ELMARCO
NANO FOR LIFE

Your partner for

Commercialization of Nanofibers Products

May 2016

Agenda

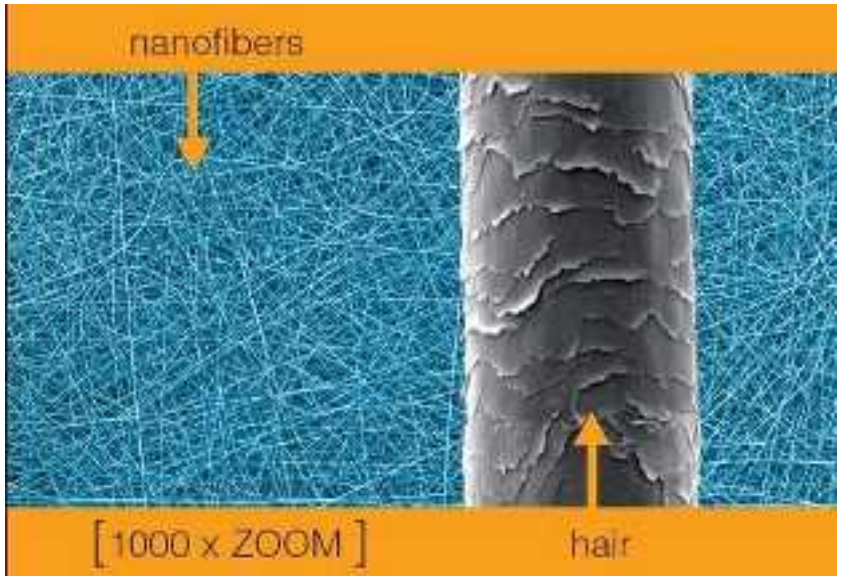
- Nanofibers - A world in 10^{-9} m
- Nanospider™ technology
- About Elmarco
- Nanospider™ Products
- Key for successful scale up towards commercialization
- Growth of Nanofibers Market & Industries
- Nanofiber applications

Nanofibers - A world in 10^{-9} m

- **Definition**
- **Nanofibers are a nanomaterial**
  - At least one dimension less than 100 nm
- **Industrial definition: diameters below 1,000 nm**
  - Made from polymers
  - Created and used as a layer or web

Benefits

- Very large **specific surface area**
- Extremely high **porosity**
- Small pore size – good **breathability**
- Wide range of **polymers** capable of spinning
- Possibility to incorporate different **additives**

