ELECTROSTATIC SPINNING OF NANOFIBERS

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Applications:

- Composites
- Filtration
- Separation membranes
- Biomedicine
  - artificial organs
  - tissue engineering
  - blood vessels
  - drug delivery systems
  - wound dressing
  - breathing masks

Applications:

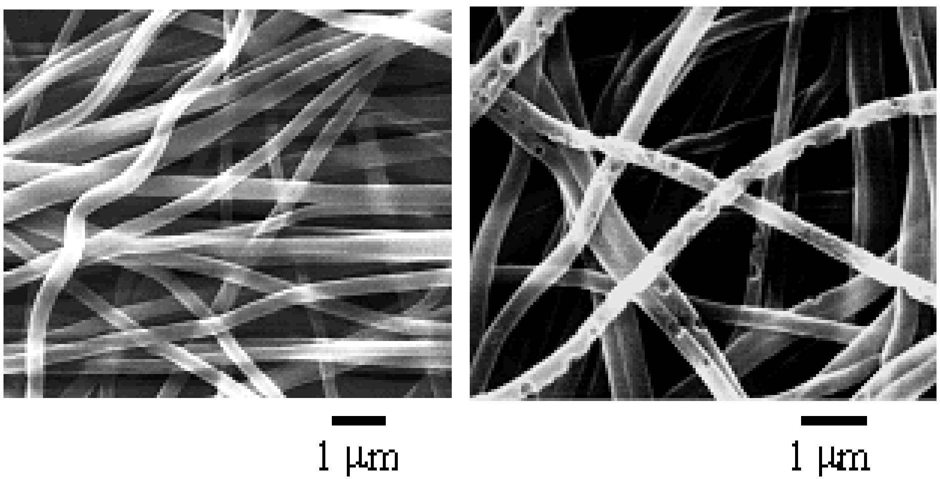
- Protective clothing
- Solar sails, light sails, and mirrors for use in space
- Application of pesticides to plants
- Nanoconductors, nanoelectric applications as field effect transistors

  and ultra-small antennas
- Chemical catalytic apparatus
- Hydrogen storage tank for fuel cell

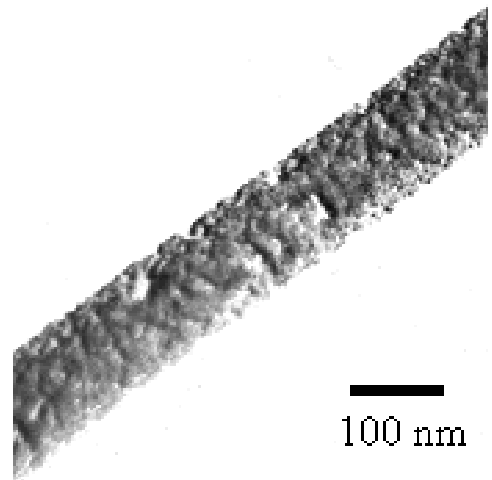
Composite applications

Composites may be reinforced by fibers. With these reinforcements, the composite materials can provide superior structural properties such as high modulus and strength to weight ratios, which generally cannot be achieved by other engineered monolithic materials alone. Nanofibers can have even better mechanical properties than micro fibers of the same materials, and hence the superior structural properties of nanocomposites can be anticipated.

Composite applications



SEM images of PAN-based carbon nanofibers before (left) and after (right) steam treatment.



TEM image of a single carbon nanofiber made from PVA.

Carbon nanofibers may be created of polymer precursors, such as PAN or PVA.

