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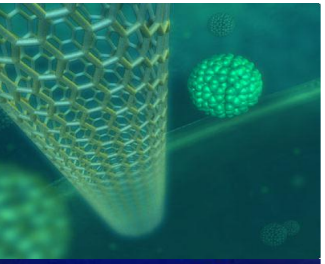
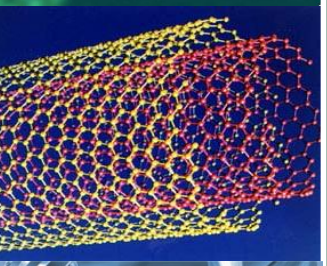

Nanofibers- preparation and potential applications

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Mehran University of Engineering and Technology, Jamshoro

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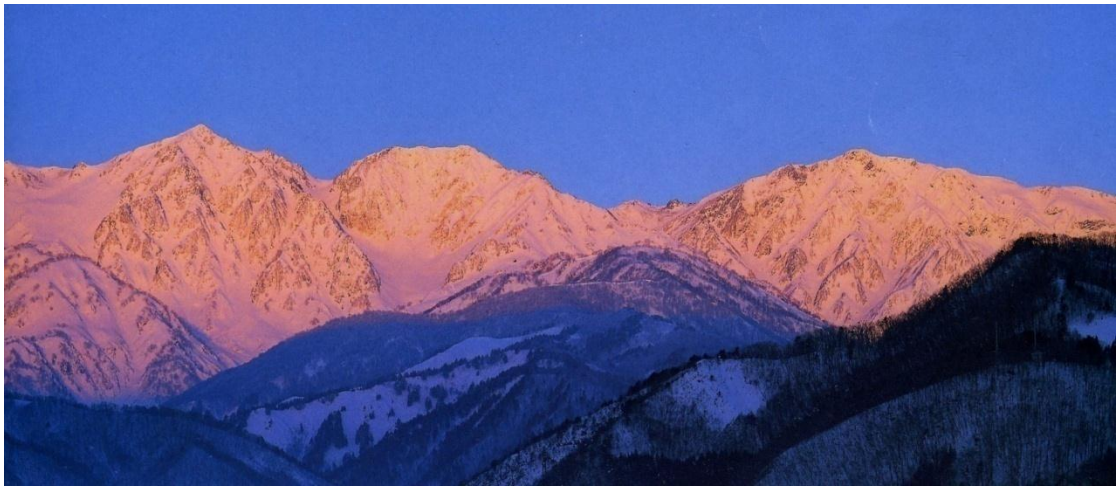
Shinshu University is located in Nagano Prefecture



The Japan Alps

NAGANO 1998

Winter Olympic Game in 1998

Old castle

Hot spring

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Contents

◎ Introduction: Why Nanofiber?

◎ Potential Applications
& Recent Research Achievements

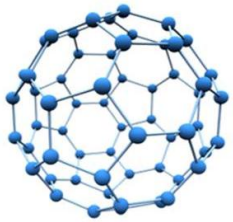
◎ Nano-Fiber Production System

What is Nano?

1 nm is to a tennis ball
what a tennis ball is to the Earth

10^7 m

Tennis ball



1 nm = 10^{-9}

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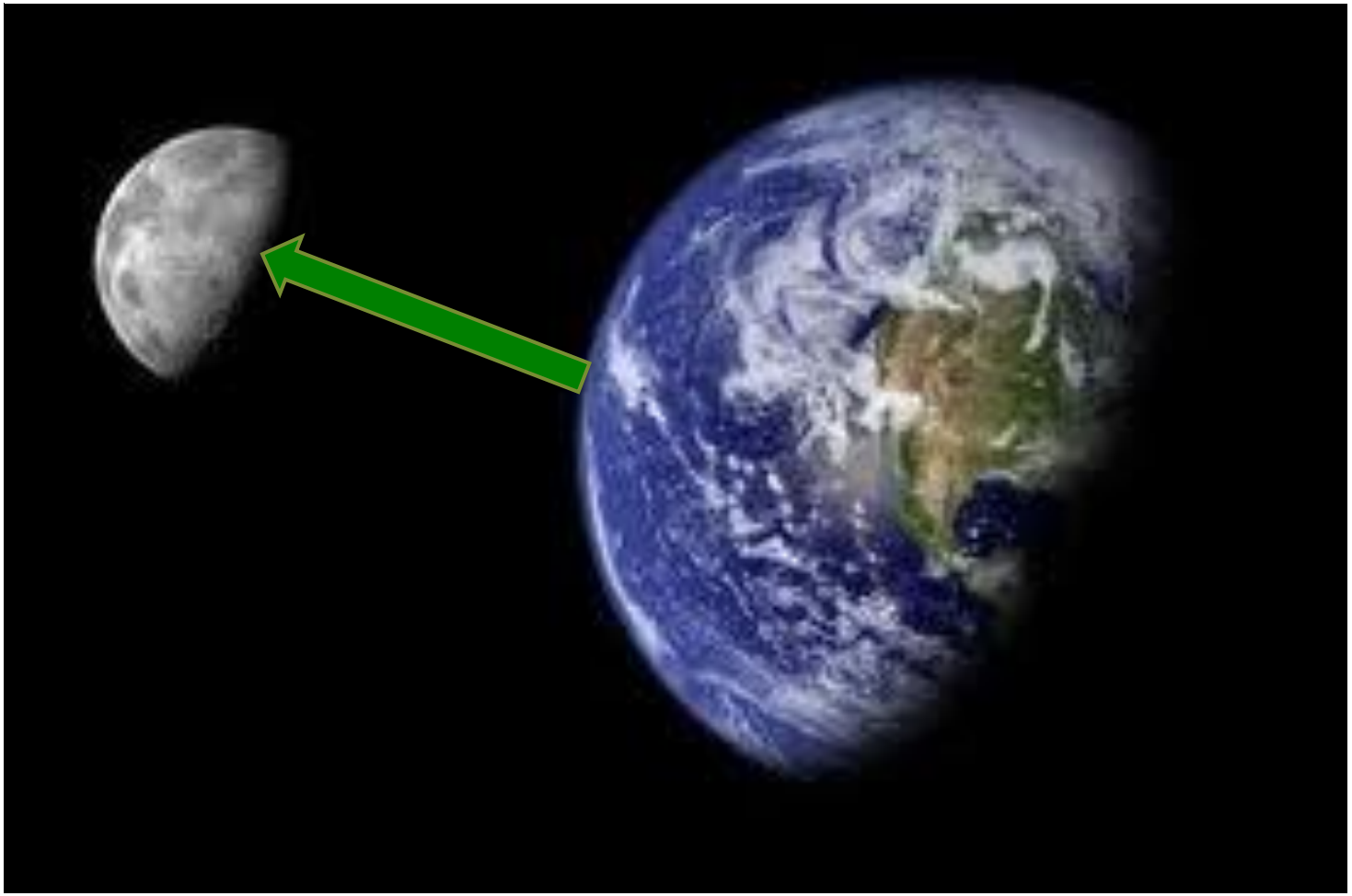
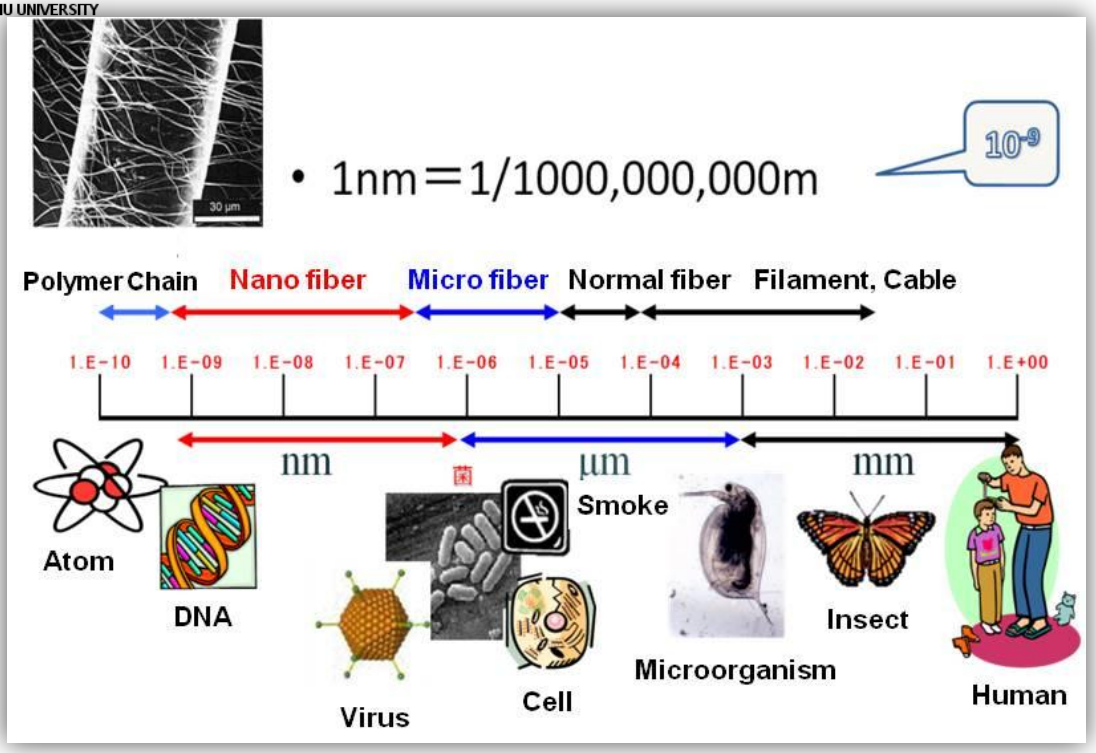
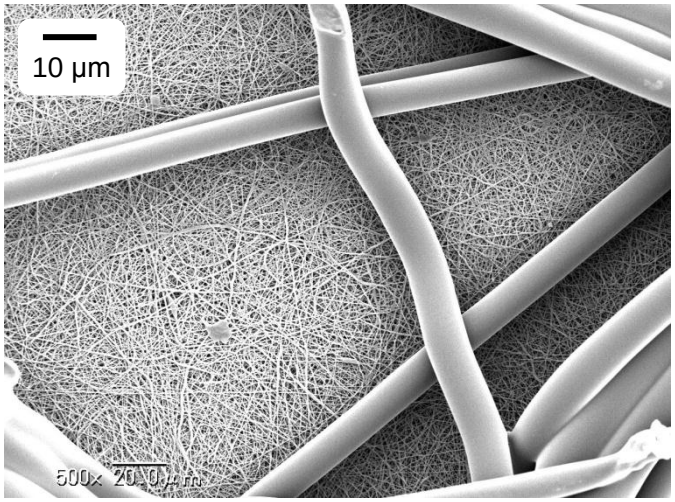
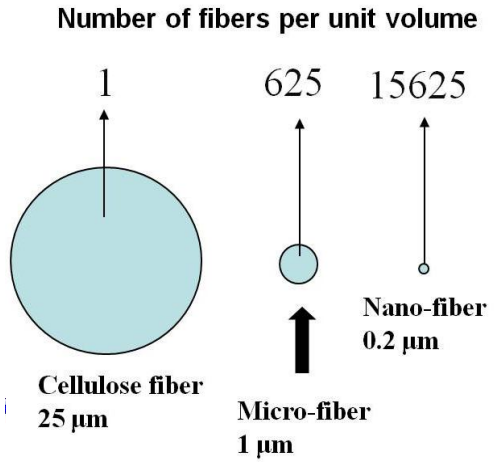
The weight needed to stretch to the Moon from the Earth
Microfiber: 450g Nanofiber: 0.15g







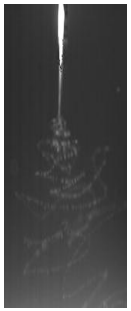
Small but Great Effect !

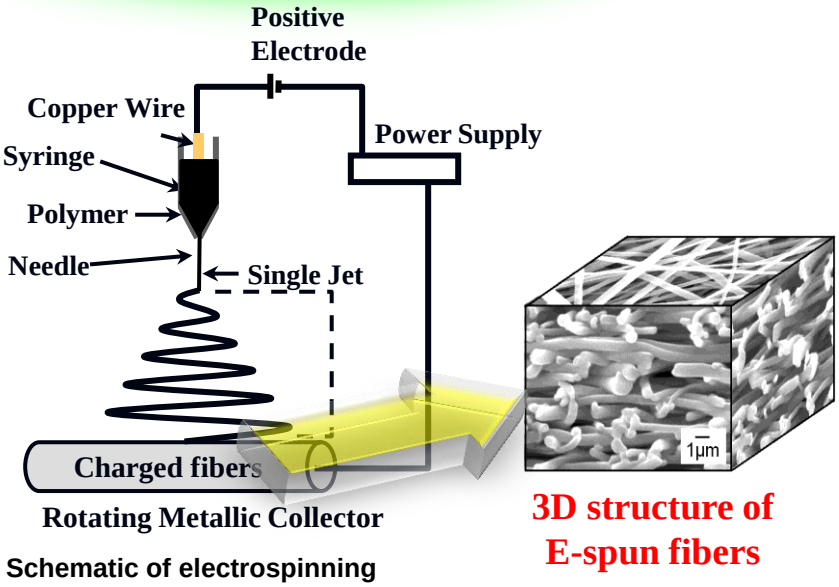


from Phillip Gibson and Heidi Schreuder-Gibson, U.S. Army Soldier Systems Center, Natick

Electrospun Nanofibers: Electrostatic Spinning

Nanofiber ▪▪▪

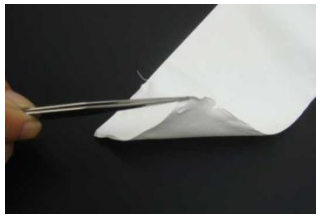


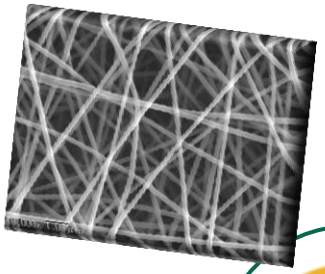


Schematic of electrospinning

3D structure of E-spun fibers

One of top-down manufacturing processes to produce polymer fibers





Electrospinning

History

1902	Initiative
1934	Patenting **(By Formhals)**
Early 1990s	Activation **(By Reneker)**

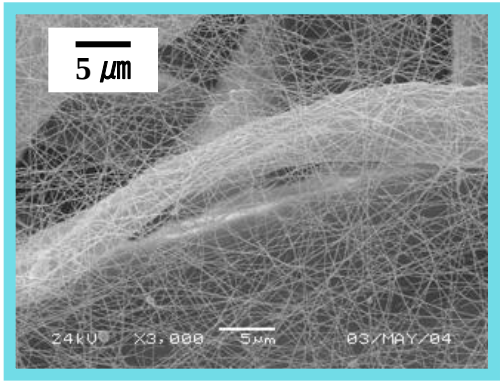
Characteristics of electrospinning;
- Various polymers are available
- Low cost for production
- Controlled diameter of the fibers from nano- to micrometers
- Easy processing
- Direction preparation of fabric sheets

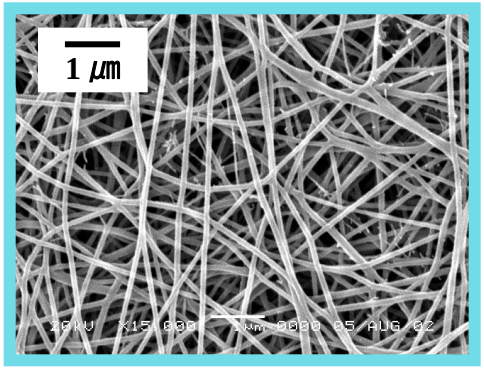
System parameters
- Mw &MWD, architecture(branched, linear etc.) of the polymer
- Solution properties (viscosity, conductivity, and surface tension)

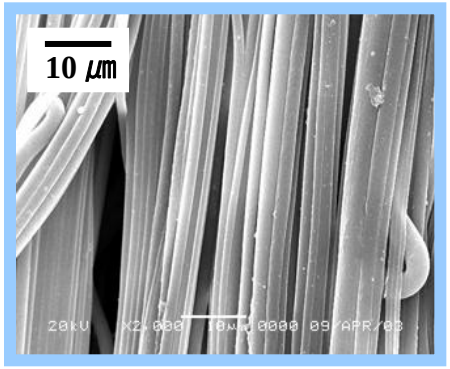
Processing parameters
- Applied voltage, flow rate, concentration, distance between the capillary tip and collector, ambient parameters (temperature, humidity, air velocity in the chamber)
- Motion of collector

Organic Polymers for Electrospinning

Coating	Nonwoven	Filaments
Nylon6, Nylon66, PVC, PU, PVC/PU, PVA, PVAc, PAN, PEI, PC, PSF, etc.	Nylon6, Nylon66, PU, PVA, PVAc, PAN, PEI, etc. -Biodegradable polymers :PCL, PLA, PLGA, etc.	PU, PU/PVC, PCL Nylon6, Nylon66, PSF, etc.