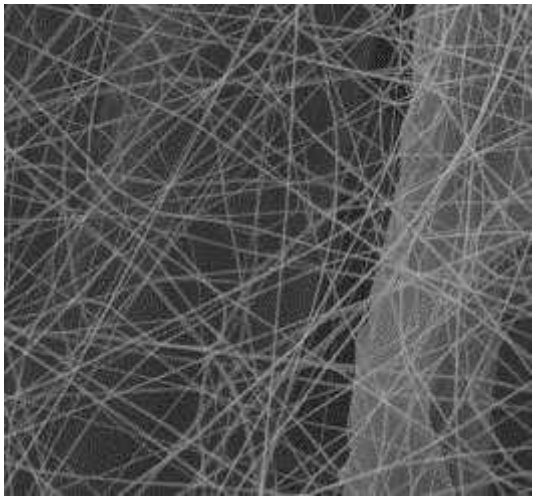


Ways to make Nanofibers

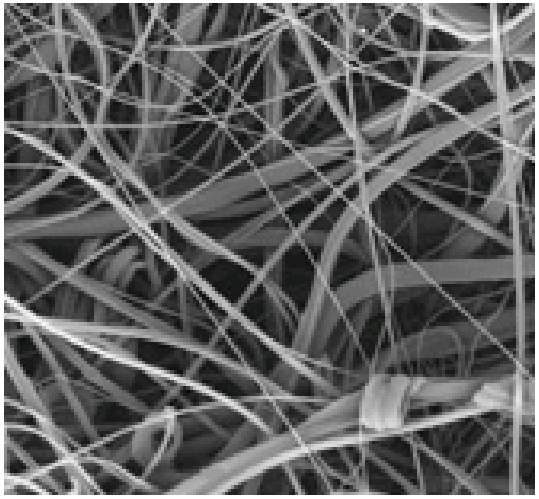
Process	Technological Advances	Can the process be scaled	Control on fiber dimensions	Material Flexibility	Fiber diameter
Drawing	Laboratory	Limited	No	Limited	2-100 nm
Template Synthesis	Laboratory	No	Limited	Limited	100 nm
Self-Assembly	Laboratory	No	No	Limited	5-100 nm
Phase Separation	Laboratory	No	No	Limited	50-500 nm
Electrospinning	Industrial	Yes	Yes	Wide	50-500 nm
Melt Electrospinning	Laboratory	No	Yes	Wide	200-800 nm
CO2 Laser	Laboratory	No	Limited	Limited	100-500 nm
Force Spinning	Laboratory	No	Limited	Wide	200-500 nm
Sea & Ireland	Industrial	Limited	Limited	Limited	200-500 nm
Melt Blown	Industrial	Yes	Yes	Wide	400-50,000 nm

Nanofibers – Scale Nano *vs.* Micro

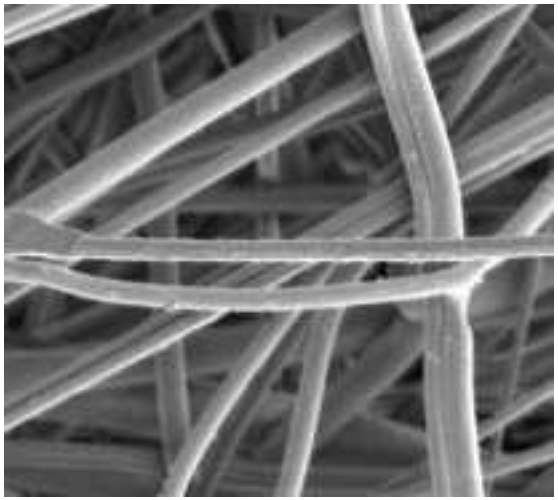
Electrospinning
Elmarco Nanospider™



Fine Fiber Meltblown



Meltblown



Fiber diameter:

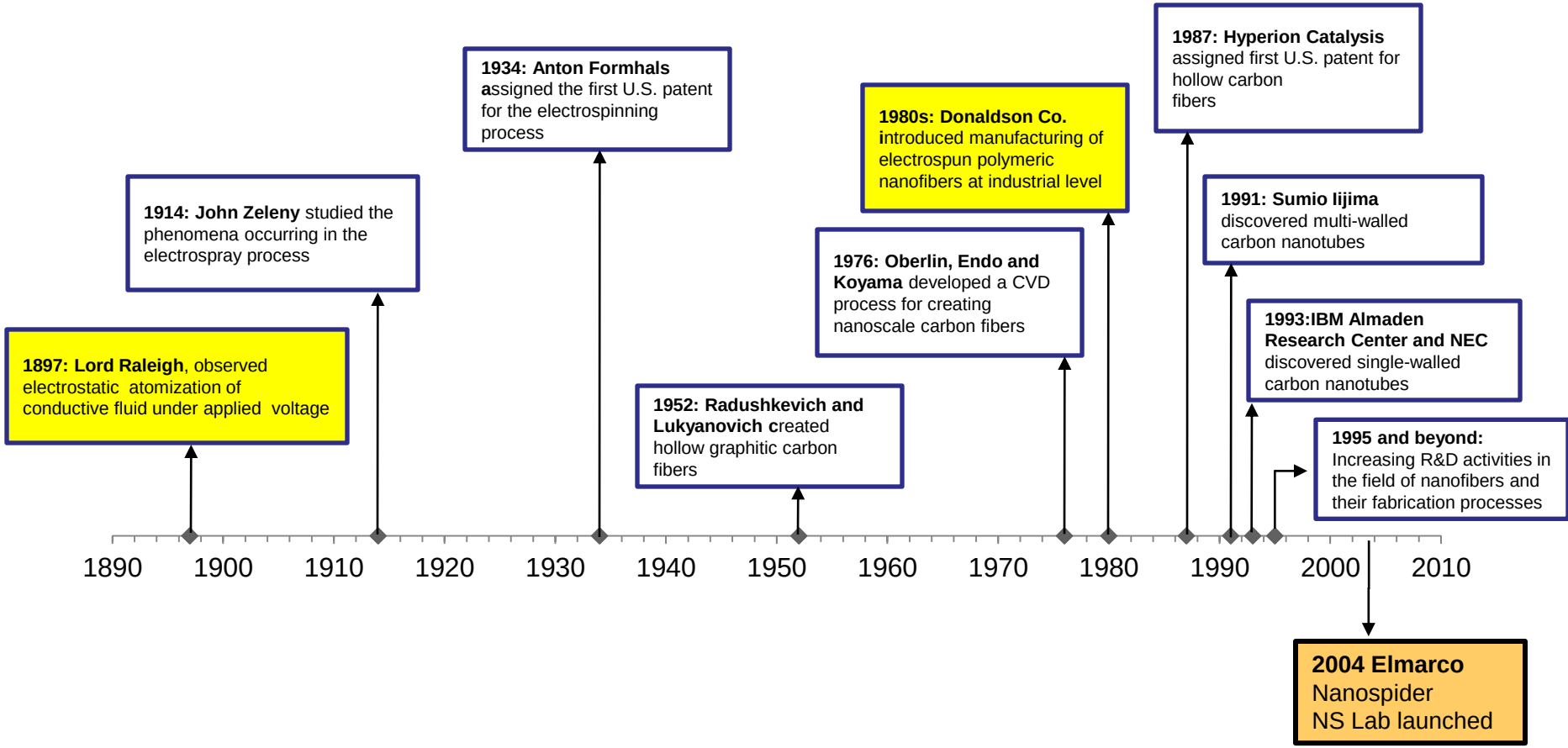
50-500 nm	100nm - 10 µm	1 - 50 µm

Nanofibers – Scale Nano *vs.* Micro

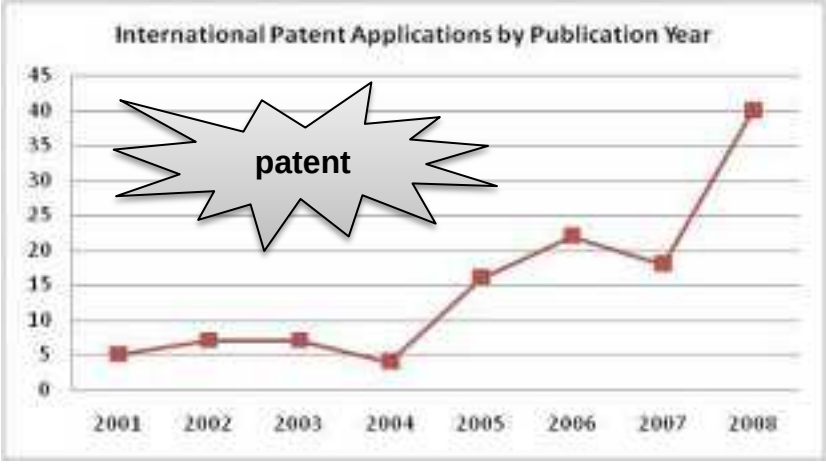