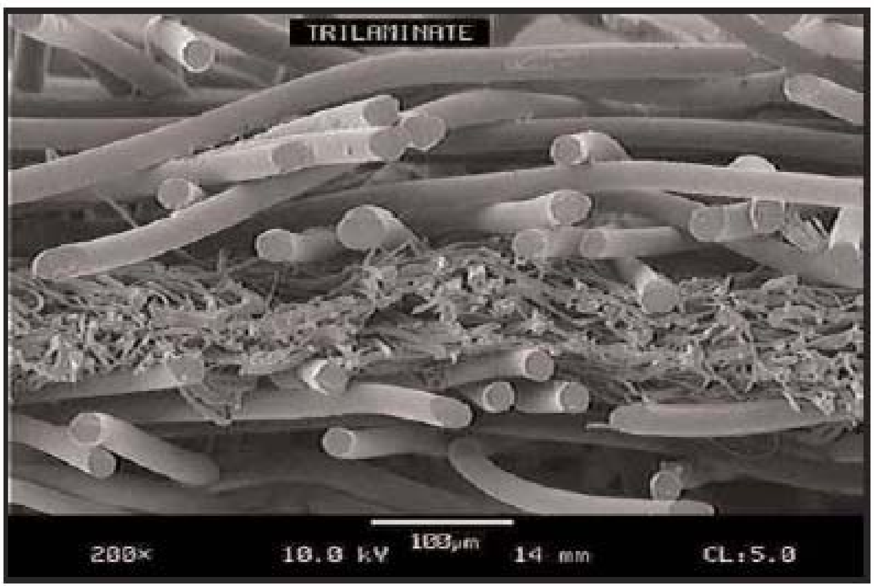
Composite applications

The advantage of nanofibrous composites is that they are transparent.

If there is a difference in refractive indices between fiber and matrix, the resulting composite becomes opaque or nontransparent due to light scattering. This limitation, however, can be circumvented when the fiber diameters become significantly smaller than the wavelength of visible light

Filtration applications

Filtration is essential for many industries. Fiber materials used for filtration media offer an advantage of high filtration efficiency and low air resistance. Currently, nonwovens created by Meltblown and Spunbond or their combinations are used for filters.



Spunbond – meltblown – spunbond composite nonwoven

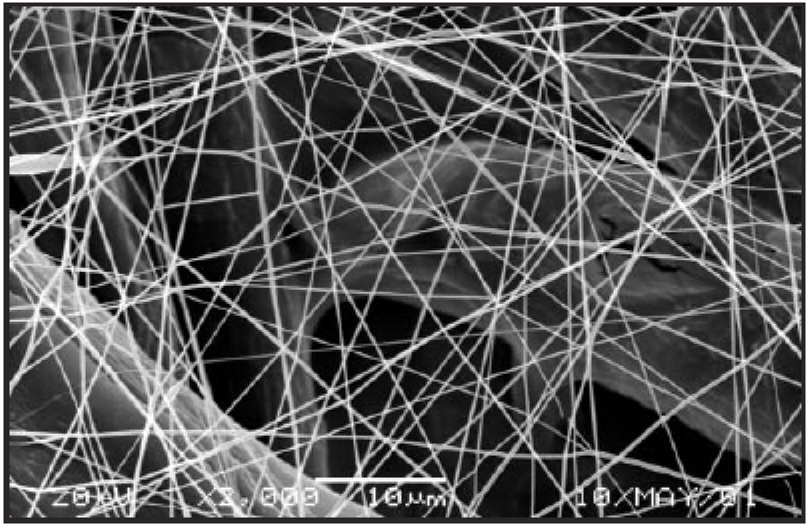
Filtration applications

Filtration efficiency is closely related to the fiber diameter. Electrospinning technology is able to produce fibers with diameter in submicron range and created materials can filter off dangerous bacterias and viruses but also the tobacco smoke and their size is noted in table below.

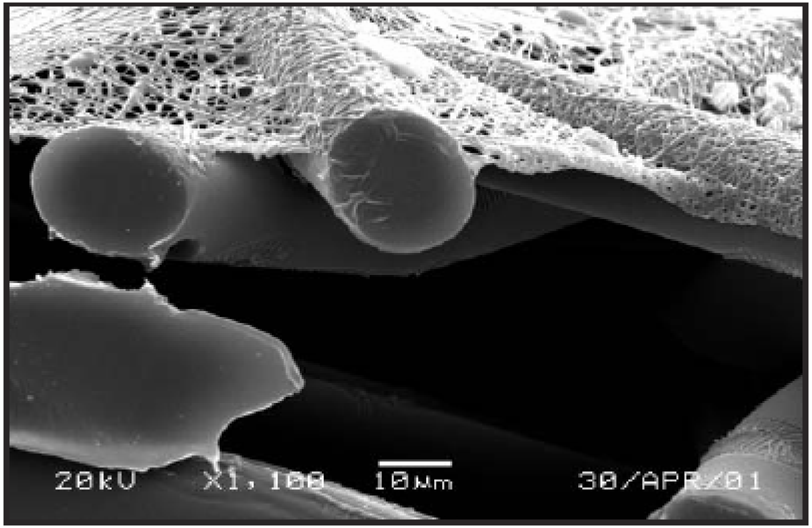
EXAMPLES OF BIOLOGICAL STRUCTURES	DIMENSION IN NANOMETERS (nm)
Leukocytes	10,000 nm
Bacteria	1,000 - 10,000 nm
Virus	75 - 100 nm
Protein	5-50 nm
DNA (width)	2 nm
Atom	0.1 nm