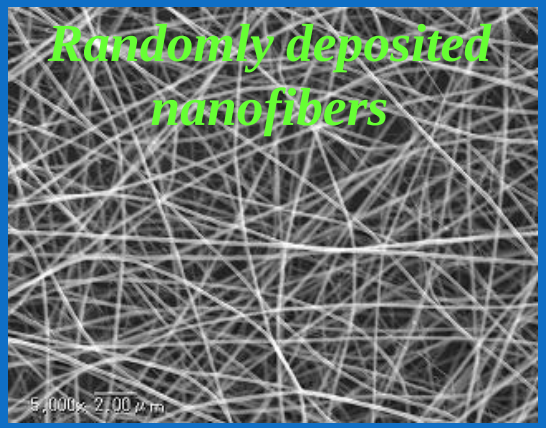


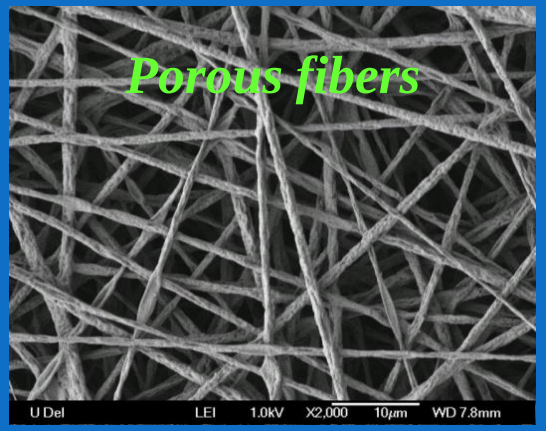


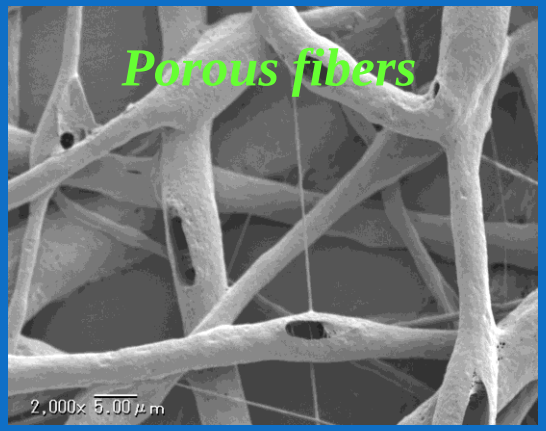


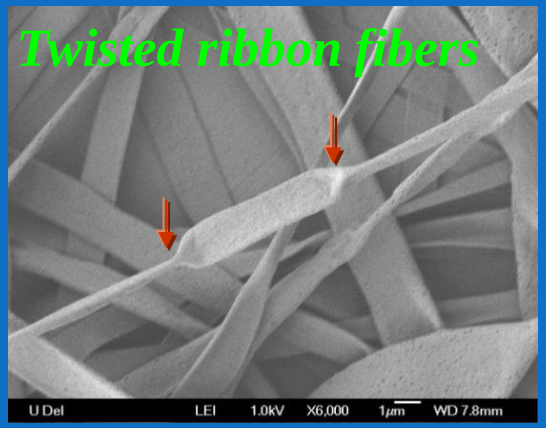
Key Technologies

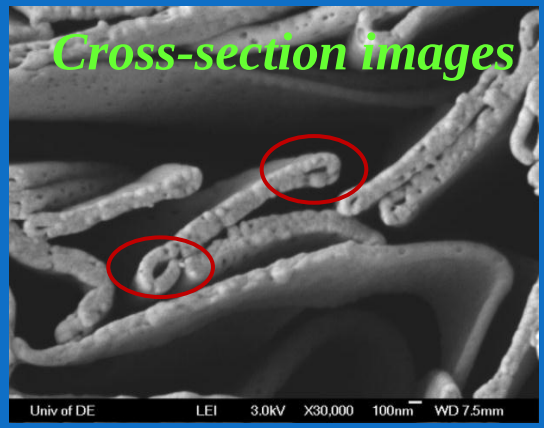
Various Nanostructured Electrospun Nanofibers





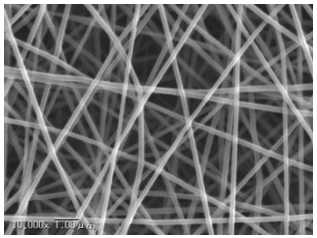




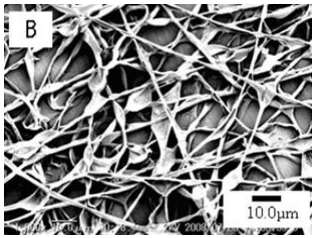


Various Electrospun Nanofibers

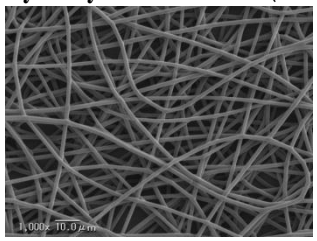
PVA



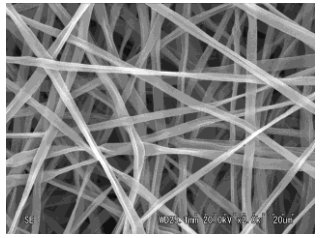
Poly(1-butene)



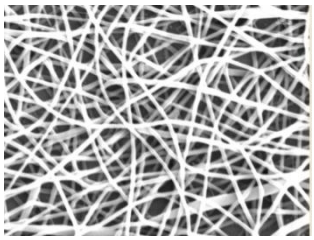
Polyvinyl acetate (PVAc)



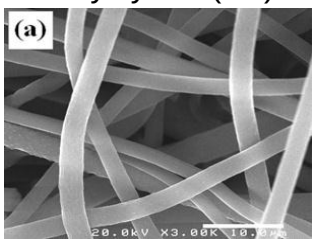
Poly-L-lactic acid (PLLA)



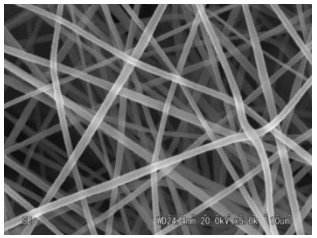
PP



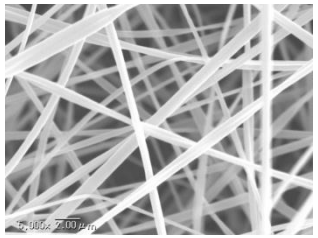
Polystyrene(PS)



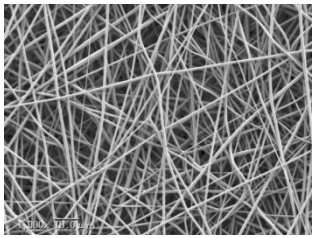
Poly(vinylidene fluoride)(PVDF)



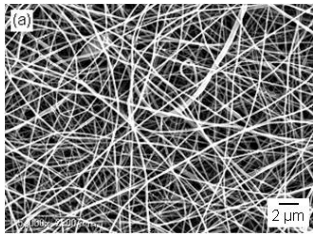
Cellulose acetate



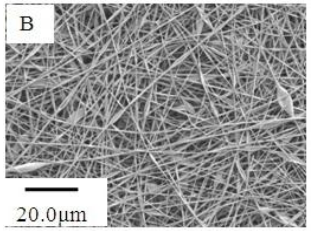
PVP



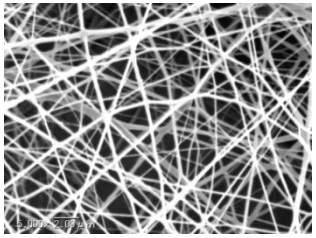
Nylon-6



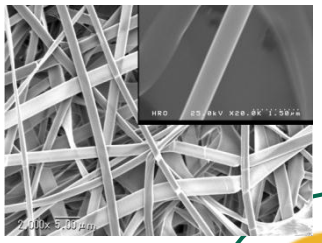
Poly(4-methyl-1-pentene)(PMP)



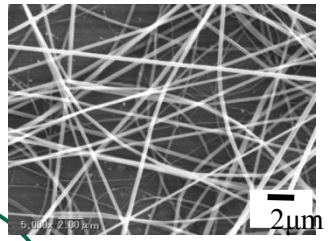
PU



Silk

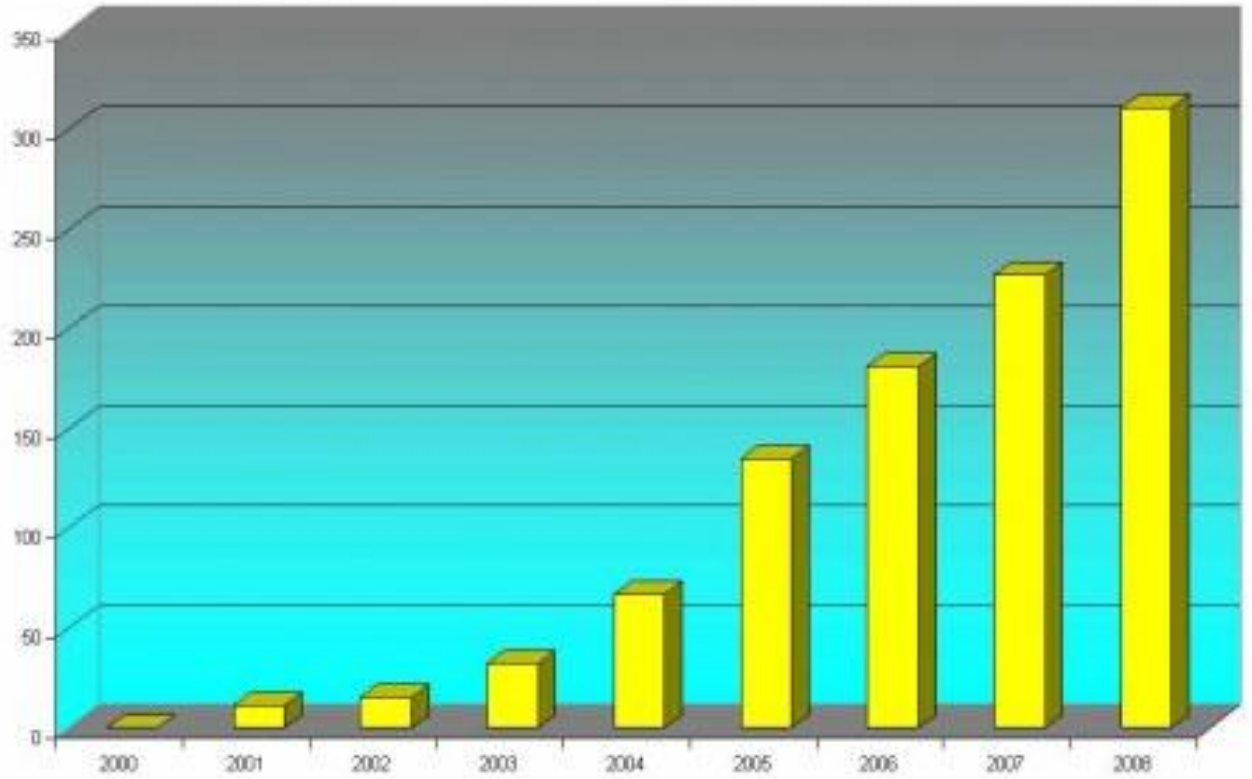


Poly(ether ketone)



Nylon66, PVC, PAN, PES, PCL, PLA etc.

Nanofibers: volumetry in biomedical publications since 2000



This chart was built by searching PubMed for publications mentionning *nanofiber* or *nanofibers* in their title or abstract.

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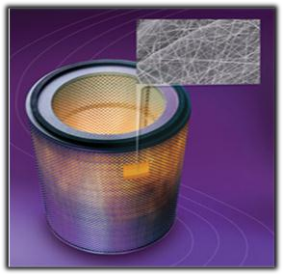
Potential Applications
&
Recent Research Achievements

Various Applications



Air filter

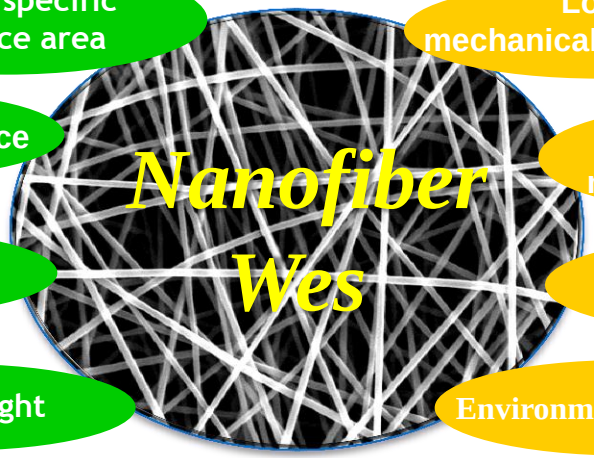
Liquid filter

Advantages

- Large specific surface area
- Low air resistance
- Small pore size
- Lightweight

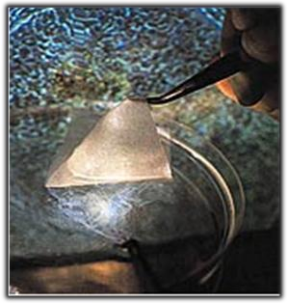
Disadvantages

- Low mechanical properties
- Difficulty of mass production
- Risks on human health
- Environmental pollution

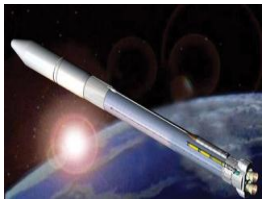


Battery separator

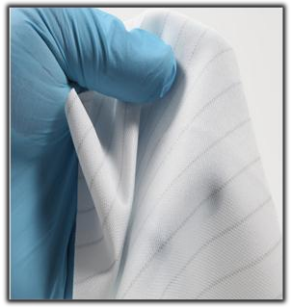
Outdoor wear



Medical uses



Carbon Fiber



Clean-room wiper

Recent Research Achievements

Advanced Electrospinning

Spinning Techniques
- Solution electrospinning
- Melt-blown electrospinning
- Hand spinning
- Ultrasonic Electrospinning

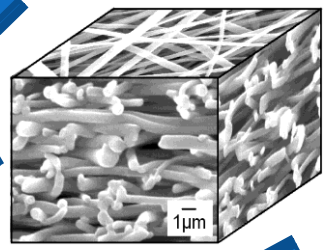
Nanofiber Assembly

Nanofiber filaments
- High strength nanofiber filaments
- Shape memory nanofiber filaments

Nanofiber tubes

Nanofiber capsules

Nanofibers



Energy

Electrics/Electronics
- **Metal nanofibers**
  - Catalysts
  - EMI shielding materials
- Filters
- Separators
- Electrodes

Healthcare

Biomedical
- **Nanofibrous scaffolds**
- Wound dressing
- **Drug delivery carriers**
- Hydrogel nanofibers

Nano-Characterization

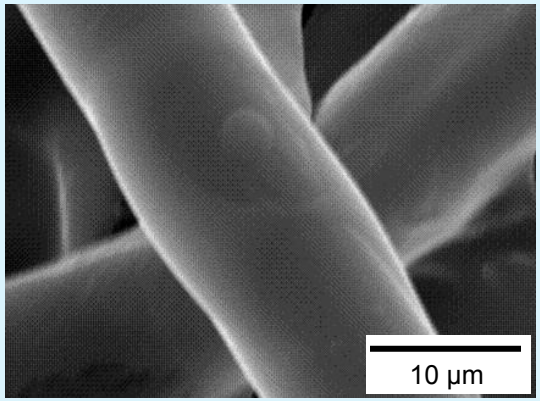
Tensile test of single nanofibers

Friction test

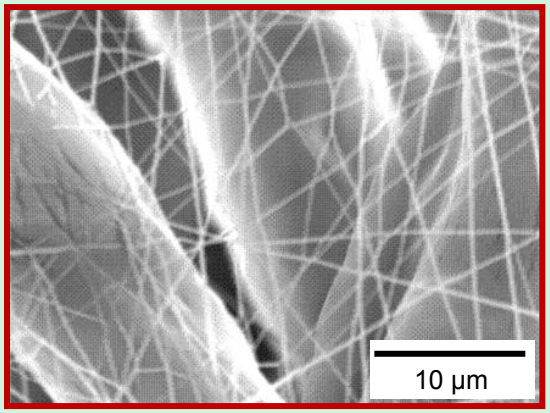
Mass Production System

Nanofiber Mass Production System

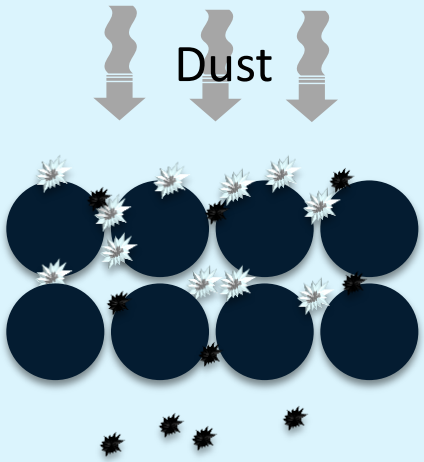
Marketed Filter



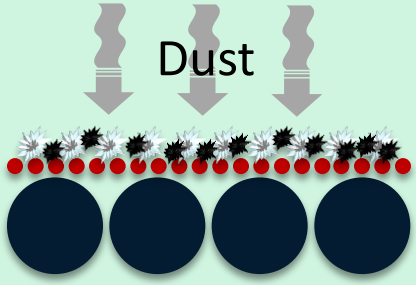
With Nanofiber



Depth Filtration

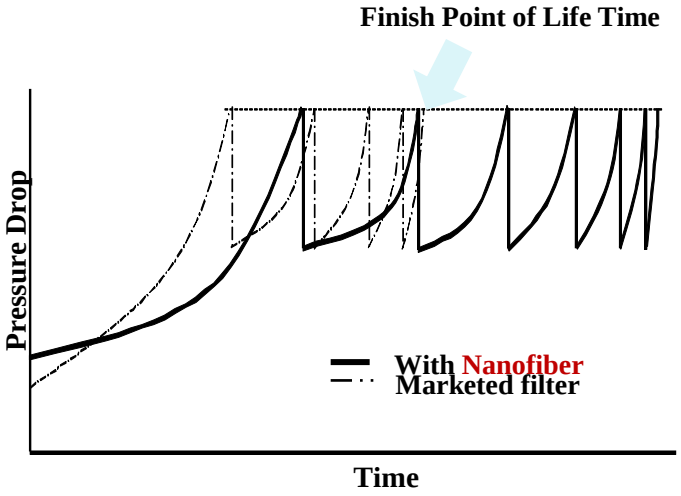


Surface Filtration

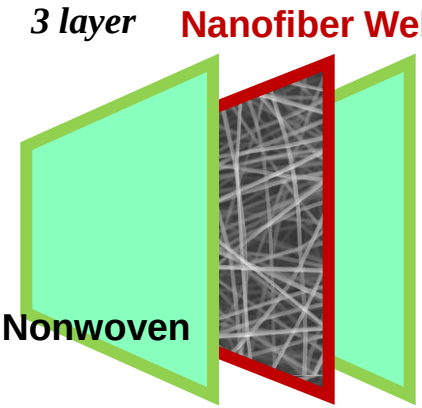


Nano Filter Advantage

- 低い圧力損失
- 高い集塵効率
- 長寿命，リサイクル
  (表面濾過方式による)