Major Nonwoven Production Process

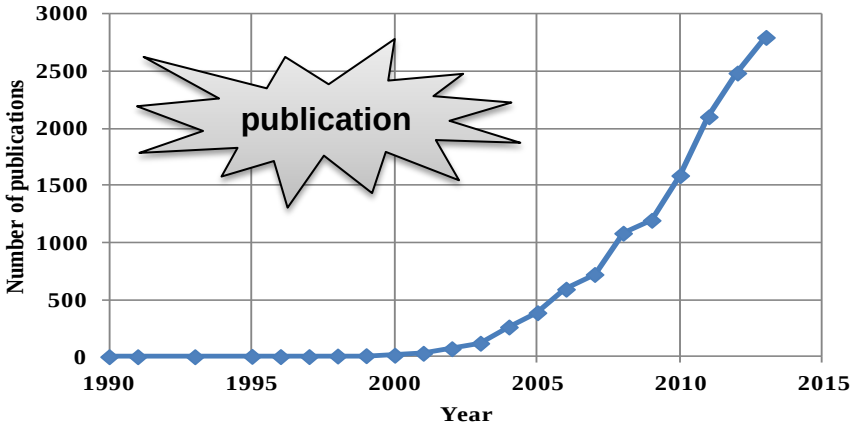
Spunbond	Meltblown	Electro Spinning Elmarco Nanospider
Fiber diameter: 5 - 100 µm	1 - 50 µm	50 - 500 nm

