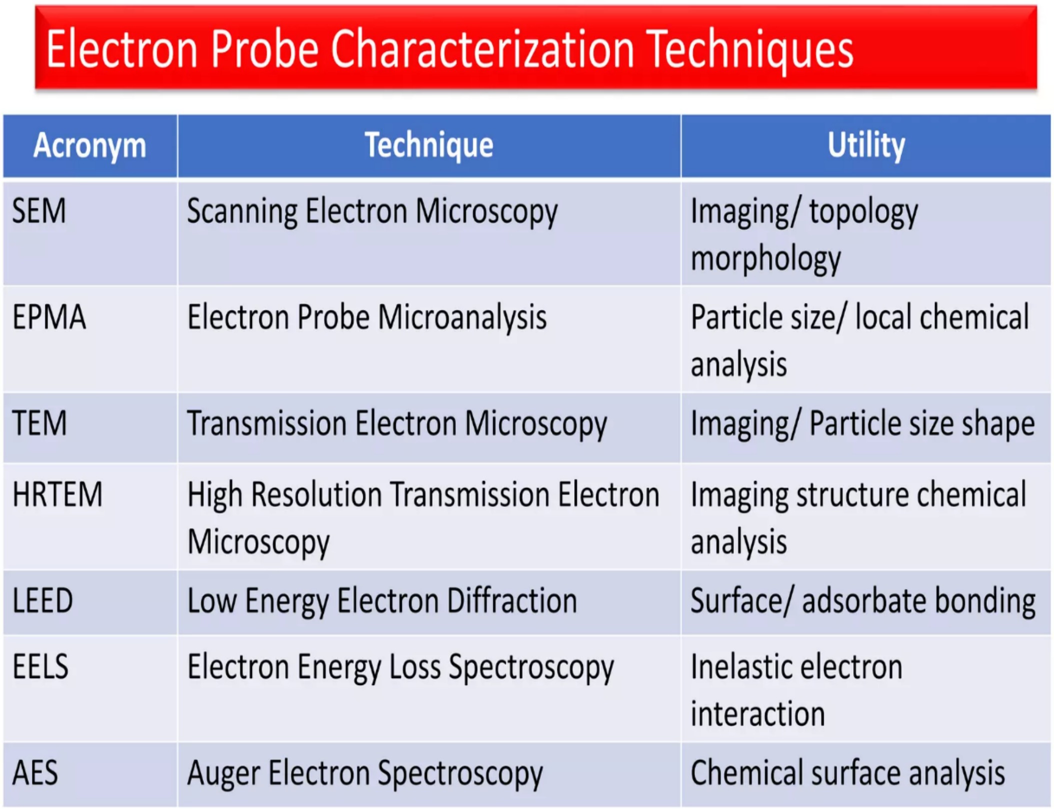
NANOFIBERS CHARACTERIZATION TECHNIQUES[44]:





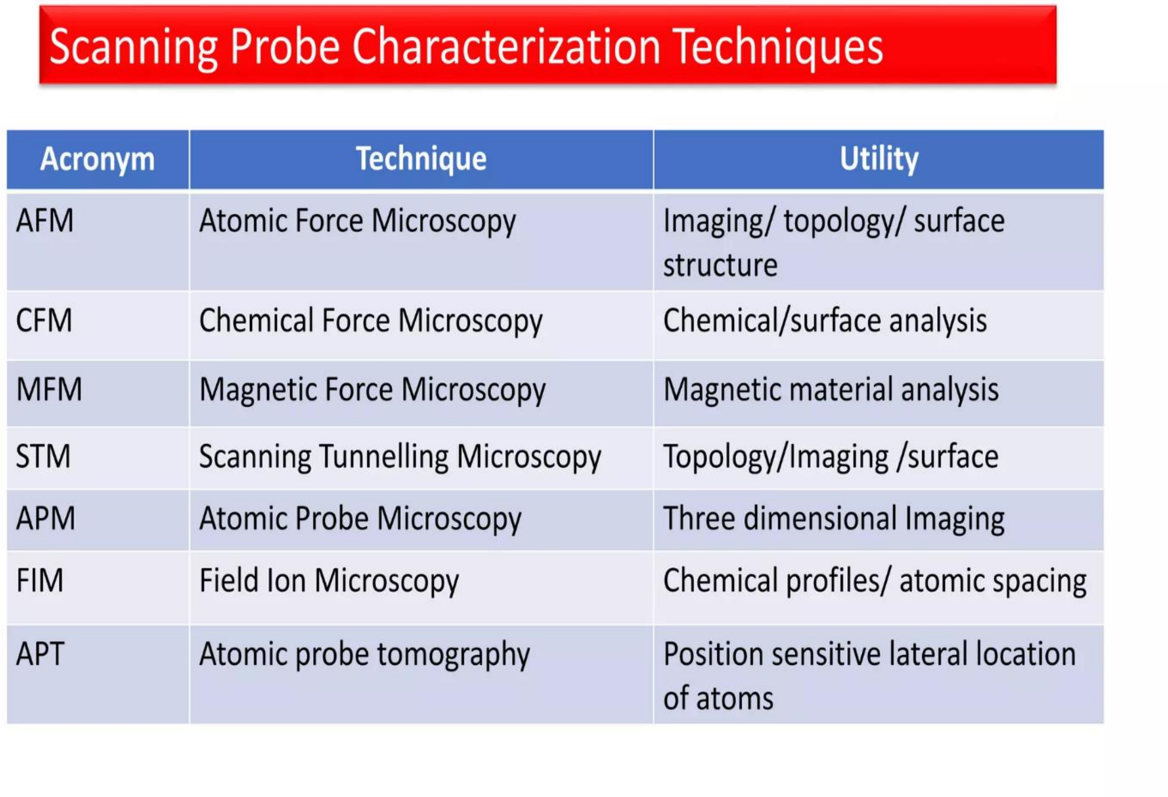
Optical (Imaging) Probe Characterization Techniques

Acronym	Technique	Utility
CLSM	Confocal laser-scanning microscopy	Imaging/ultrafine morphology
SNOM	Scanning near-field optical microscopy	Rastered images
2PFM	Two-photon fluorescence microscopy	Fluorophores/biological systems
DLS	Dynamic light scattering	Particle sizing
BAM	Brewster angle microscopy	Gas-liquid interface Imaging



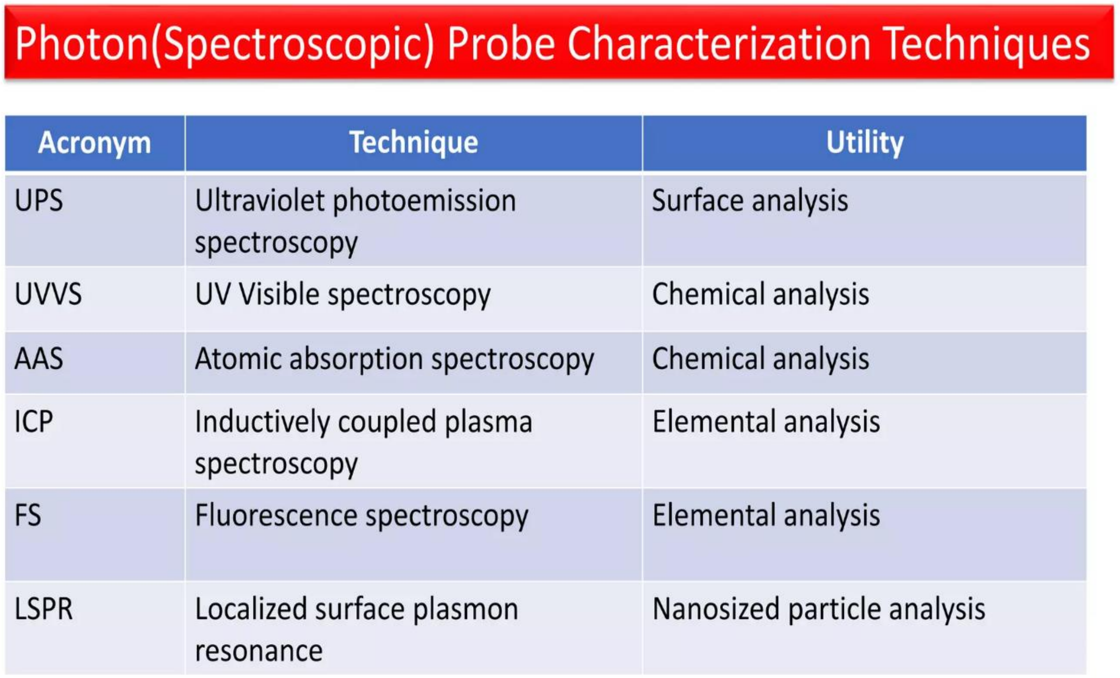
Electron Probe Characterization Techniques