ULPA, HEPA and Nanofiber

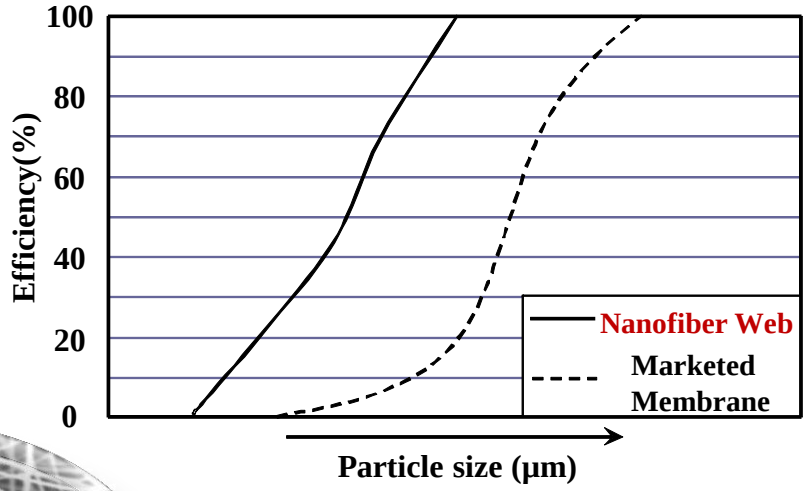


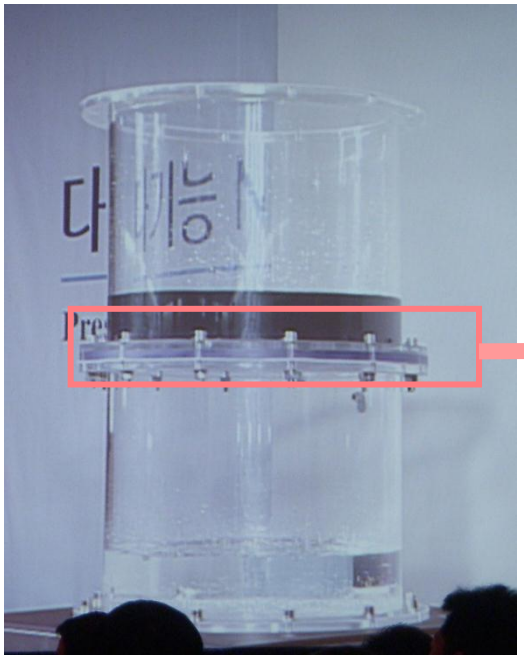
	Air Permeability ($cc/cm^2/sec$)	Pressure drop (mmH_2O)	Efficiency (%)
HEPA	5.4	20.5	99.9
Nanofiber	14.7	5.8	HEPA同等
ULPA	2.01	34.7	99.999
Nanofiber	11.5	7.8	UEPA同等

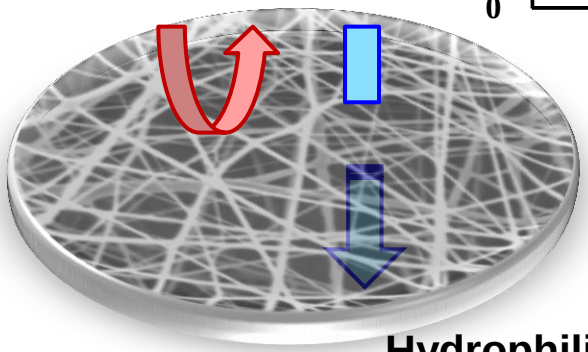
Filters

	Marketed Filter	Nanofiber Filter
Trapping mechanism	Mechanical capture (pore size)	Mechanical capture (pore size)
	Adsorption (Ionic bond , etc.)	Bacteria retention ability
Removal efficiency (%)	80 ~ 99	99.999

Efficiency test

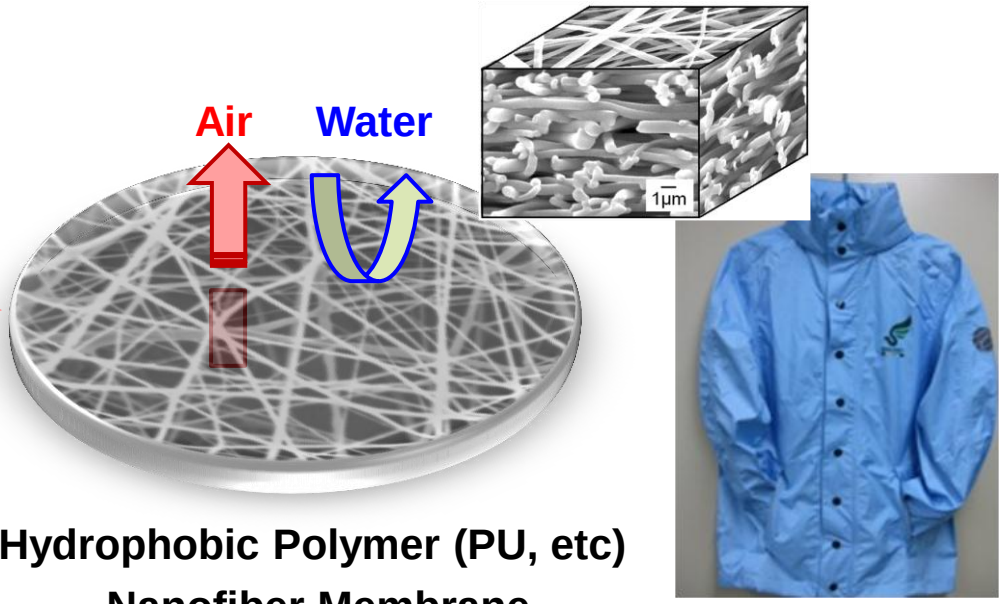






Hydrophilic Polymer (Nylon, PU, etc)
Nanofiber Membrane

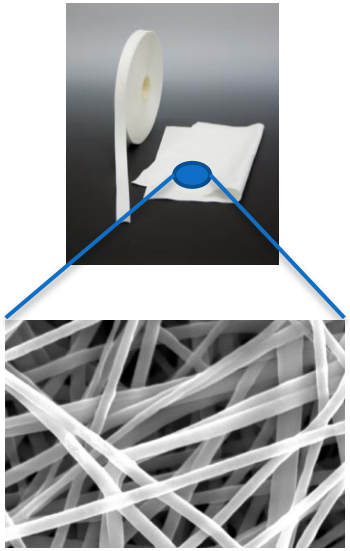
Breathable Waterproof Fabric

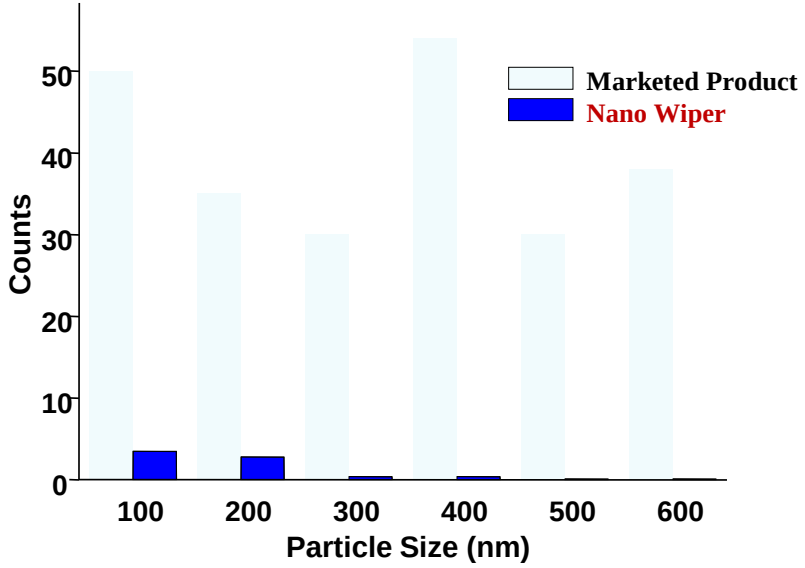


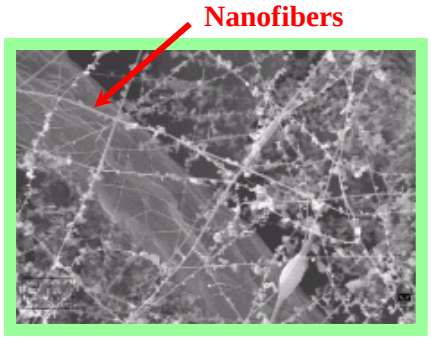
Hydrophobic Polymer (PU, etc)
Nanofiber Membrane

Physical Property	Sample 2005	Sample 2007	Test Method
Thickness (micron)	15	14	JIS L1096
Air Permeability (cc/cm・sec)	0.80±0.05	0.50±0.05	JIS L1096A
Water-proofness (mmH_2O)	5,000±100	12,000±500	JIS L1092B
Vapor Transmission Rate(g/m^2・24hr)	140,000±5,000	160,000±5,000	JIS L1099B-2

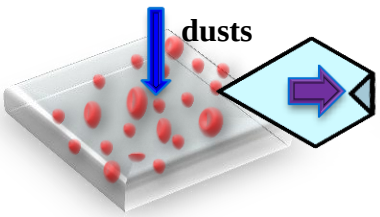
Nano-Wiper



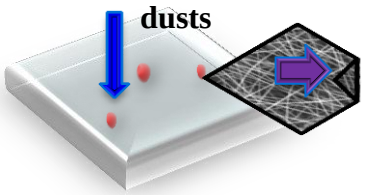




Contains the size of particles ranging from 0.1 to 1.0 microns



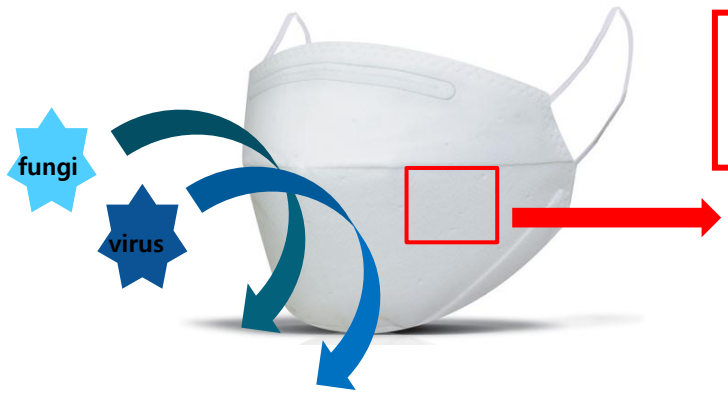
Commercial wiper



Nano wiper

Nanofiber-Mask

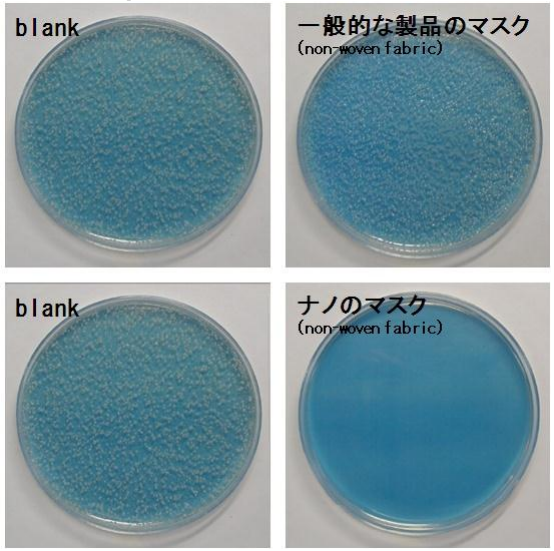
Dust size: 3~5μm
Virus size: 0.1~0.3μm



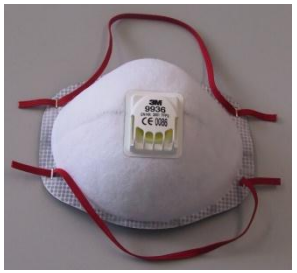
Nano fiber
+
Antibacterial powder

Nanomask
- lightweight
- Low constricting of the breath
- Blocking of harmful substances and providing immune function.（99.9%high antivirus function）

Bacteria : Klebsiella pneumoniae ATCC 4352
Standard fabric : Cotton



		Blank	Sample
Normal Mask	At beginning	2.0×10^4	2.0×10^4
	After 18 hrs	4.5×10^7	5.8×10^7
	Bacteriostatic reduction rate	-	0
Nanofiber Mask	At beginning	2.0×10^4	2.0×10^4
	After 18 hrs	4.5×10^7	<10
	Bacteriostatic reduction rate	-	99.9



Nanofiber-Wallpaper

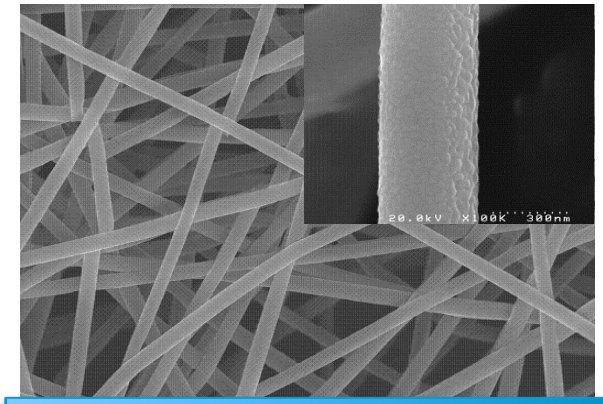
Nano Wallpaper (Nanofilm+Paper+Nonwoven)