Examples of biological structures and their size

Filtration applications

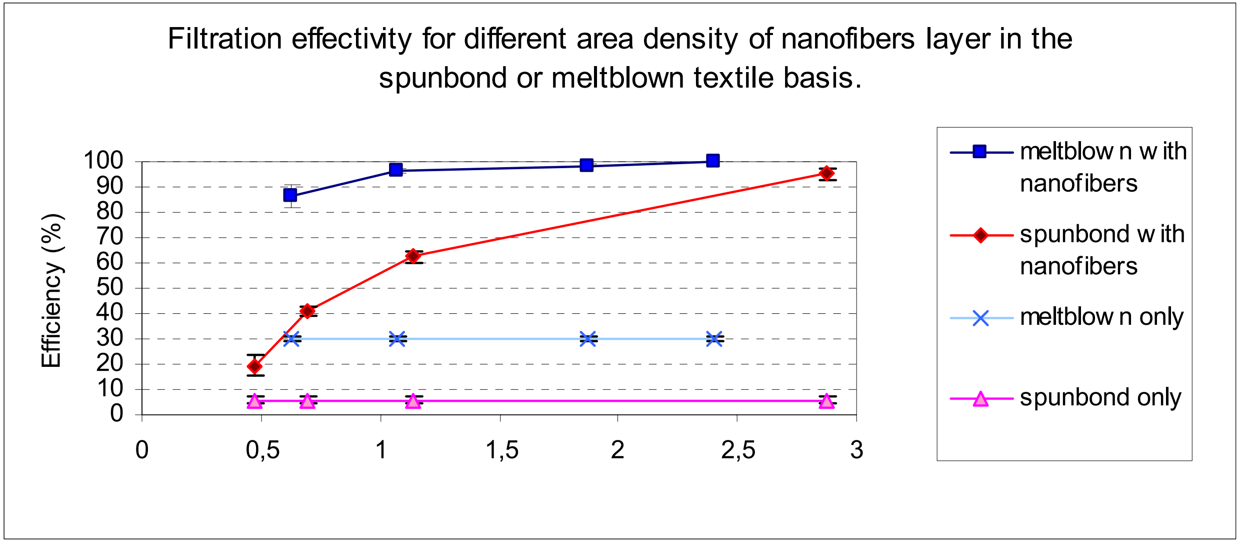


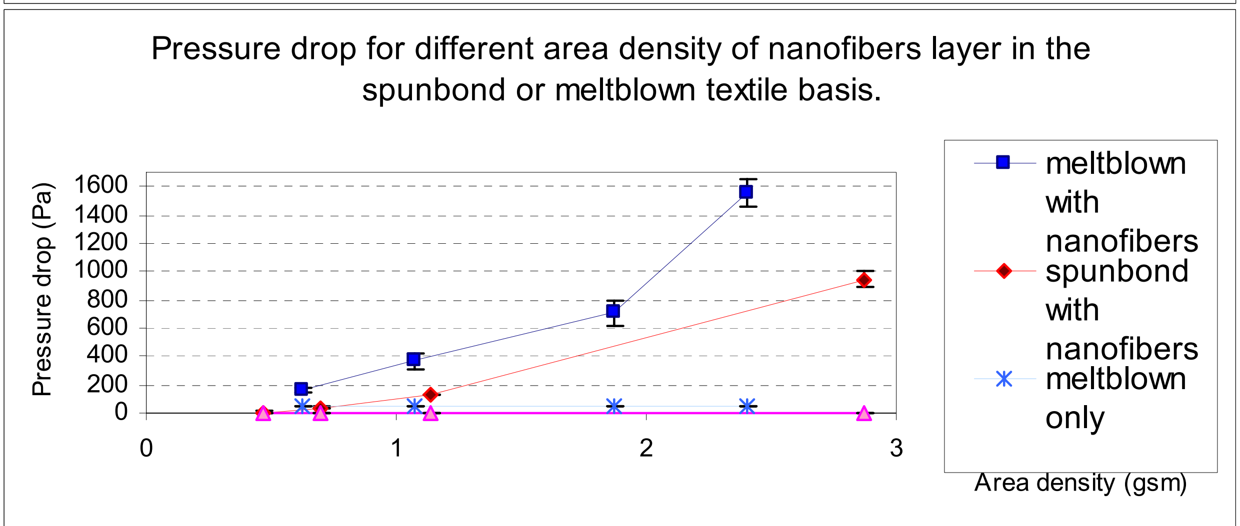
Nanofibers on a wetlaid cellulose substrate for air filtration