Technological Milestones

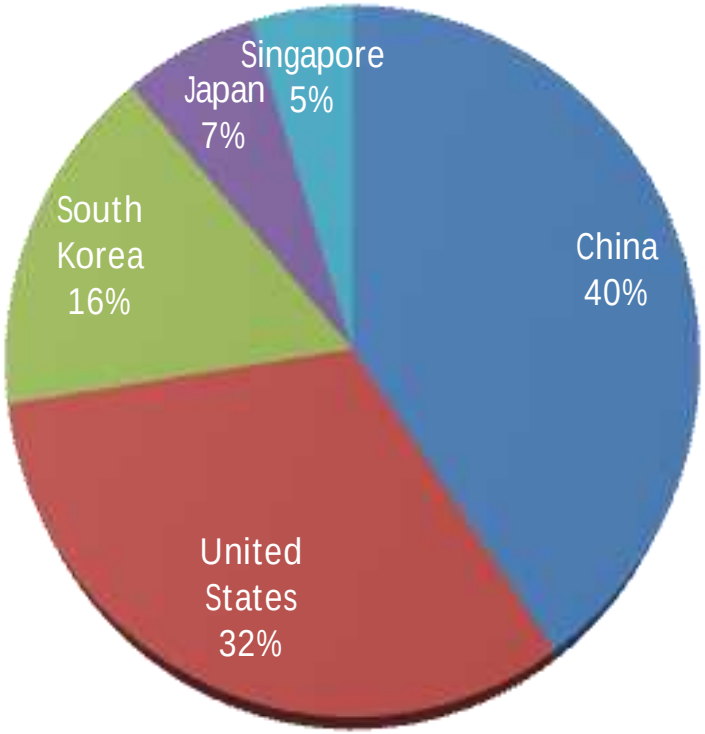


Electro Spinning: A growing technology



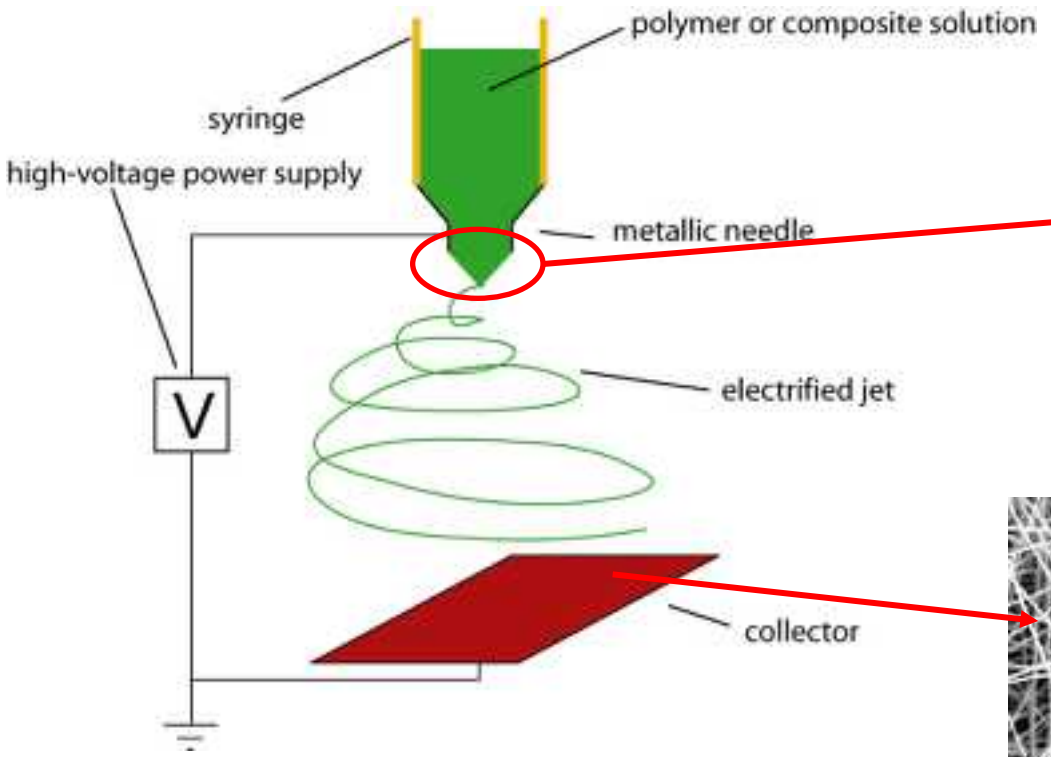


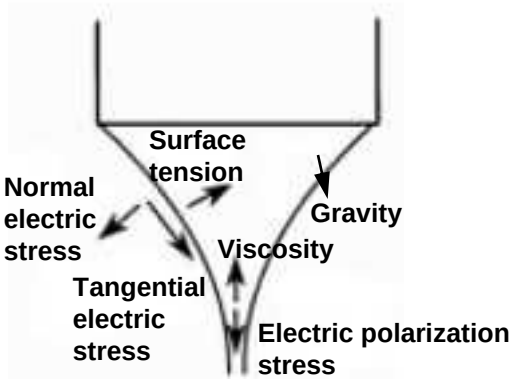
Electro Spinning Related Publications by Country of Origin

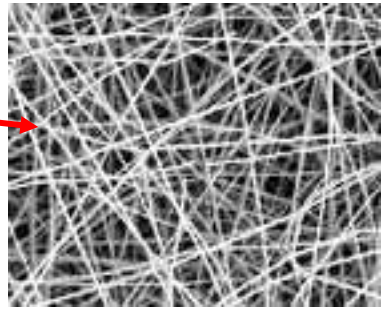


Movie

Electrospinning (ES) –
How to make nanofiber web ? – Conventional approach







Movie

The process of electrospinning was patented by J.F Cooley in February 1902 (U.S. Patent 692,631) and by W.J. Morton in July 1902 (U.S. Patent 0,705,691