After 2 weeks

***We see only a stain that is not mold.**

Metallized nanofibers

Metalized Nanofibers



Ag: Antimicrobial

Cu: Electrical conductivity

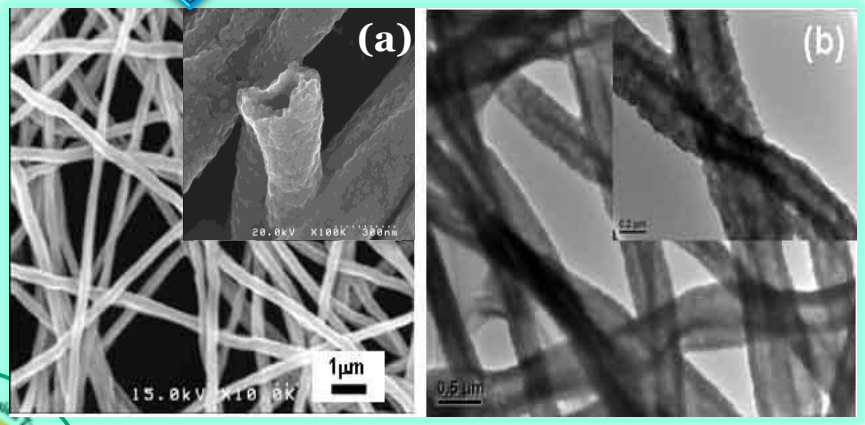
Au, Ni: Catalytically / electrical

TiO_2: Anti-UV / photocatalysis

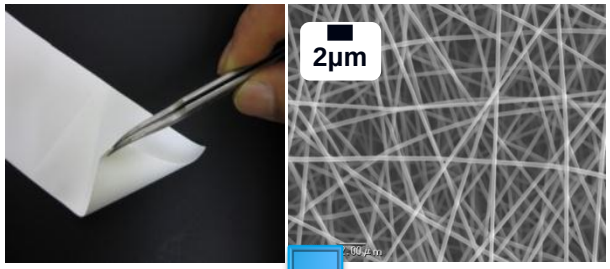
Other materials

Metal deposited PU nanofiber web

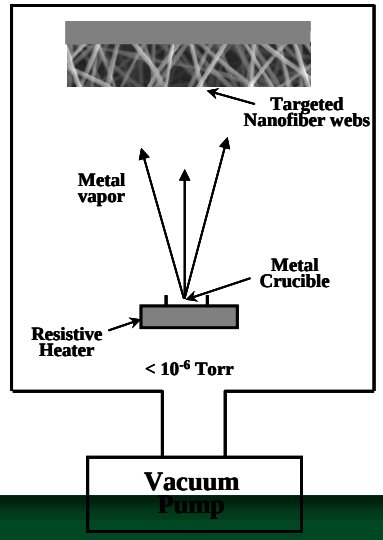
Calcination at 400℃



Electrospinning



Metal Deposition



Metallized nanofibers

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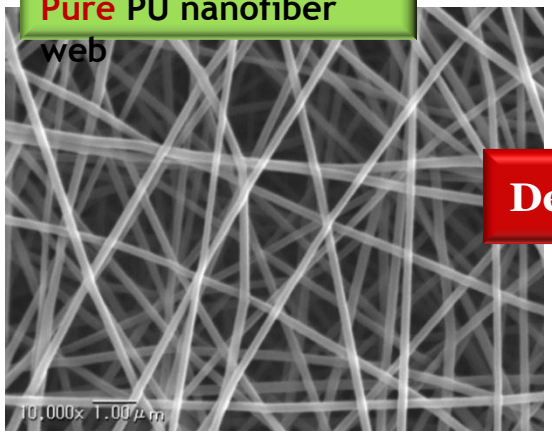
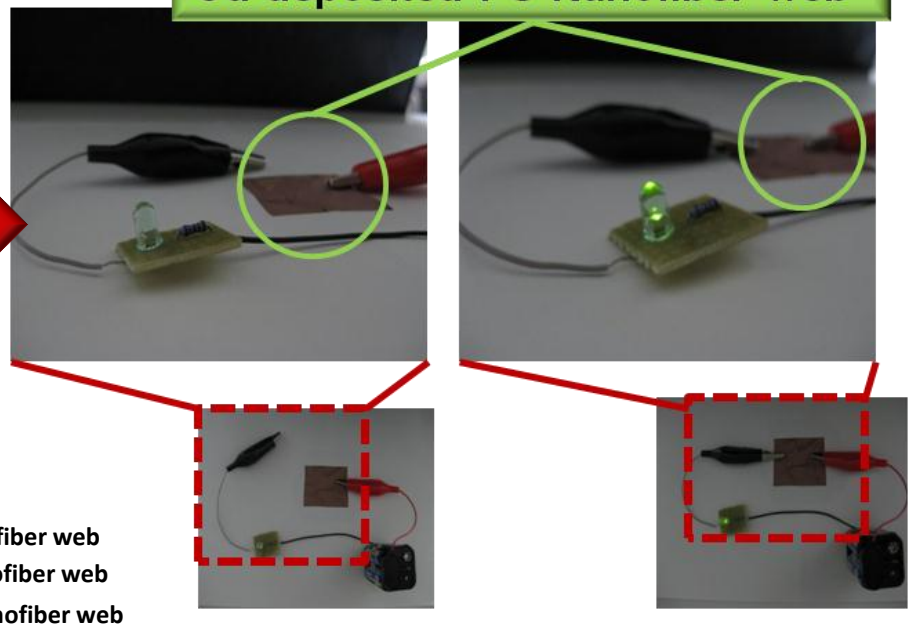
Metal nanofibers

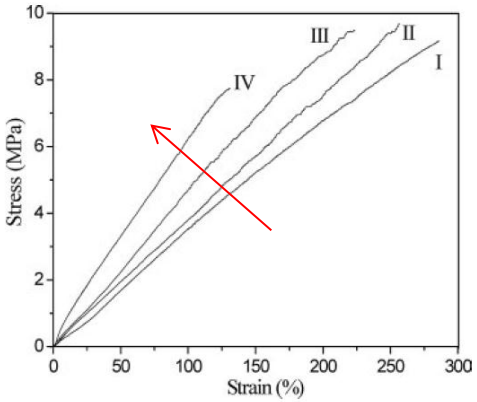
Pure PU nanofiber web



Deposition

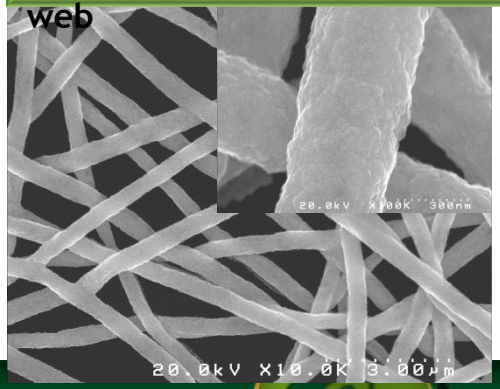
Cu-deposited PU Nanofiber web





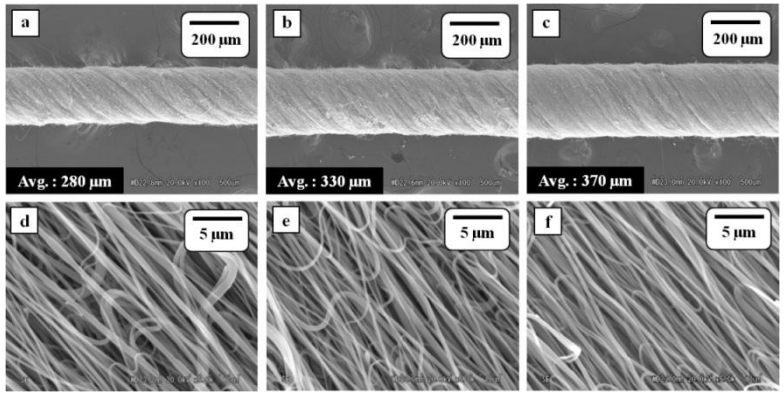
Ⅰ. Pure PU
Ⅱ.10nm Cu-deposited PU nanofiber web
Ⅲ. 50nm Cu-deposited PU nanofiber web
Ⅳ. 100nm Cu-deposited PU nanofiber web