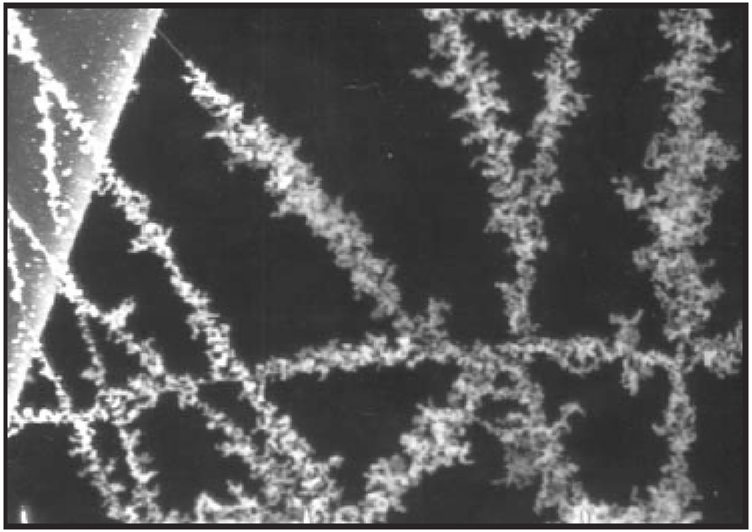
Cross section view of nanofiber web on spunbond substrate

Filtration applications





Filtration applications



Picture shows a composite media sample that has been exposed to a submicron sodium chloride contaminant, with particles in the size range of 0.01 to 0.5 microns. By replacing the salt crystals with functional materials, such as pharmaceuticals for drug delivery applications, or antimicrobial chemistry for wipes and clothing applications, new uses for nanofiber webs as a high surface area functional chemistry delivery structures can be imagined

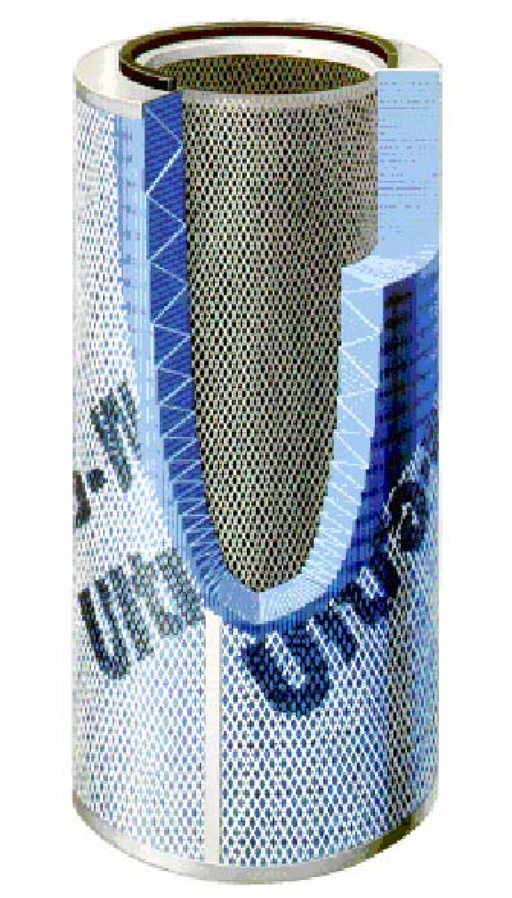
Filtration applications

Filtration properties of nanofibers may be also evaluated visually by the help of scanning electron microscopy of nanofiber media exposed to contamination