Acronym	Technique	Utility
SEM	Scanning Electron Microscopy	Imaging/ topology morphology
EPMA	Electron Probe Microanalysis	Particle size/ local chemical analysis
TEM	Transmission Electron Microscopy	Imaging/ Particle size shape
HRTEM	High Resolution Transmission Electron Microscopy	Imaging structure chemical analysis
LEED	Low Energy Electron Diffraction	Surface/ adsorbate bonding
EELS	Electron Energy Loss Spectroscopy	Inelastic electron interaction
AES	Auger Electron Spectroscopy	Chemical surface analysis



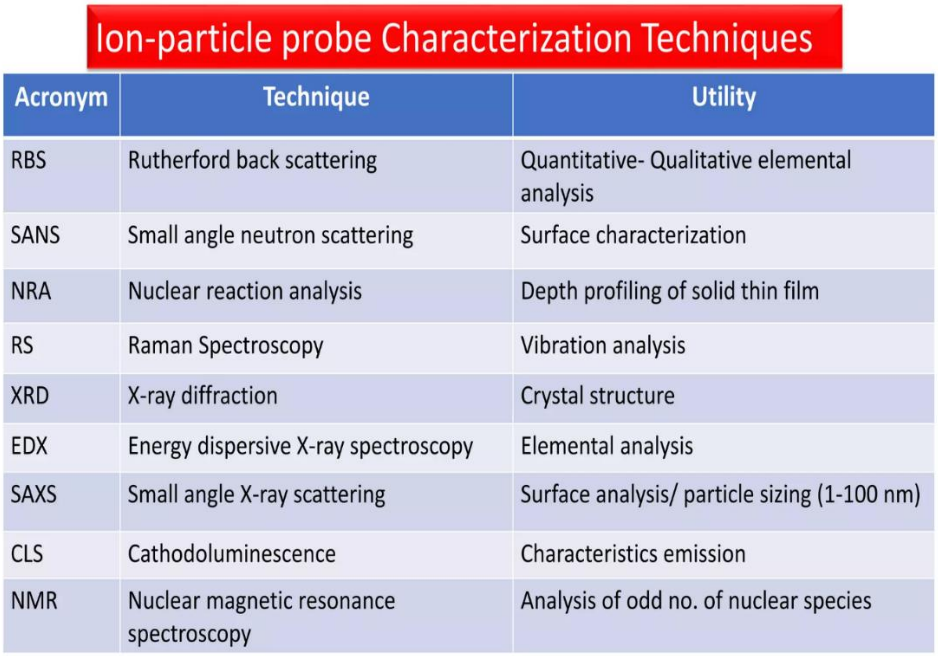
Scanning Probe Characterization Techniques

Acronym	Technique	Utility
AFM	Atomic Force Microscopy	Imaging/ topology/ surface structure
CFM	Chemical Force Microscopy	Chemical/surface analysis
MFM	Magnetic Force Microscopy	Magnetic material analysis
STM	Scanning Tunnelling Microscopy	Topology/Imaging /surface
APM	Atomic Probe Microscopy	Three dimensional Imaging
FIM	Field Ion Microscopy	Chemical profiles/ atomic spacing
APT	Atomic probe tomography	Position sensitive lateral location of atoms