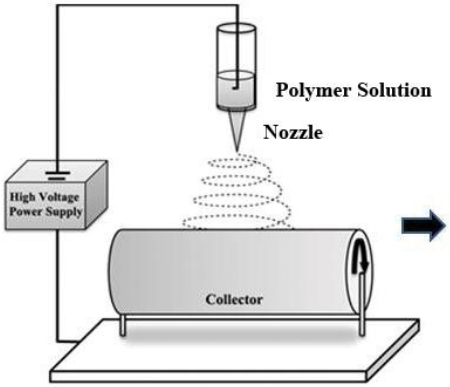
Metal deposited PU nanofiber web

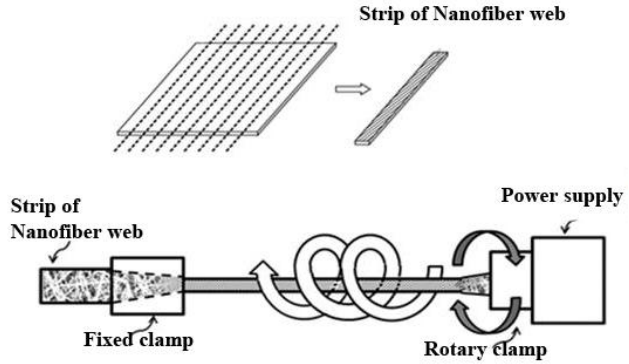


Enhanced mechanical property and electrical conductivity

High strength nanofiber filaments



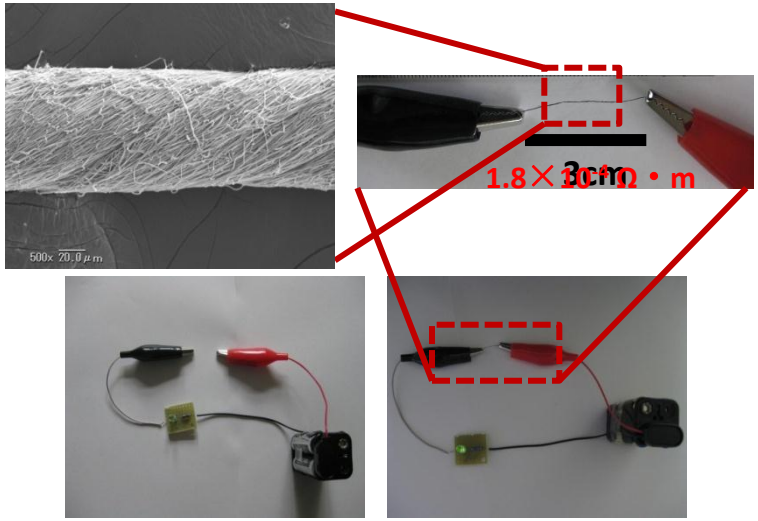


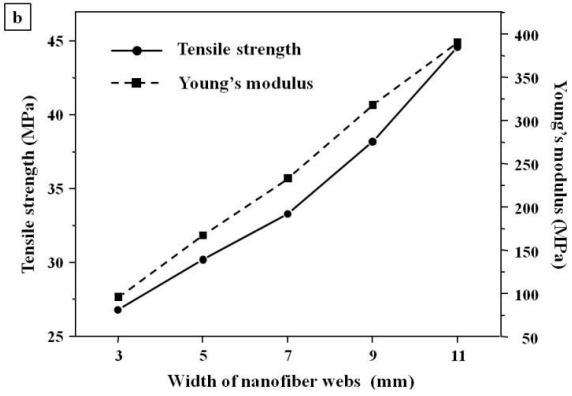


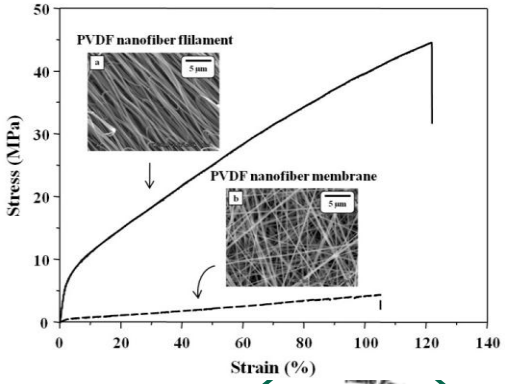
1) Electrospinning

2)Slitting and twisting

高分子ナノ繊維からなる糸の製造方法　特願2010-081120

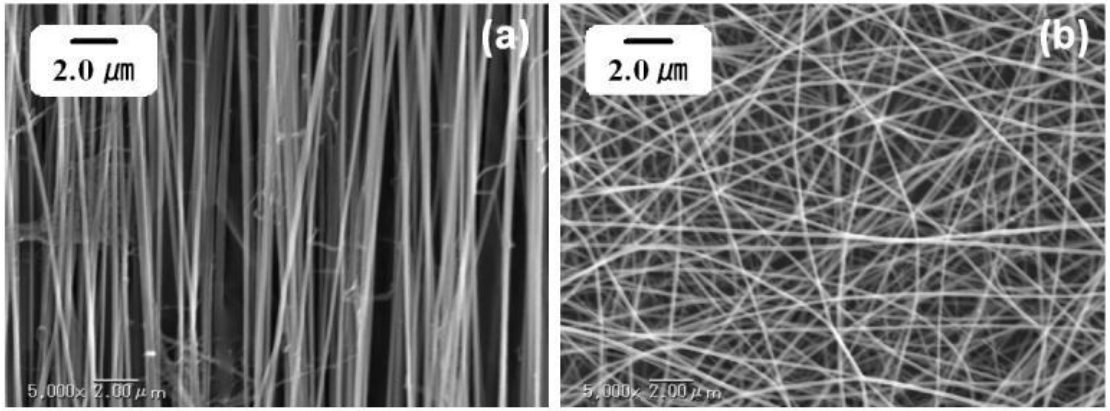


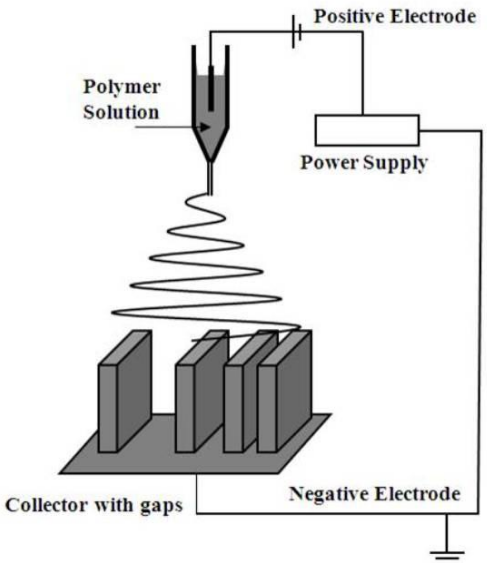


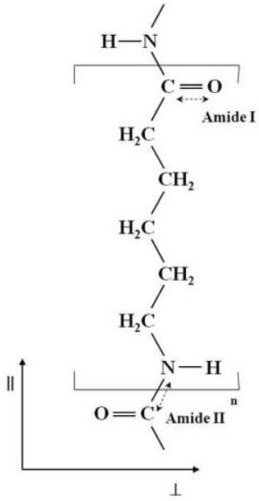


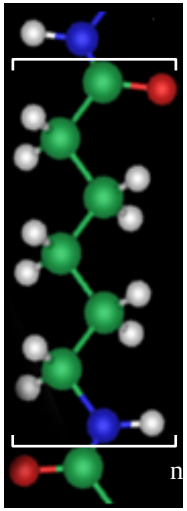
Nanofiber Assembly: Aligned Nanofibers

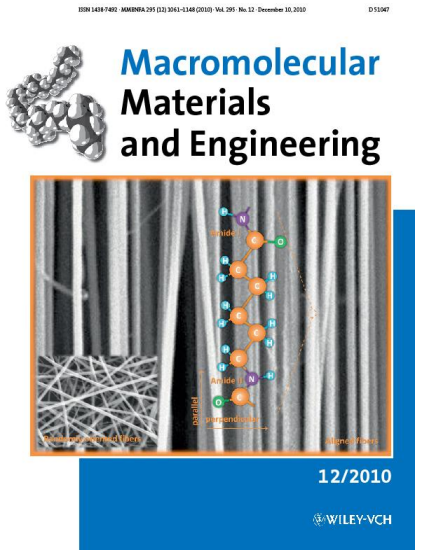
Aligned nanofibers





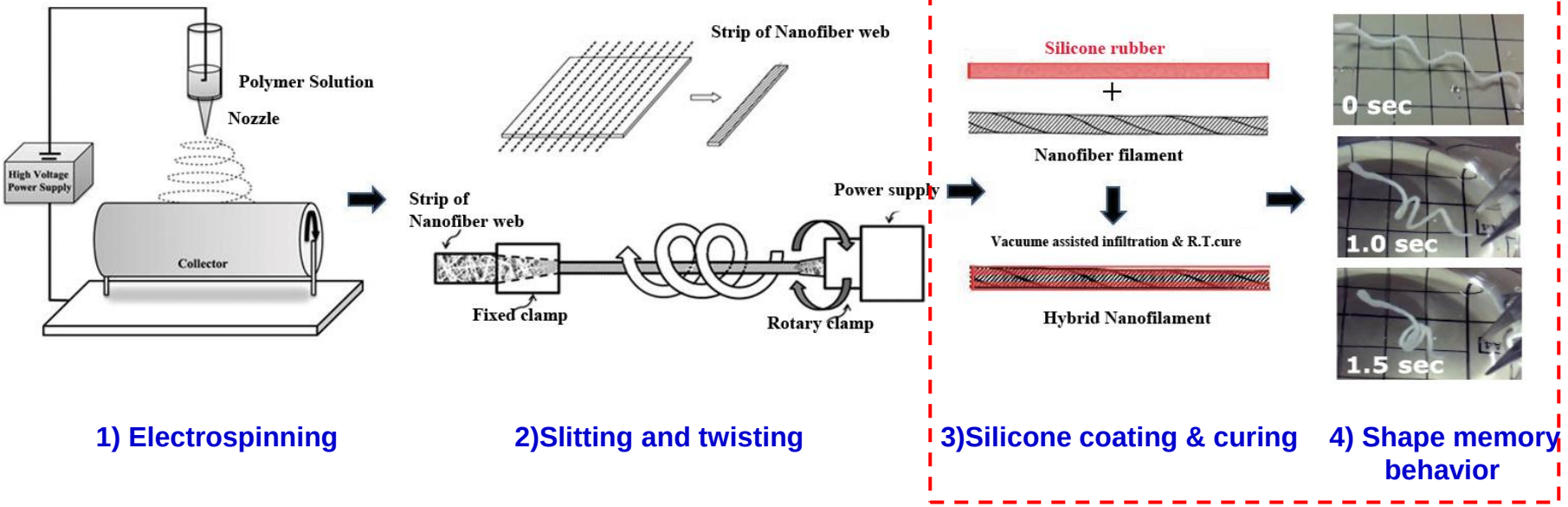






N. Kimura, H. K. Kim, B. S. Kim, K. H. Lee, I. S. Kim, *Macromol. Mater. Eng.* **2010**, *295*, 1090-1096.

Shape memory nanofiber filaments

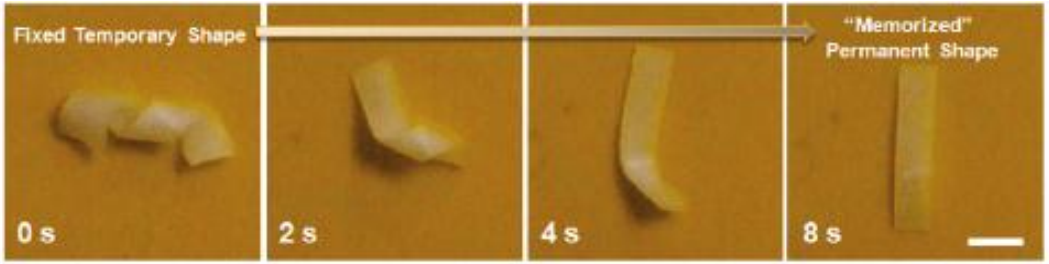


1) Electrospinning

2)Slitting and twisting

3)Silicone coating & curing

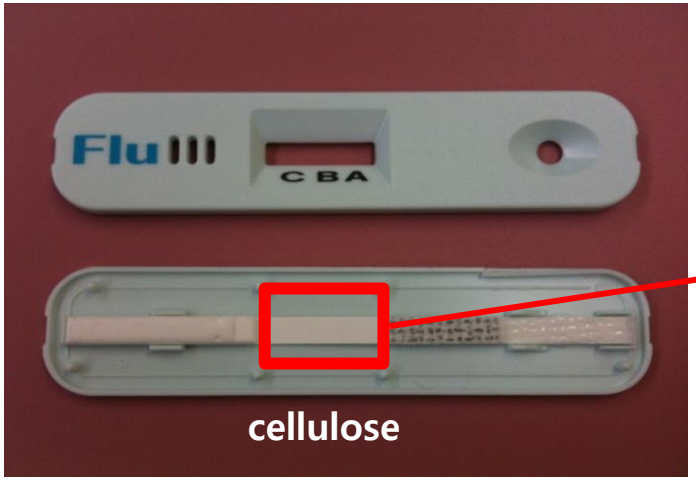
4) Shape memory behavior

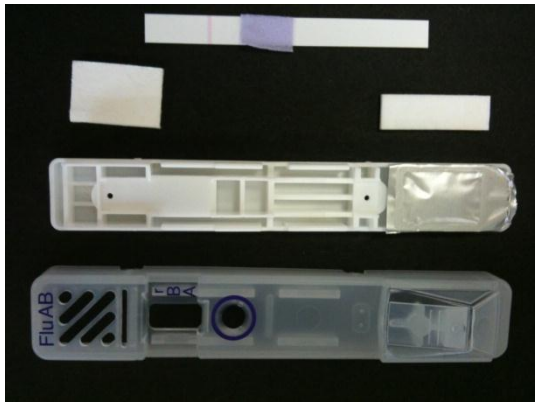


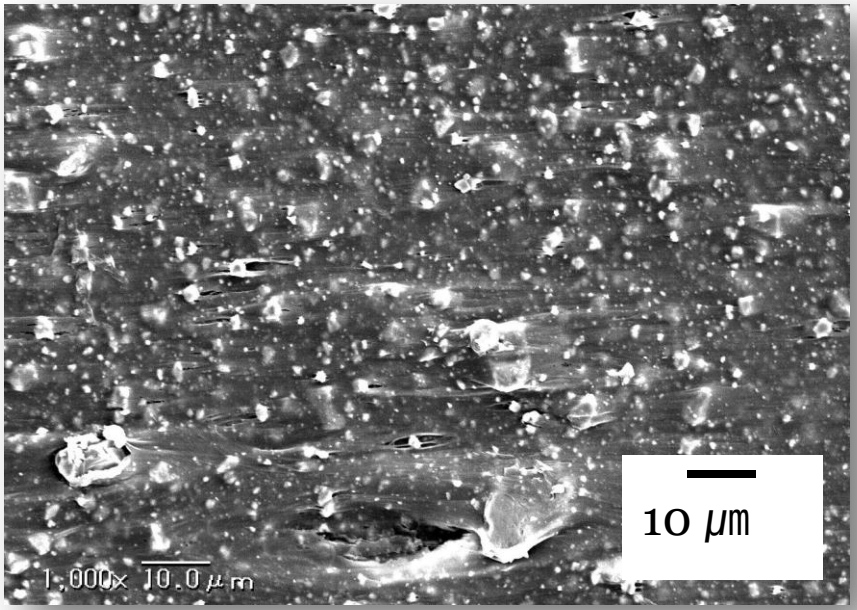
Y. Lee, et al., to be submitted (2011).

X. Luo, P. T. Mather, *Macromolecules* **2009**, *42*, 7251-7253.

Blood Sugar Bio-sensor





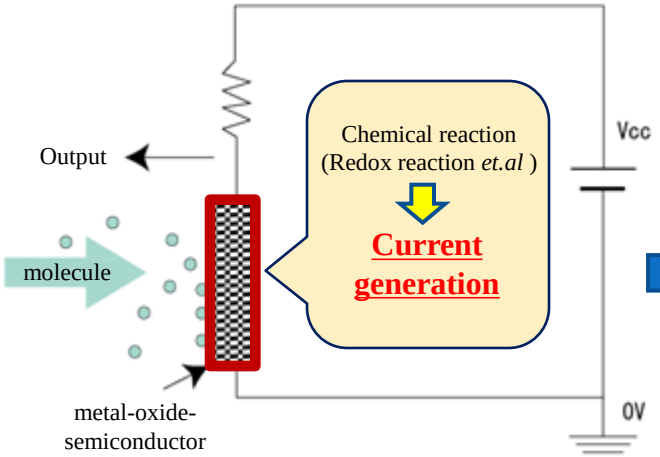


Expected blood sugar Bio-sensor

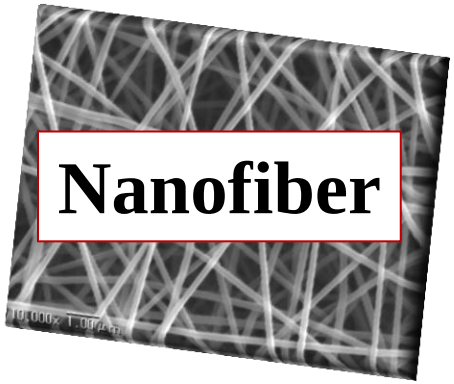
Using Nano-fibers

- **Very high sensitive**
- **Faster**

Sensor Field

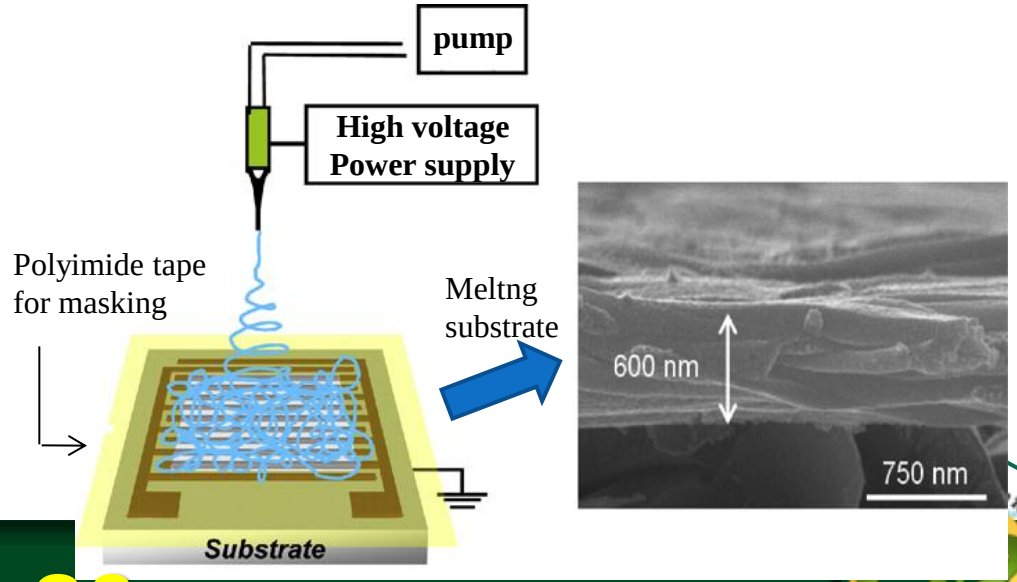


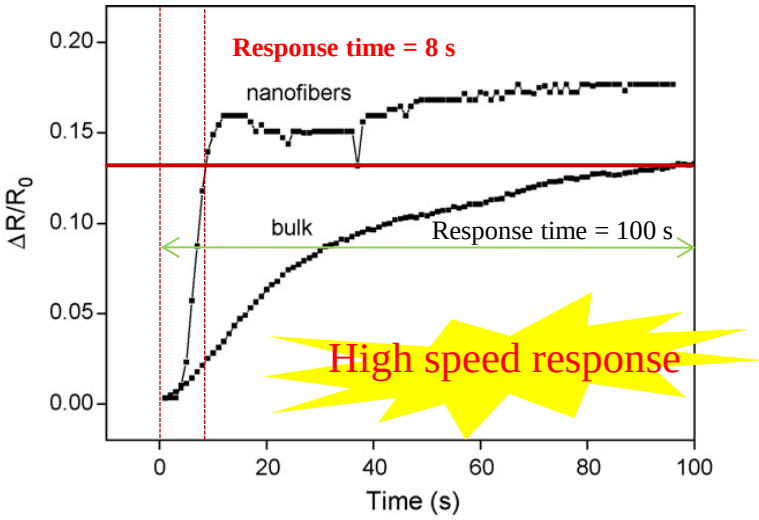
Sensor mechanism
(Gas sensor, humidity sensor *et.al.***)**



High Sensitve Sensor

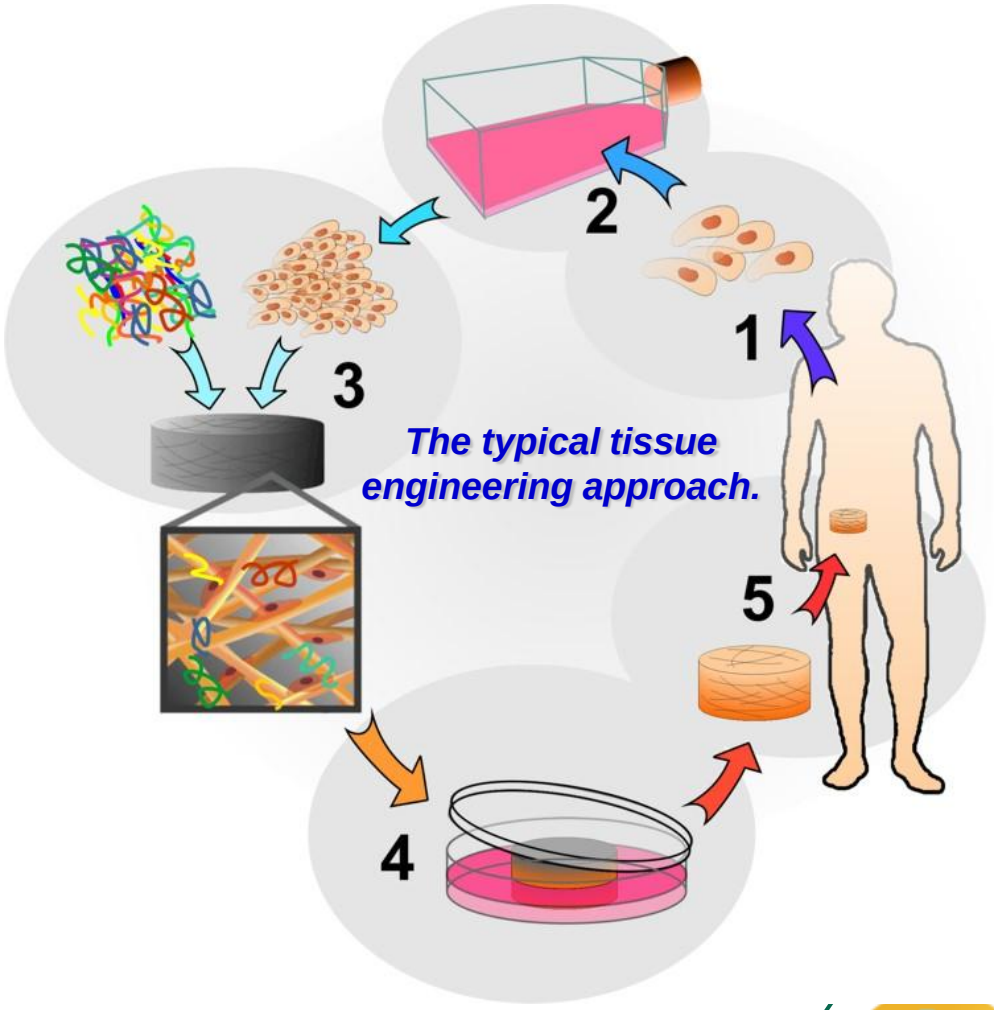
Because…
High surface-to-volume ratio
→ reaction area up!!





Comparing response of bulk PPy and PPy nanofibers upon exposure to 20ppm of NH_3.

Tissue Engineering



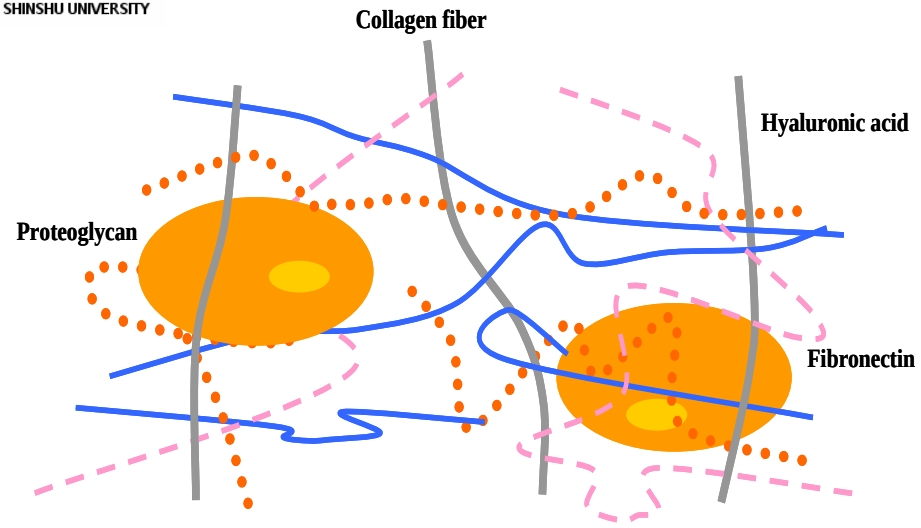
The typical tissue engineering approach.

Combination

- Cells
- Engineering
- Materials
- Suitable biochemical
- Physio-chemical factors

1. Remove cells
2. Expand number in culture
3. Seed onto an appropriate scaffold
4. Place into culture
5. Re-implant engineered tissue repair damaged site

Tissue Engineering



Extracellular Matrix (ECM)

The extracellular matrix is part of animal tissue that usually provides structural support to the cells in addition to performing various other important functions.

Seeking to imitate the functions of ECM, we used many method. These mainly involve the use of synthetic scaffolds fabricated from biocompatible materials to carry, support and guide cells towards tissue regeneration.

Function of scaffold material

- Biocompatibility
- Moderate strength
- Supporting to cell proliferation and differentiation

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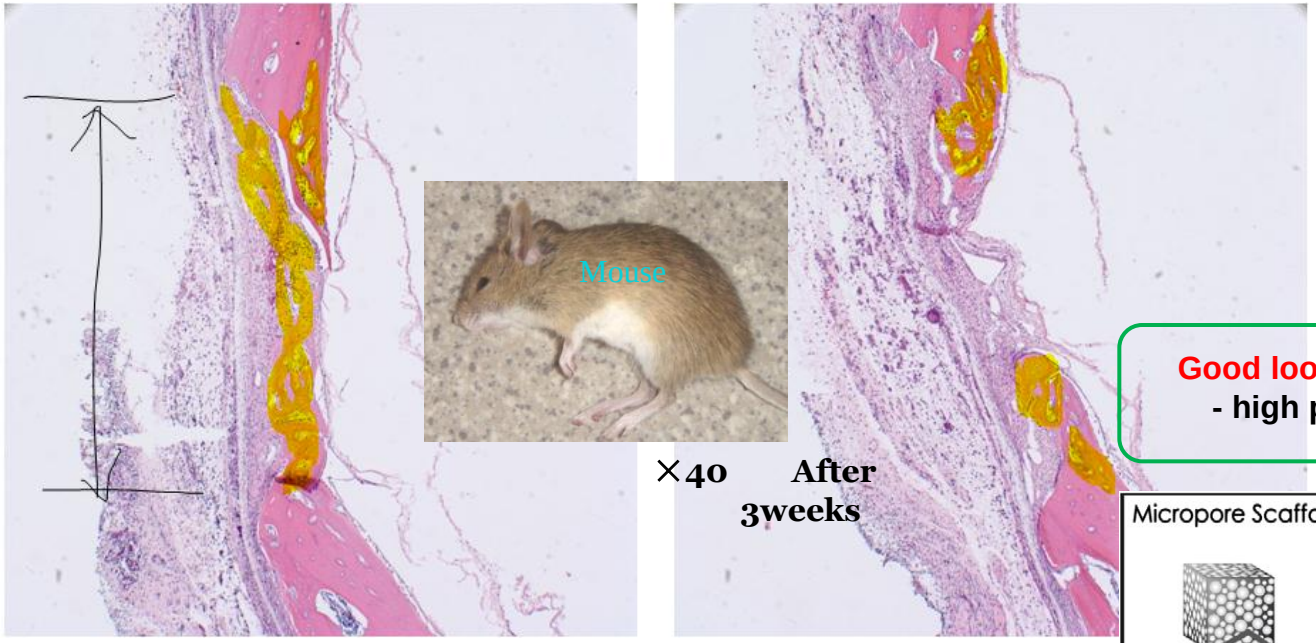
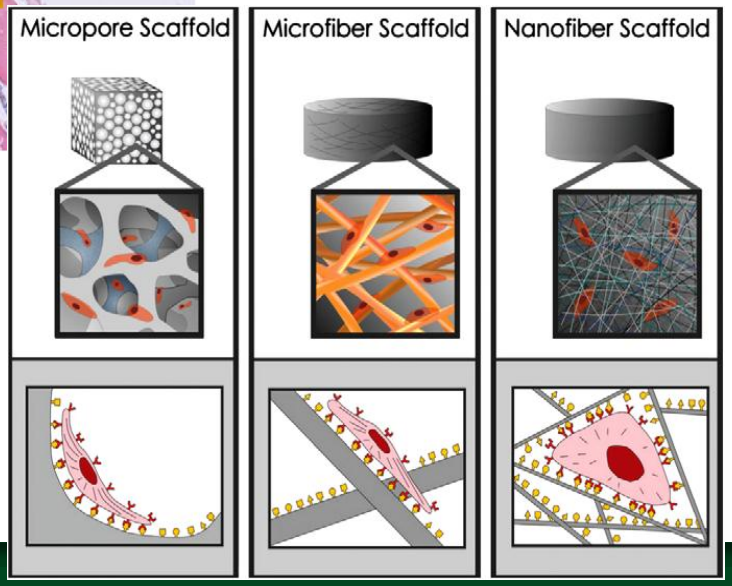
With Nanofiber **Without**