Cellulose filter media with ISO Fine Test dust loading (left).
Nanofiber filter media with ISO Fine Test Dust loading (right)

Filtration applications

Donaldson Company Inc. developed filters containing nanofiber layers for air filtration



Commercial air filtration cartridge using nanofiber filter media

Filtration applications

Polymer nanofibers can also be electrostatically charged to modify the ability of electrostatic attraction of particles without increase in pressure drop to further improve filtration efficiency. In this regard, the electrospinning process has been shown to integrate the spinning and charging of polymer into nanofibers in one step. In addition to fulfilling the more traditional purpose in filtration, the nanofiber membranes fabricated from some specific polymers or coated with some selective agents can also be used as, for example, molecular filters. For instance, such filters can be applied to the detection and filtration of chemical and biological weapon agents.

Biomedical applications

To this area belongs the tissue engineering, templates for cell growth and medical prostheses especially vascular grafts. From a biological viewpoint, almost all of the human tissues and organs are deposited in nanofibrous forms or structures. Examples include: bone, dentin, collagen, cartilage, and skin. All of them are characterized by well organized hierarchical fibrous structures realigning in nanometer scale.

Biomedical applications - prostheses

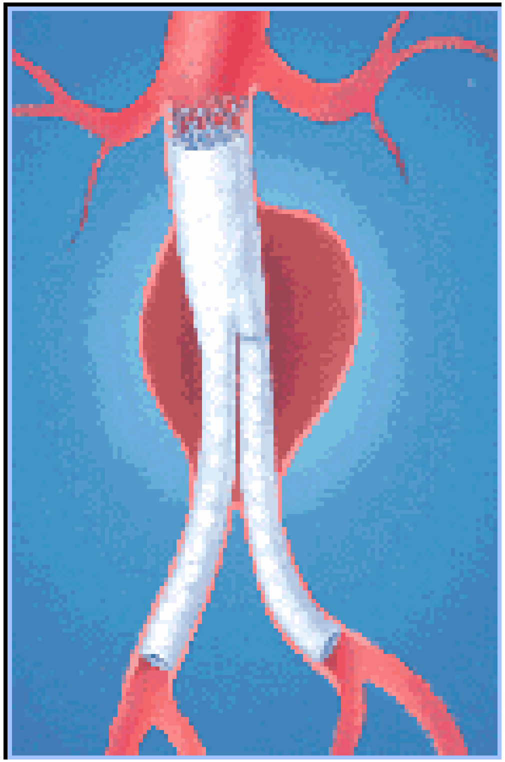
Polymer nanofibers fabricated via electrospinning have been proposed for a number of soft tissue prostheses applications such as blood vessel, vascular, breast, etc. In addition, electrospun biocompatible polymer nanofibers can also be deposited as a thin porous film onto a hard tissue prosthetic device designed to be implanted into the human body. This coating film with gradient fibrous structure works as an interphase between the prosthetic device and the host tissues, and is expected to efficiently reduce the stiffness mismatch at the tissue/device interphase and hence prevent the device failure after the implantation.

Biomedical applications – prostheses – bones

Bone is a composite made when proteins in collagen fibers coax calcium, phosphate, and hydroxide ions in solution to condense atop the fibers and grow into a rigid structure of tiny crystallites of hydroxyapatite all aligned in the same direction. Hydroxyapatite gives bone its toughness. Although research teams have induced hydroxyapatite crystallites to grow atop other materials such as polymers and they can assume the same structure as in the real bone.

Biomedical applications – prostheses – blood vessels

Traditional heart bypass surgeries require using veins from the leg to replace damaged blood vessels. Using a nanotechnology it would be possible to use artificial blood vessels grown in a laboratory. After the scaffold is spun, smooth muscle cells are “seeded” or placed on its surface in a laboratory. The cells grow and within three-to-six weeks the tissue-engineered blood vessel is ready to implant.



Artificial blood vessel

Biomedical applications – tissue template

Human cells can attach and organize well around fibers with diameters smaller than those of the cells. In this regard, nanoscale fibrous scaffolds can provide an optimal template for cells to seed, migrate, and grow. A successful regeneration of biological tissues and organs calls for the development of fibrous structures with fiber architectures beneficial for cell deposition and cell proliferation. Of particular interest in tissue engineering is the creation of reproducible and biocompatible three-dimensional scaffolds for cell ingrowth resulting in bio-matrix composites for various tissue repair and replacement procedures.