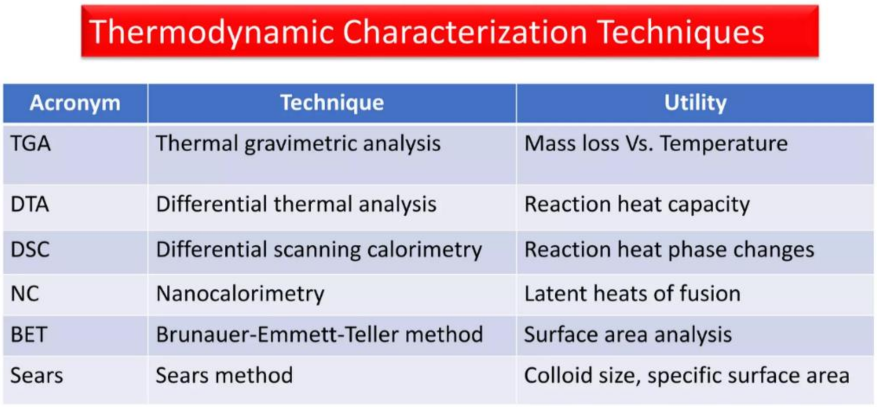
Photon(Spectroscopic) Probe Characterization Techniques

Acronym	Technique	Utility
UPS	Ultraviolet photoemission spectroscopy	Surface analysis
UVVS	UV Visible spectroscopy	Chemical analysis
AAS	Atomic absorption spectroscopy	Chemical analysis
ICP	Inductively coupled plasma spectroscopy	Elemental analysis
FS	Fluorescence spectroscopy	Elemental analysis
LSPR	Localized surface plasmon resonance	Nanosized particle analysis



Ion-particle probe Characterization Techniques

Acronym	Technique	Utility
RBS	Rutherford back scattering	Quantitative- Qualitative elemental analysis
SANS	Small angle neutron scattering	Surface characterization
NRA	Nuclear reaction analysis	Depth profiling of solid thin film
RS	Raman Spectroscopy	Vibration analysis
XRD	X-ray diffraction	Crystal structure
EDX	Energy dispersive X-ray spectroscopy	Elemental analysis
SAXS	Small angle X-ray scattering	Surface analysis/ particle sizing (1-100 nm)
CLS	Cathodoluminescence	Characteristics emission
NMR	Nuclear magnetic resonance spectroscopy	Analysis of odd no. of nuclear species



Thermodynamic Characterization Techniques

Acronym	Technique	Utility
TGA	Thermal gravimetric analysis	Mass loss Vs. Temperature
DTA	Differential thermal analysis	Reaction heat capacity
DSC	Differential scanning calorimetry	Reaction heat phase changes
NC	Nanocalorimetry	Latent heats of fusion
BET	Brunauer-Emmett-Teller method	Surface area analysis
Sears	Sears method	Colloid size, specific surface area

METHODS:

Electrospinning:

This technique is the most commonly employed to create nanofibers is electrospinning. The invention of electrospinning as a workable technique for producing nanofibers may be tracked back to a 1934 patent that was made in the process of generating artificial suits by applying a high electric field.

Fig 6: Electrospinning equipment

The study focused on the effects of electrostatic force on liquids. This evolves into an electrically charged cone when it approaches a liquid droplet in a microcapillary. The apex of the cone may emit small jets when the charge density rises significantly. The fibers were electrospun while they were placed on a receiver**[45].** The electrospinning technology is divided into two categories: melt electrospinning and solution electrospinning, depending on how the polymer is made **[46].** The study focused on the effects of electrostatic force on liquids. This evolves into an electrically charged cone when it approaches a liquid droplet in a microcapillary. The apex of the cone may emit small jets when the charge density rises significantly..

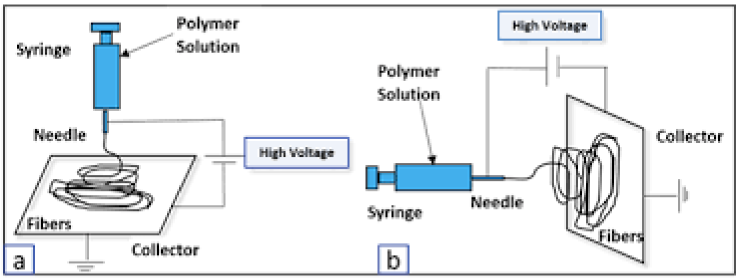


Fig 7: components of electrospinning equipment

The most popular technology is electrospinning since it is simple, scalable, affordable, and reproducible. Electrospun fibers form a vast, interconnected, porous network. Gene transfection has been effectively applied to both synthetic and natural polymers. **[47]**.
Three categories of elements may be identified that influence the properties of nanofibers: parameters related to the process, parameters related to the material, and parameters related to the environment. **[48, 49]**.