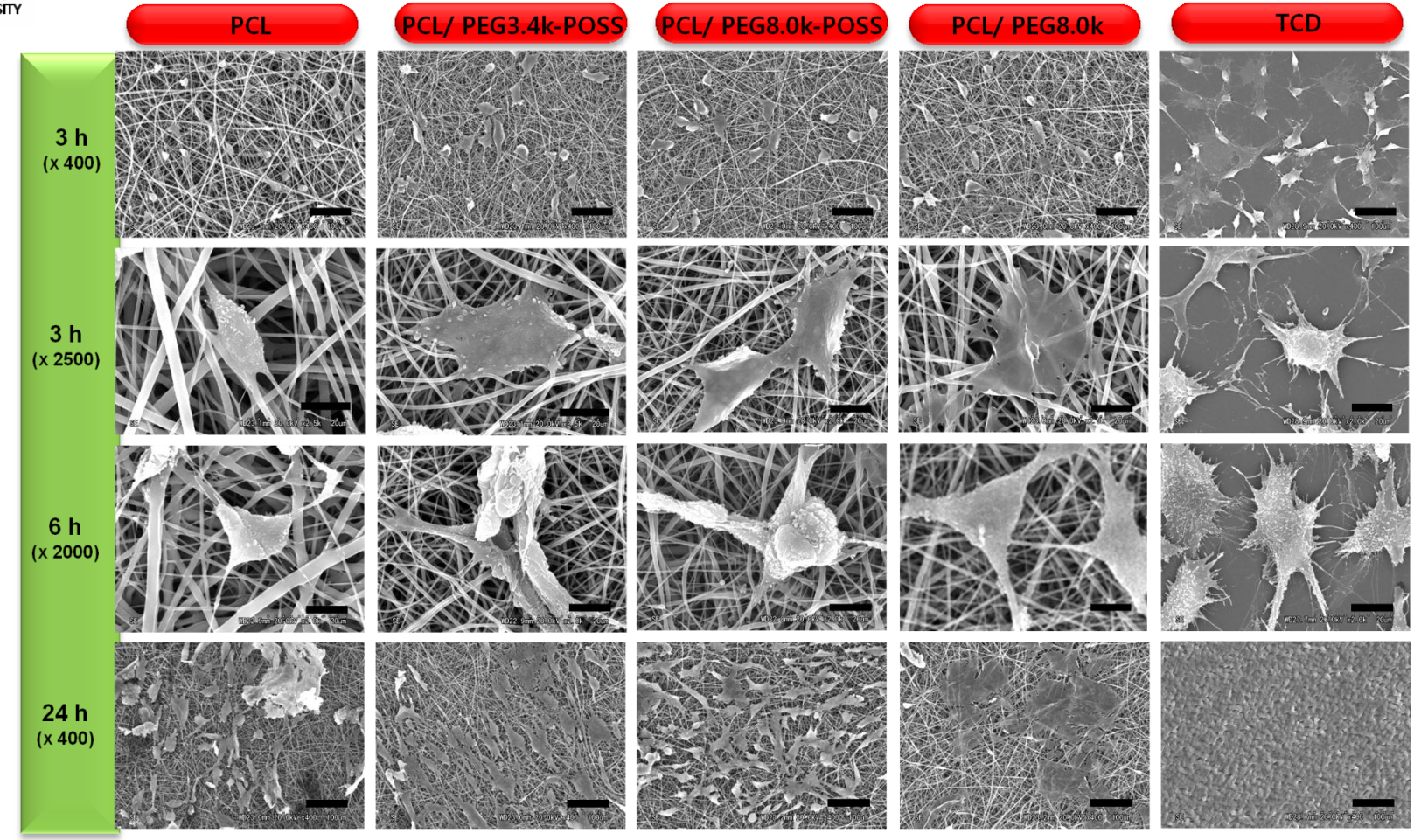


Good loosely connected 3D porous mats
- high porosity and high surface area

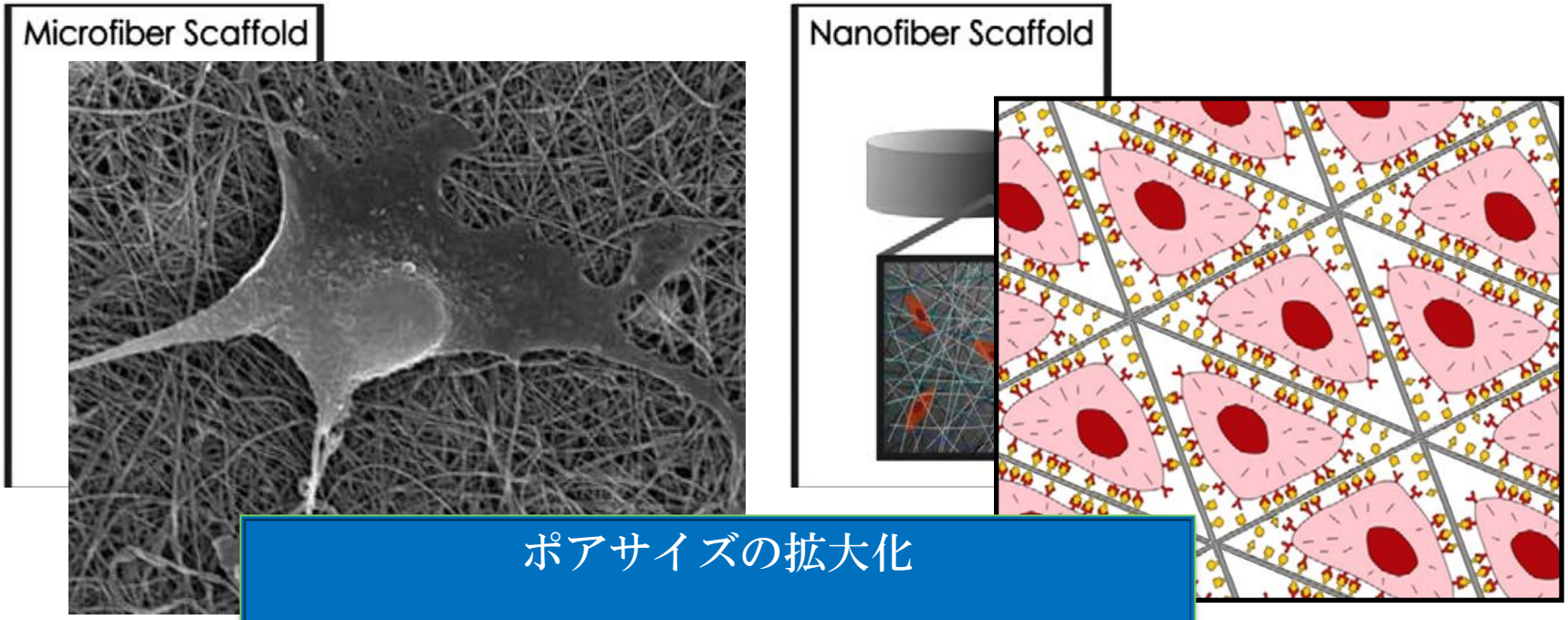


- **Commercially available synthetic polymer**
  polylactide (PLA), polycaprolactone (PCL), poly(glycolic acid) (PGA), and their copolymers etc. and especially synthesised novel biomaterials that are designed

SEM Images of Cultured PCL/PEG-POSS Scaffolds



3D Nanofibrous Scaffolds for Cell Culture



ポアサイズの拡大化

Kai Wei, Yuan Li,
Abe, Guo-Qiang Chen, Ick-Soo Kim.
Fabrication of nano-hydroxyapatite on ele
their effects in osteoblastic behavior.
JOURNAL OF BIOMEDICAL MATERIALS

研究目的

細胞培養の高効率化に向けた
ナノファイバー不織布の形態制御

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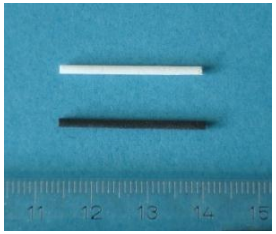
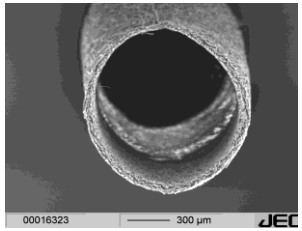
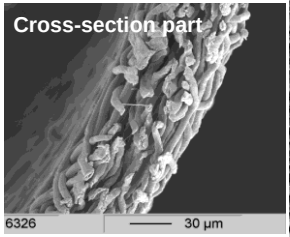
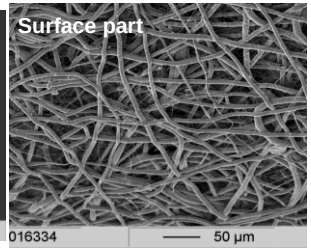
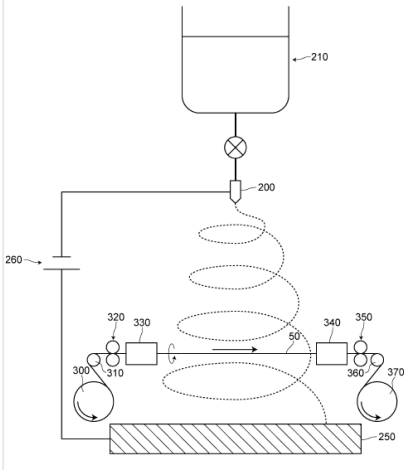
Nanofiber tube