Biomedical applications – antiadhesive membranes

There was created a nanofiber membrane that serves for prevention of sticking of a tissue during the healing process. It degrades in the body such as biodegradable sutures in the course of time. This anti-adhesive material is prepared by electrospinning. The experimental team in its previous work found that surgical adhesion of the scar tissue formed in the abdominal cavity or pelvis in the healing process after surgery was significant medical problem causing for example infertility or viscera impaction.

Biomedical applications – drug delivery systems

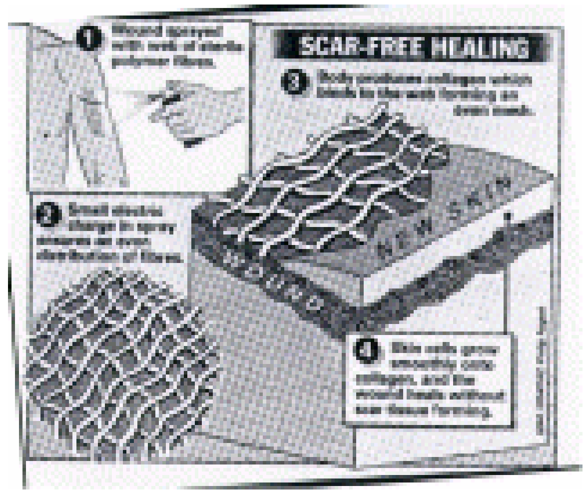
The smaller the dimensions of the drug and the coating material required to encapsulate the drug, the better the drug to be absorbed by human being. Drug delivery with polymer nanofibers is based on the principle that dissolution rate of a particulate drug increases with increasing surface area of both the drug and the corresponding carrier if needed.

(1) drug as particles attached to the surface of the carrier which is in the form of nanofibers,
(2) both drug and carrier are nanofiber-form, hence the end product will be the two kinds of nanofibers interlaced together,
(3) the blend of drug and carrier materials integrated into one kind of fibers containing both components, and
(4) the carrier material is electrospun into a tubular form in which the drug particles are encapsulated.

Biomedical applications – wound dressing

Polymer nanofibers can also be used for the treatment of wounds or burns of a human skin, as well as designed for haemostatic devices with some unique characteristics. With the aid of electric field, fine fibers of biodegradable polymers can be directly sprayed/spun onto the injured location of skin to form a fibrous mat dressing which can let wounds heal by encouraging the formation of normal skin growth and eliminate the formation of scar tissue which would occur in a traditional treatment. Non-woven nanofibrous membrane mats for wound dressing usually have pore sizes ranging from 500 nm to 1μm, small enough to protect the wound from bacterial penetration via aerosol particle capturing mechanisms. High surface area of 5–100 m2/g is extremely efficient for fluid absorption and dermal delivery.

Biomedical applications – wound dressing



Formation of wound dressing on the skin

Biomedical applications – respirators

In age of SARS, one of the most important things the world needs is better respirators.

Biomedical applications – respirators

Typical respirators are uncomfortable when worn for long periods. But nanofiber material for a mask that would be comprised of just less than 2 percent material, more than 98 percent air making for a more comfortable and efficient fit.

Current respirators are composed of 90% of glass microfibers with average diameter around 500 nanometers, but nanofibrous respirators are made of polymer nanofibers with diameter in range of 20 to 30 nanometers. Small size of fiber material is important because the size of bacterias is in order of micrometers. Viruses are even smaller, most of them are in nanometer range.

Biomedical applications – protective clothing

The protective clothing in military is mostly expected to help maximize the survivability, sustainability and combat effectiveness of the individual soldier system against extreme weather conditions, ballistics and NBC (nuclear, biological, and chemical) warfare. In peace ages, breathing apparatus and protective clothing with the particular function of against chemical warfare agents such as sarin, soman, tabun and mustard gas from inhalation and absorption through the skin become special concern for combatants in conflicts and civilian populations in terrorist attacks.