TYPES:

Co-axial electrospinning:

It is mostly used technique in the preparation of nanofibers. This creates the possible way of nanofibers . These nanofibers are three-dimensionally networked and have been successfully used to transport drugs in combination with growth hormones, proteins, antibiotics, and other biological agents **[54]**. This technique preserves the drugs' biological activity while protecting the loaded molecule's core-shell structure.During the electrospinning process, the biomolecule functions better when it is inside the jet and is protected from damage by the polymer solution outside the jet. **[55]**.

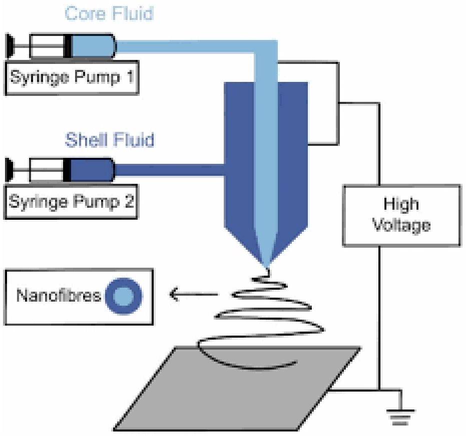


Fig 8: co-axial electrospinning

Multi jet electrospinning:

Large nanofibers were produced using multi-nozzle electrospinning systems, which increased output and coverage. Skin-core structures have purportedly been developed with the use of multi-needle electrospinning. Nanofiber filaments were made by two principles **[56].** Electrospun nanofiber jets can be generated by an electrospinning device with many nozzles or fewer. Polymers can combine nanofiber mats with appropriate dispersibility and a uniform thickness using a multi Jet electrospinning device. This technique can also be used to produce mixed nanofiber mats made of many polymers **[57]**.

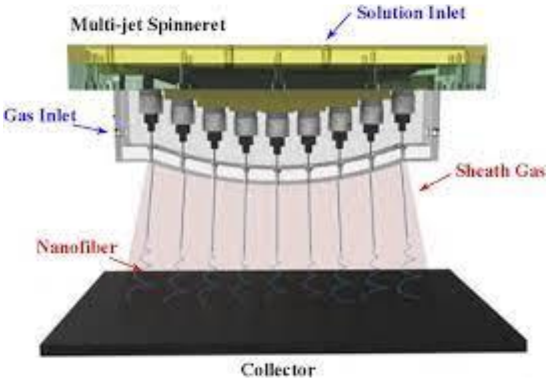


Fig 9: multijet electrospinning

Emulsion electrospinning:

A rapid, affordable, and promising technique for creating electrospun core-shell nanofibers is emulsion electrospinning. This method is adaptable and promising for the nanofiber encapsulation of many medications. Emulsion electrospinning was found to be a best technique, in terms of changing the rate at which medications are released. **[58].**

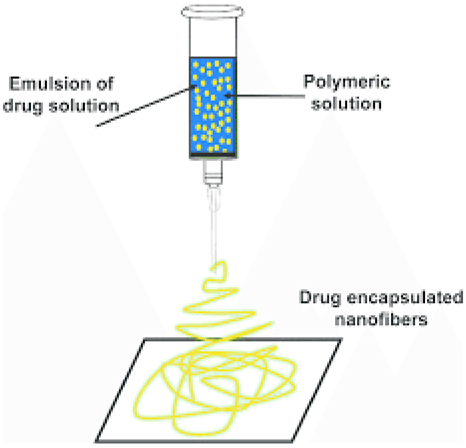


Fig 10: Emulsion electrospinning

Bubble electrospinning:

The family of extremely complex electrospinning techniques has recently expanded to include the ground-breaking method known as bubble electrospinning. Surface tension in the resulting bubbles is broken by electrospinning using electrical forces.The size and shape can affect surface tension. This method has several challenges. A bubble starts to appear on the fluid's surface. But this phenomenon is not very sensitive .The method of aqueous solvent bubble electrospinning is employed to create 100 nm-diameter nanofibers **[60].**