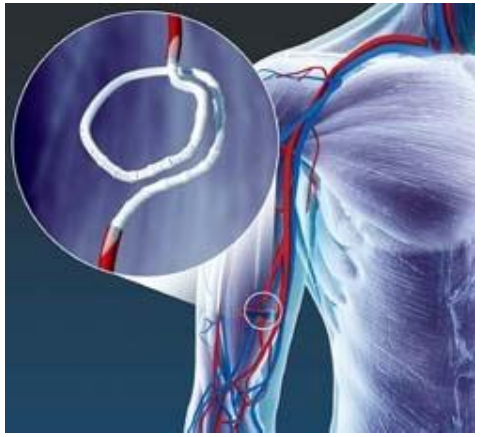


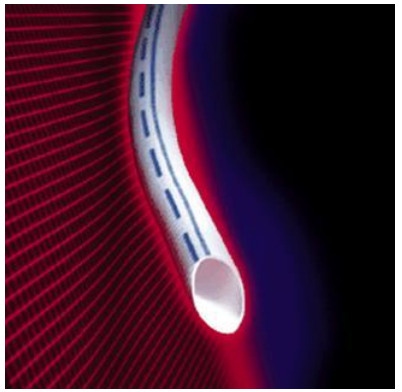




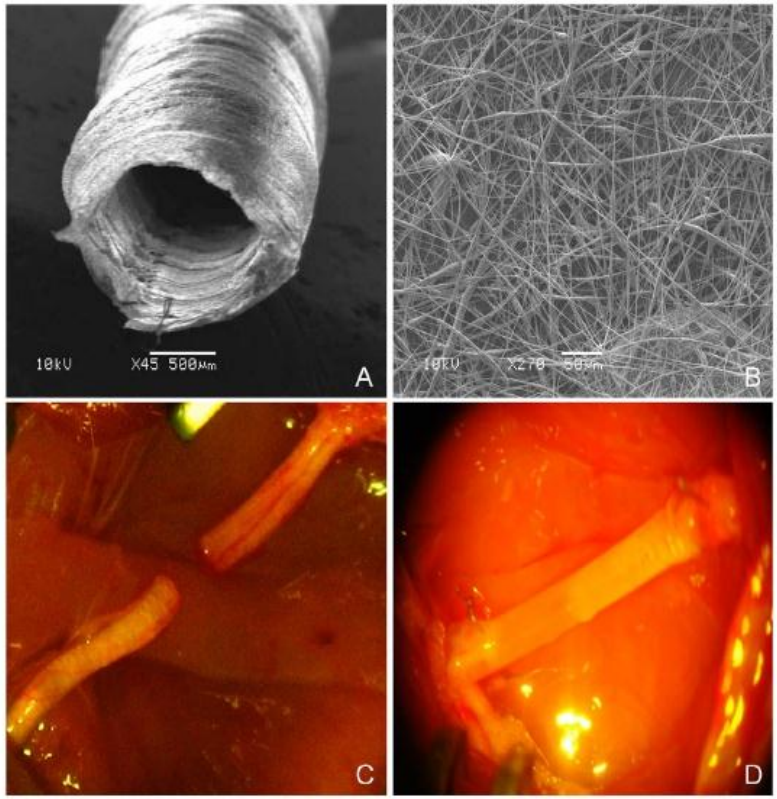


Blood vessel prosthesis





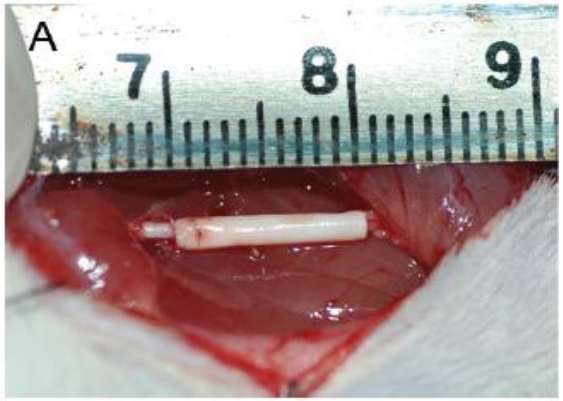
Meadox Exxcel™
ePTFE Vascular Grafts

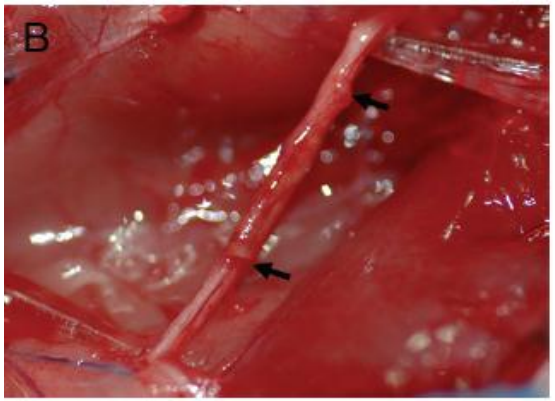


Electrospun PLGA/PCL nerve guide conduit

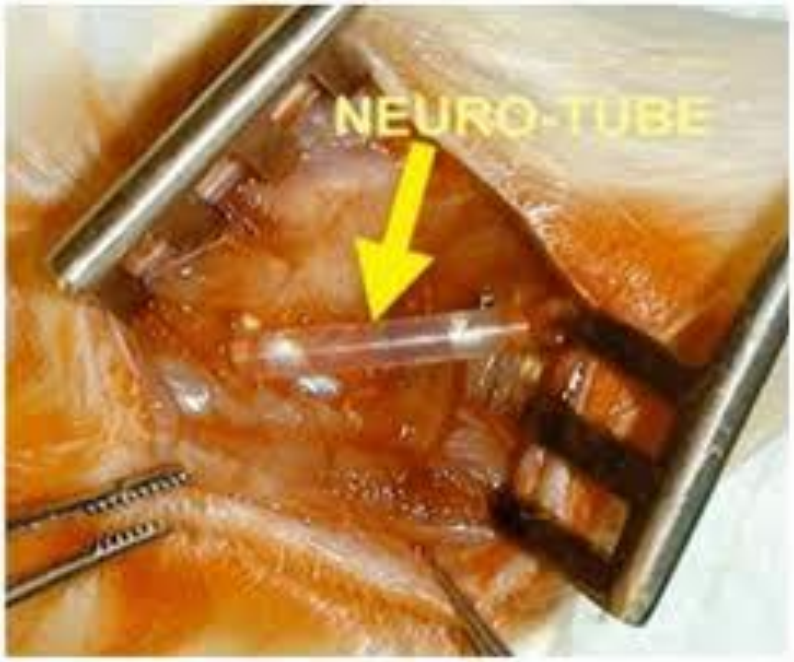
Post operation, regenerated nerve

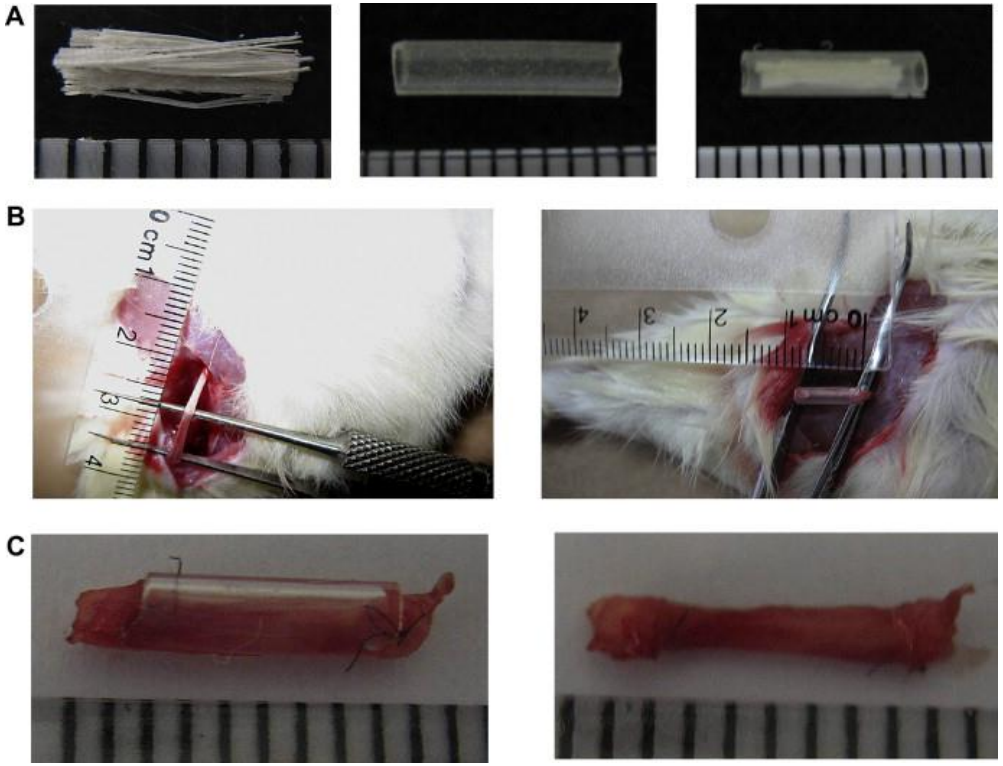
4 months



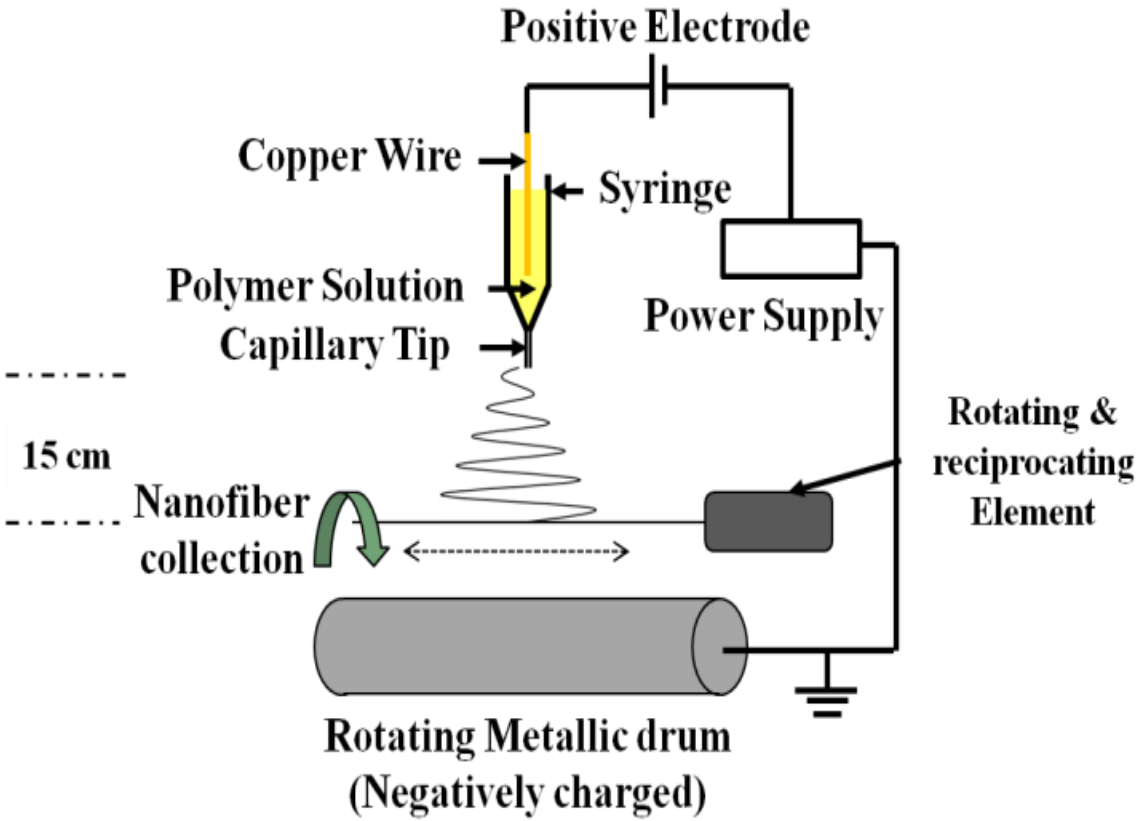


Electrospun Collagen/PCL nerve guide conduit


NEURO-TUBE

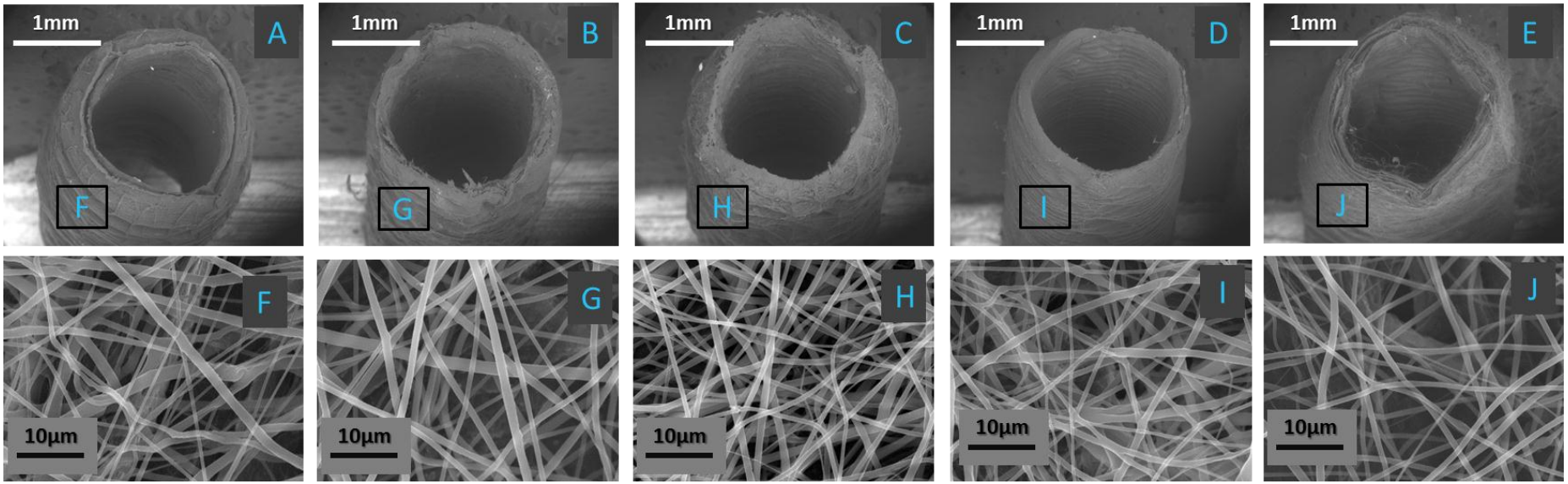

A
B
C

Electrospinning setup

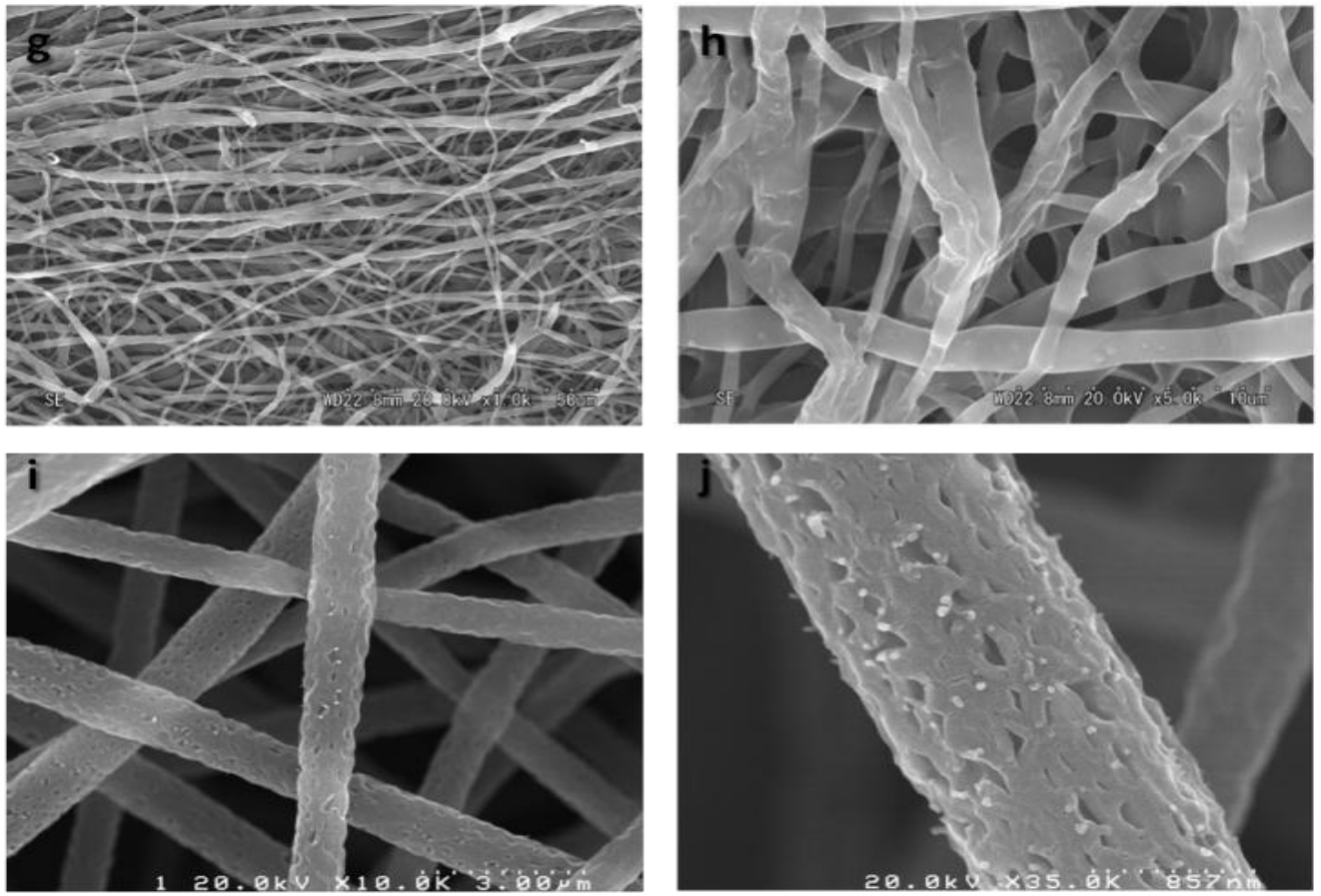



10
20
30
40
STANDARD
AT20℃

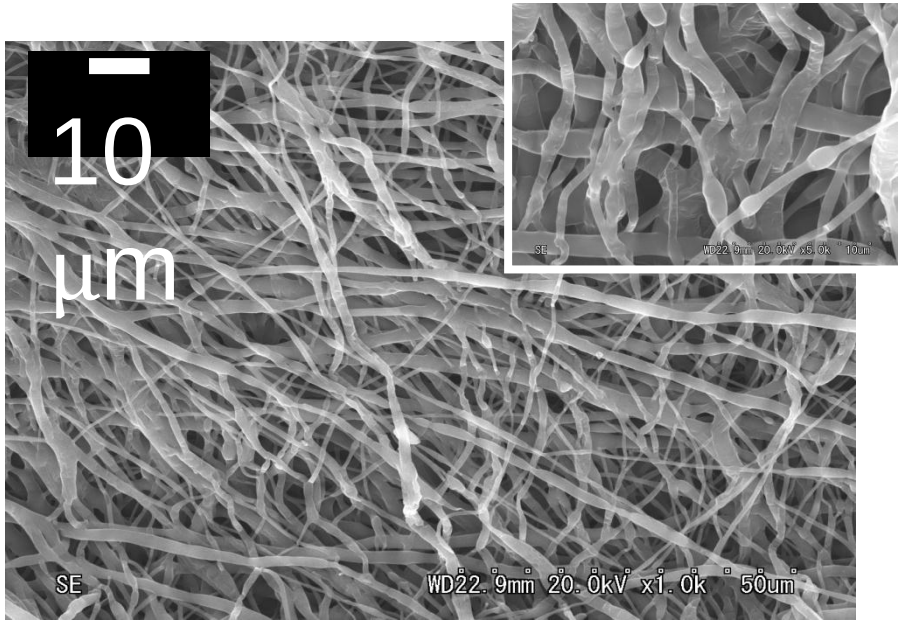
Morphology of nerve guides

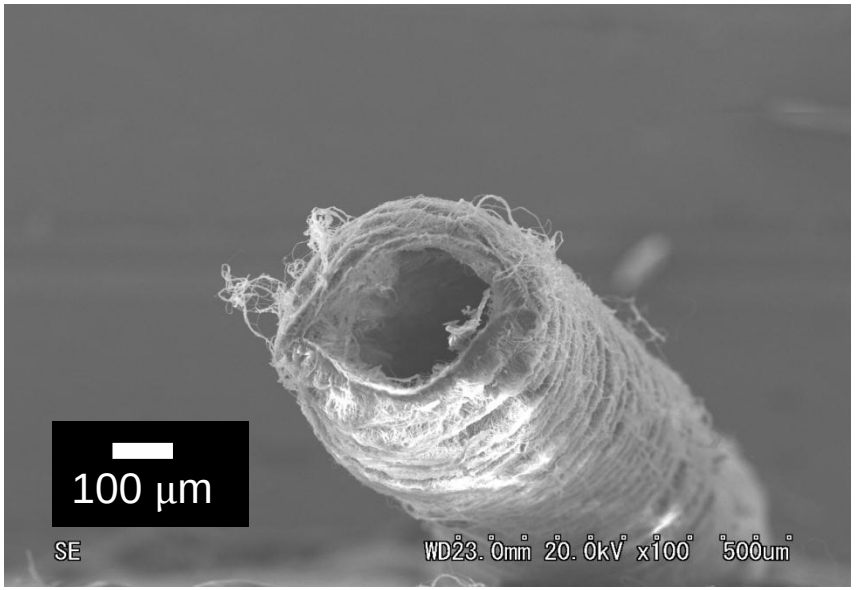


Morphology of nanofibers

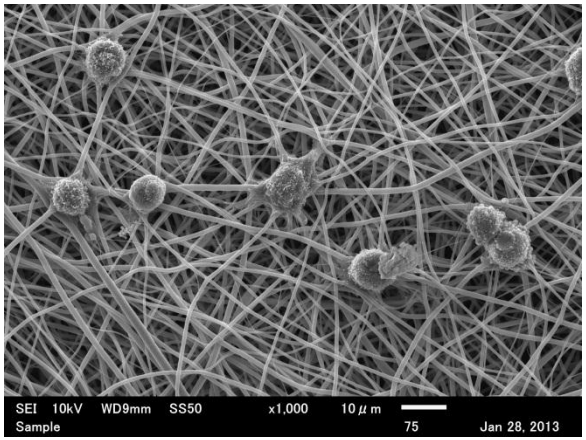


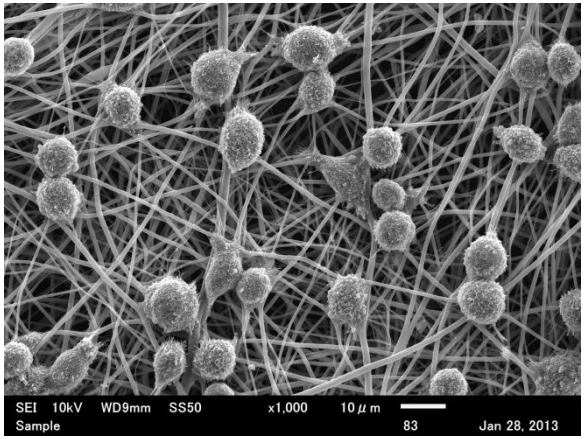
PCL nerve guide- 0.3mm

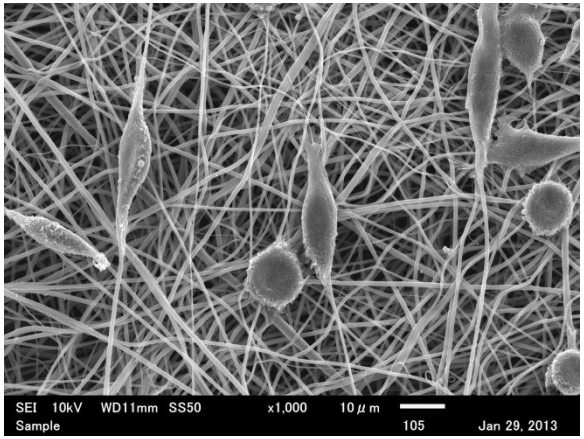




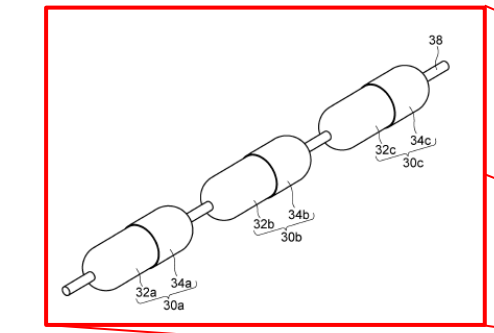
Cell Adhesion Behavior

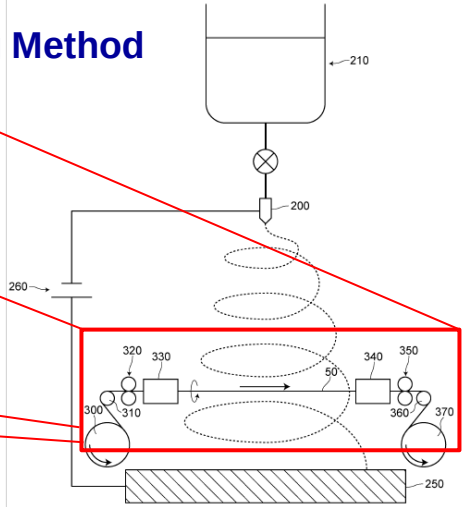




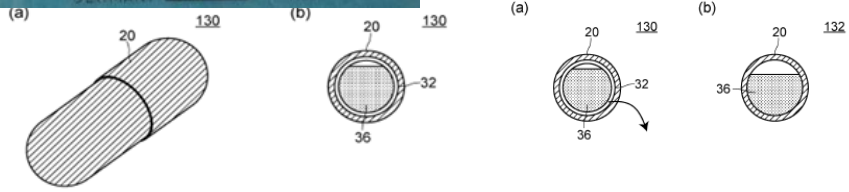


Nanofiber capsule : 3D wrapping/coating by Electrospinning Method



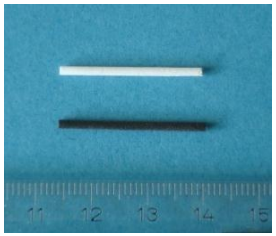


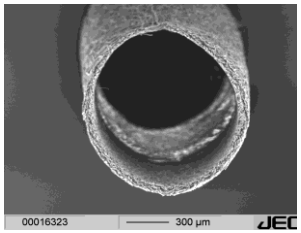
【図１２】

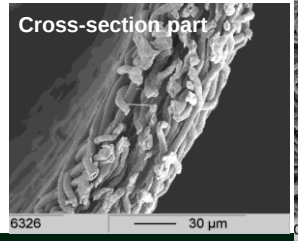


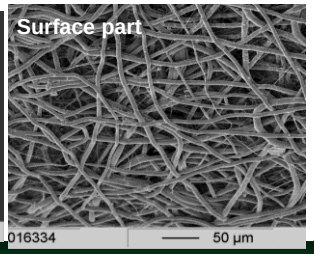
- Nanoparticles (ex. TiO2, ZnO3, Silica, Etc.)
- Nano micelles with drugs

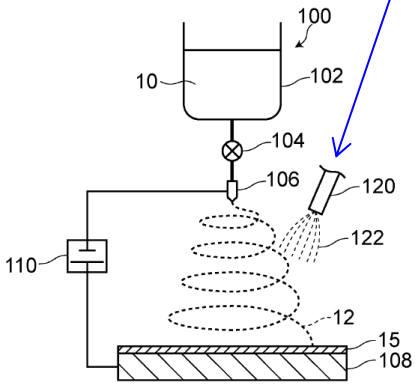
Nanofiber tube

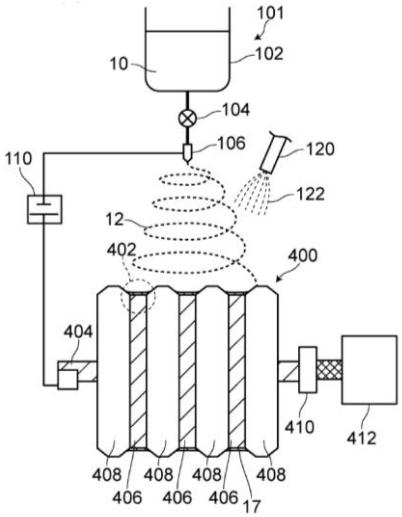




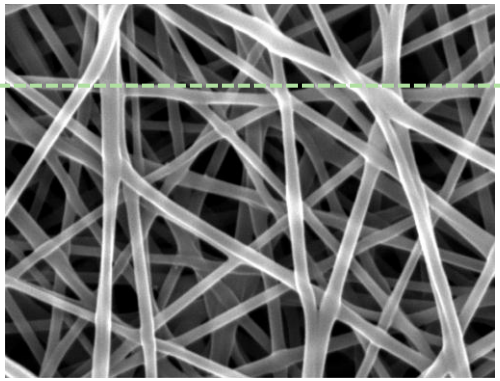






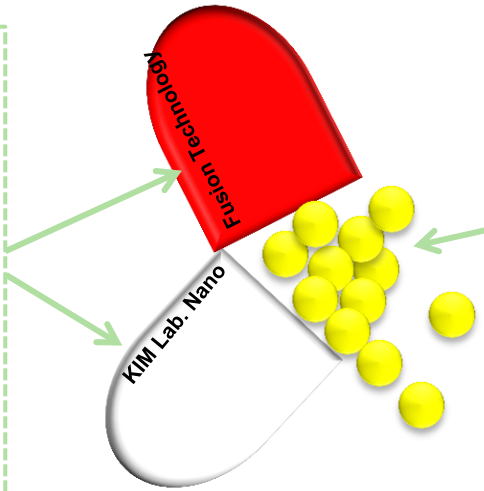


Smart drug delivery

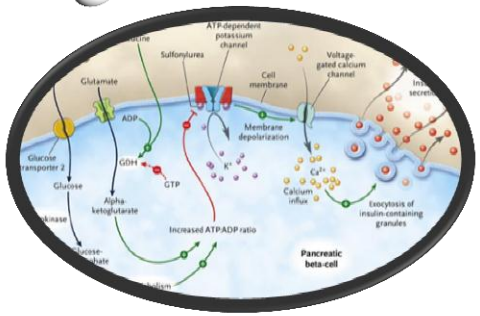


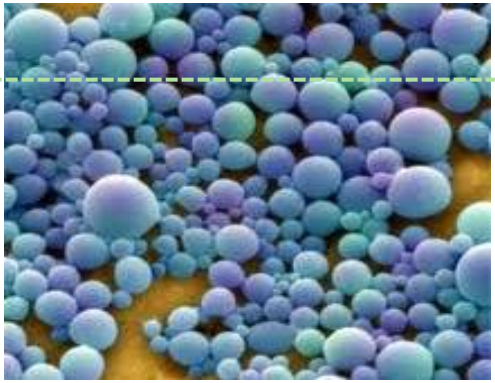
Nanofibers

- To enhance the therapeutic activity by prolonging drug half-life
- To be released through diffusion system



In vivo
•Glucose reaction

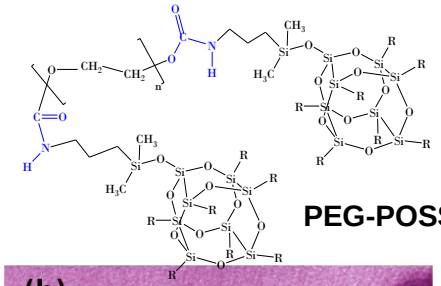




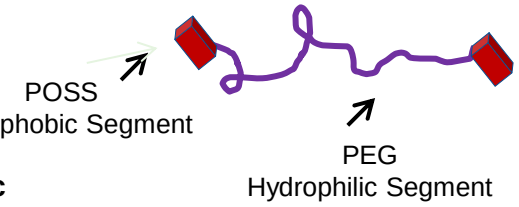