Biomedical applications – protective clothing

Electrospinning results in nanofibers laid down in a layer that has high porosity but very small pore size, providing good resistance to the penetration of chemical harm agents in aerosol form. Preliminary investigations have indicated that compared to conventional textiles the electrospun nanofibers present both minimal impedance to moisture vapor diffusion and extremely efficiency in trapping aerosol particles as well as show strong promises as ideal protective clothing.

Biomedical applications – cosmetics

The current skin care masks applied as topical creams, lotions or ointments may include dusts or liquid sprays which may be more likely than fibrous materials to migrate into sensitive areas of the body such as the nose and eyes where the skin mask is being applied to the face. Electrospun polymer nanofibers have been attempted as a cosmetic skin care mask for the treatment of skin healing, skin cleansing, or other therapeutical or medical properties.

Electrical a optical applications

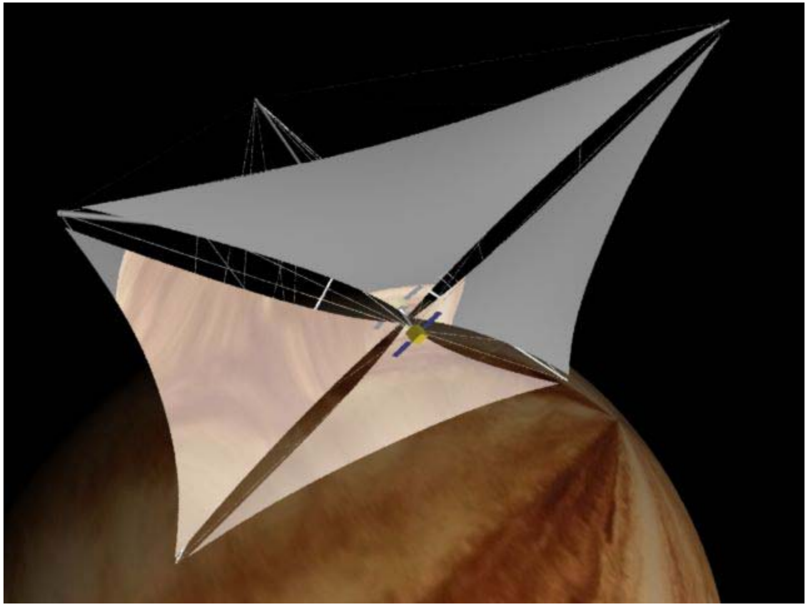
Conductive nanofibers are expected to be used in the fabrication of tiny electronic devices or machines such as Schottky junctions, sensors and actuators. The rate of electrochemical reactions is proportional to the surface area of the electrode, conductive nanofibrous membranes are also quite suitable for using as porous electrode in developing high performance battery. Conductive (in terms of electrical, ionic and photoelectric) membranes also have potential for applications including electrostatic dissipation, corrosion protection, electromagnetic interference shielding, photovoltaic device and for LCD devices where the fiber size is used for determining sensitivities of the refractive index differences between the liquid crystal material and the fibers and consequently governs the transmisivity of the device.

Solar sails

A solar sail is a spacecraft with a large, lightweight mirror attached to it that moves by being pushed by light reflecting off of the mirror instead of rockets. Nanofiber layers have a very low area weight and that is the reason why they are interesting in that area of research.

Solar sails work off of the principal that light has momentum. When light strikes an object (incident light), it transfers its momentum to that object. When light is reflected, there is a second momentum exchange with the object. The total force on the object is the vector sum of the forces from the incident and reflected light.

Solar sails



Solar sail

Other applications

- Nanofibers from polymers with piezoelectric effect such as polyvinyliden fluoride will make the resultant nanofibrous devices piezoelectric.

- Electrospun polymer nanofibers could also be used in developing functional sensors with the high surface area of nanofibers facilitating the sensitivity.

- Highly sensitive optical sensors based on fluorescent electrospun polymer nanofiber films were also recently reported .

Other applications

- Nanoscale tubes made from various materials including carbon, ceramics, metals, and polymers are important in many industry fields. Ultrafine fibers prepared from electrospinning can be used as templates to develop the various nanotubes.

- Another possible applications include device for electro-magnetic shielding, material preventing composite delamination, device with liquid crystals, carriers of chemical catalyzer and application of pesticides to plants.