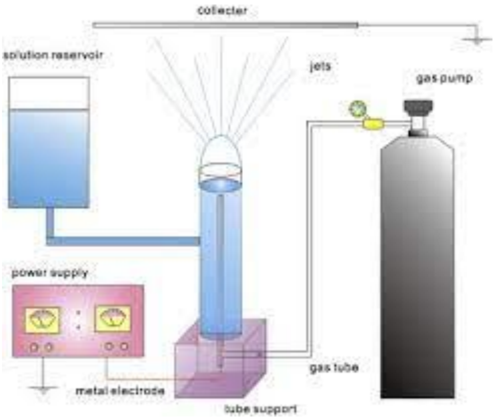


Fig 11: bubble electrospinning

APPLICATIONS:

Nanofibers have a lot to offer when it comes to the administration of pharmaceuticals with a wide range of biomedical applications. Recent advancements in nanotechnology may simplify the process of creating nanofibers with various forms and release properties. The most promising biological applications include tissue engineering, cardiovascular issues, viral disorders. **[67]**.

Cardiovascular diseases:

A range of synthetic and natural biomaterials have been electrospun to create nanofiber scaffolds containing stem cells. **[67]**. To improve their effectiveness as stem cell transporters, nanofibers have undergone a number of alterations, It has also been shown that stem cell-containing nanofibers can treat cardiovascular conditions like atherosclerosis and cardiomyocyte regeneration **[68]**.

Bone regeneration:

The adaptability of the electrospinning approach helps the scientists are also investigating alternative methods for creating scaffolds for bone healing and repair **[70,71]**. To promote osteogenesis and result in bone regeneration, the ideal material needs to be both bioactive and biocompatible. In order to expedite bone regeneration, a number of medical researchers have employed electrospun scaffolds to fabricate bone grafts. These scaffolds include bioactive compounds that promote osteoblast proliferation and mineralization. For bone tissue engineering, a scaffold that is biocompatible, biodegradable, and has the right mechanical properties for the environment of the bone should be utilized.

Wound healing:

A wound is the outcome of external laceration-induced skin trauma. Acute wounds heal faster than chronic wounds. The four phases of wound healing include proliferation, remodeling, inflammation, and hemostasis. It have recently piqued the tissue engineering because of their biocompatibility, flexibility, and efficient drug release, which enable the regeneration of injured tissue **[71]**. The prior approach to wound care was therapeutic. More effective medication release than with traditional therapy is made possible by combining drugs with polymers and spinning them into nanofibers **[72]**. Some even cause healing processes like vasodilation. Because collagen electrospun nanofiber scaffolds promote cell growth and penetration into the created matrix, they are the most biomimetic alternative to skin. In contrast to electrospun scaffolds made of single polymers. **[71]**.

contraceptives:

They are now a practical choice for localized and systemic medication deliveryThe majority of drugs intended for vaginal use have been used to address conditions that directly affect the sexual and reproductive health of women. The most common uses of hormonal contraception are for the management of bacterial vaginosis, luteal phase defect, cervical softening to promote labor, and vaginal infections **[72]**.

RECENT ADVANCEMENTS IN NANOFIBER TECHNOLOGY:

Growth factor delivery:

Because of the versatility of the electrospinning process, protein growth factors can be incorporated into polymer nanofibers, potentially leading to the production of a continuous and regulated release of the growth factor. By using two concentric needles instead of one, coaxial electrospinning has allowed proteins to be incorporated into the centers of these nanofibers **[77]**. This method provides protection against the organic solvent that dissolves the outer polymer layer. Growth factors have been attempted to be incorporated into nanofibers previously, despite the fact that coaxial electrospinning studies have primarily concentrated on proteins. **[78]**.

CONCLUSION AND FUTURE PERSPECTIVES:

A few of the advanced properties that nanofibers displayed were the ambient characteristics are in addition to the nanofiber's shape-changing capability. Numerous healthcare-related applications, including as biosensors, tissue regeneration, wound healing, and medication delivery, can make use of it **[75].** Similar challenges have been faced by applications utilizing energy devices based on electrospun nanofibers. These include higher energy densities, stability, repeatability, enhanced durability, longer shelf life, ineffective inhibition, and insufficient redox stimulation that is both effective and prolonged **[74].**

In addition to this, each field has flaws specific to its application. Despite their special qualities, nanofibers are not biodegradableand , are persistently incompatible with the extracellular matrix of bone. Applications of electrospun nanofiber-based energy devices have run into similar issues. Higher energy densities, stability, repeatability are a few of these requirements **[74].**

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