Nanoparticles

- Improving solubility of hydrophobic drugs
- Reducing potential immunogenicity

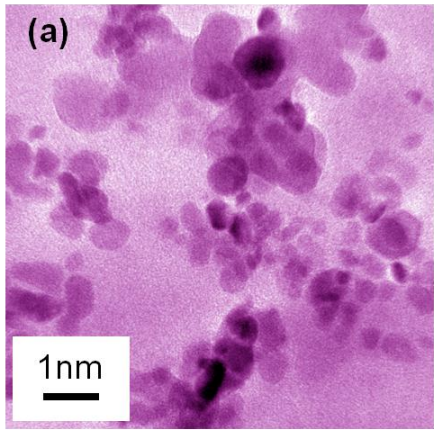
Core-Shell Nanostructured Particles

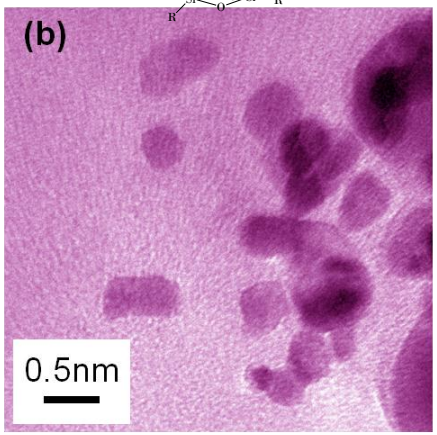


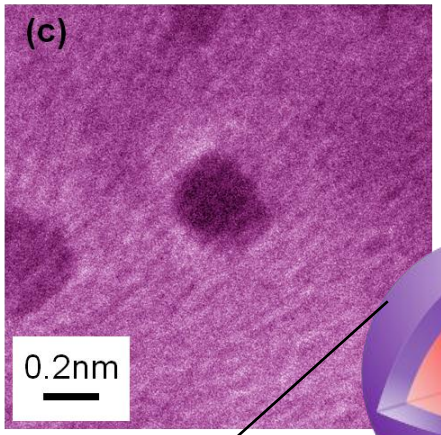
PEG-POSS Telechelic



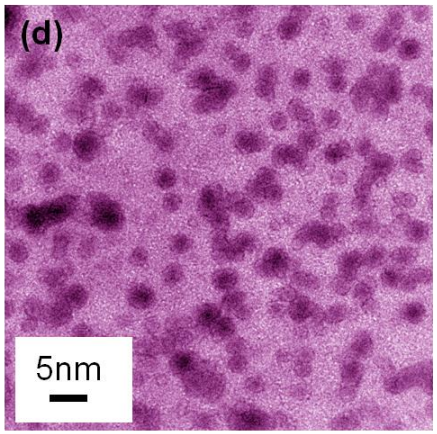
PEG3.4k-POSS NPs

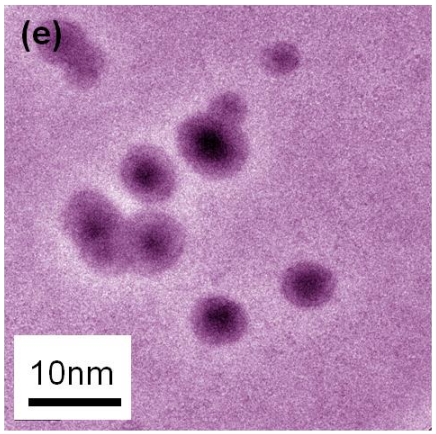


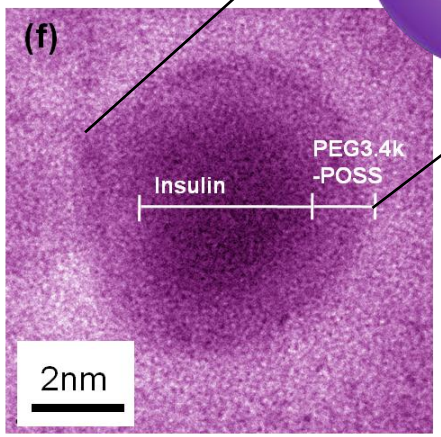


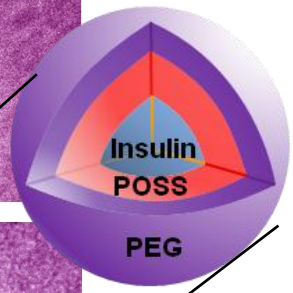


PEG3.4k-POSS/Insulin NPs

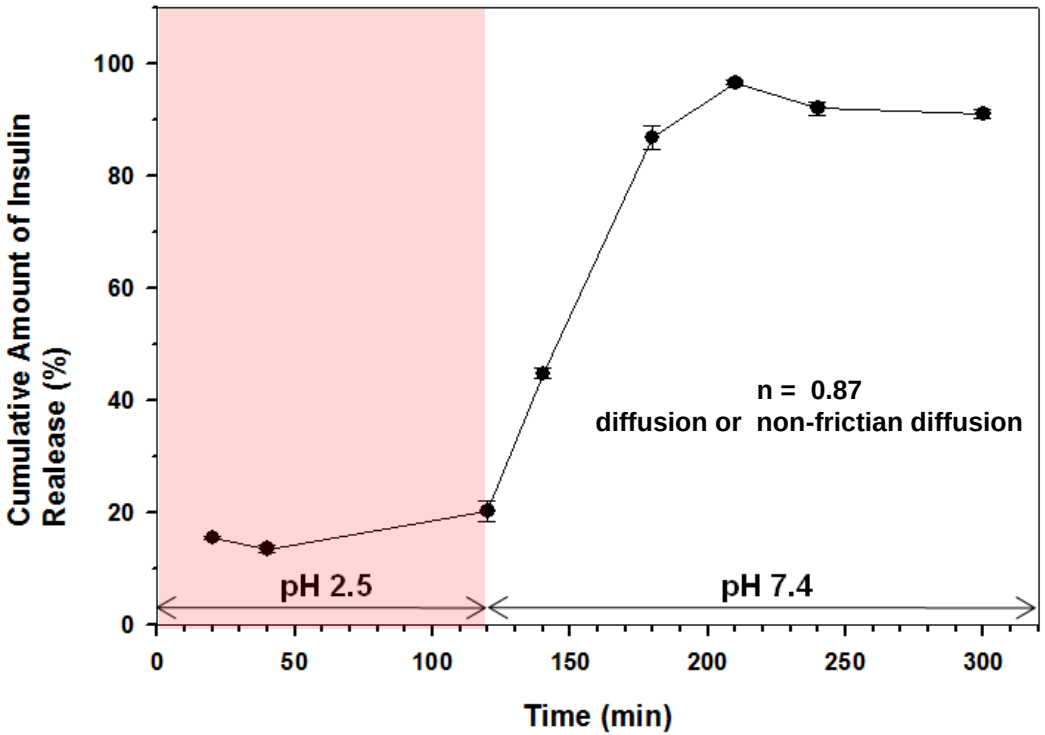








In-vitro Insulin Release Behavior



K.O. Kim, B.S. Kim, I.S. Kim, *Journal of Biomaterials and Nanobiotechnology*, **2011**, 2, 201-206.

- ***Diffusion controlled mechanism***

The drug release behavior according to diffusion controlled mechanism is usually governed by the following equation,

$$M_t/M_\infty = kt^n$$

where M_∞ is the total amount of insulin in dosage form, M_t is the amount of insulin released at time t, k is kinetic constant, and n is diffusion or release exponent constant.

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Nanofiber Production Systems

Global Companies Worldwide for Nanofiber Production

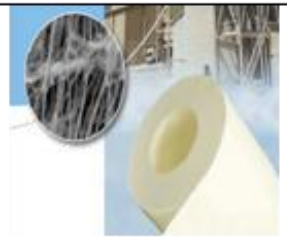
E 社
-Czech Republic

N 社
-Turkey

F社
-Japan

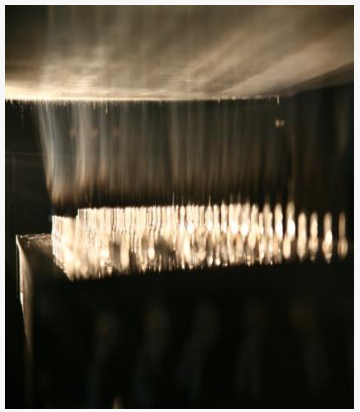
M社
-Japan

K社
-Japan



D社
-USA

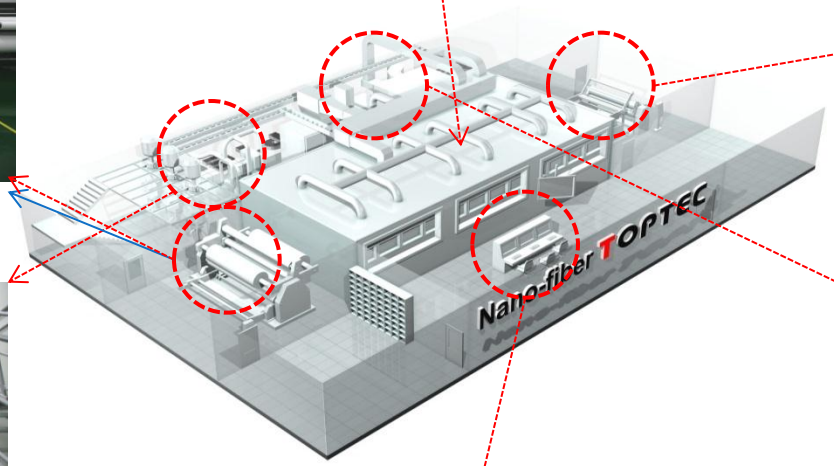
- Development of nanofiber production equipment by global companies worldwide
- Currently developed equipment in lab scale: 60cm in width and max. 0.5m/min in capacity
- For mass production of the nanofibers, facility development, polymer recipe, electrical, electronics, and control of the complex technologies should be proceeded.



Nano-I

TOPTEC´s Unique Nanofiber Production System

Nanofiber Mass Production Plant



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Many thanks for your attention

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Questions & Comments