Technical Challenges by Needle type technology for mass production

Conventional NEEDLE TYPE

Electrospinning is NOT Suitable for

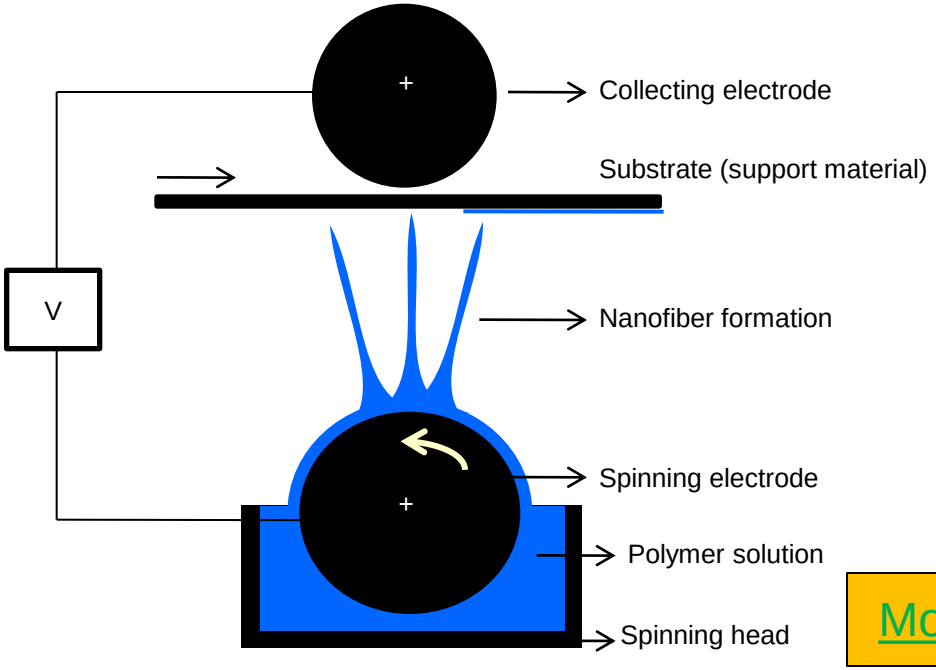
Industrial Scale Production

- **CLOGGING AT NEEDLE (NOZZLE) TIP**
- **MECHANICAL COMPLEXITY OF DESIGN**

Nanospider™ Electrospinning

The Elmarco Way

NanoSpider™ Technology does NOT use Needles



Movie

Nanospider™ - Needle-free technology

Benefits

Electrode is uniformly coated in polymer

Nature defines the distance between Taylor cones

- Mechanically simple
- Lower operating costs
- Lower equipment costs
- Higher fiber packing density
- Higher fiber uniformity
- Higher web uniformity

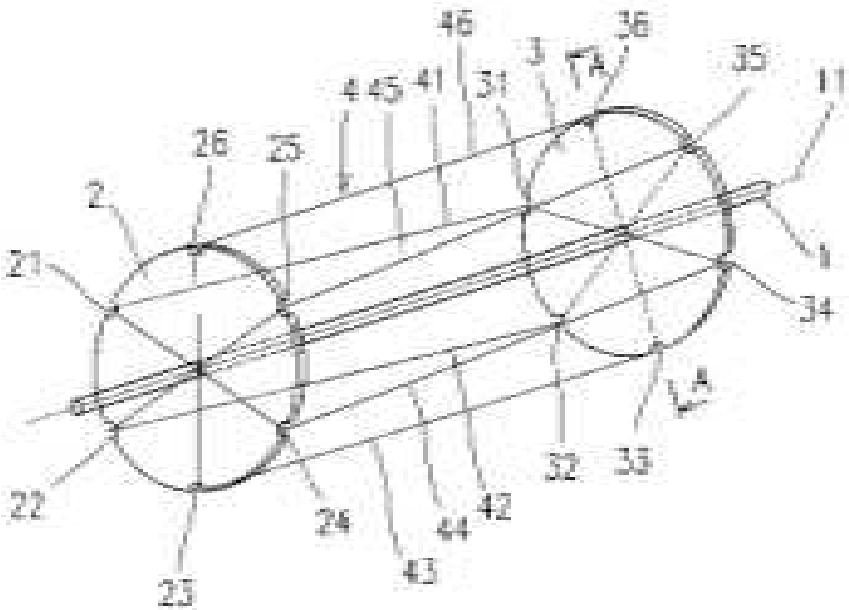
Nanospider™ IN ACTION

Production Line Photos – Courtesy by ATIRA - Ahmedabad Textile Industry's Research Association (India)

Movie

Nanospider™ - Technology Development
Generation 1.1 – non-Water Solvents

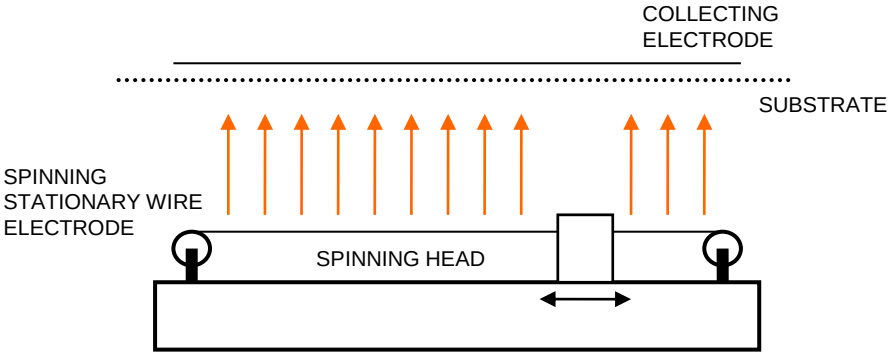
- Principle:
  - Describe in many patents
  - Example: PCT/CZ2007/000082
- Shape of spinning electrode
  - Wire place on rotation shape

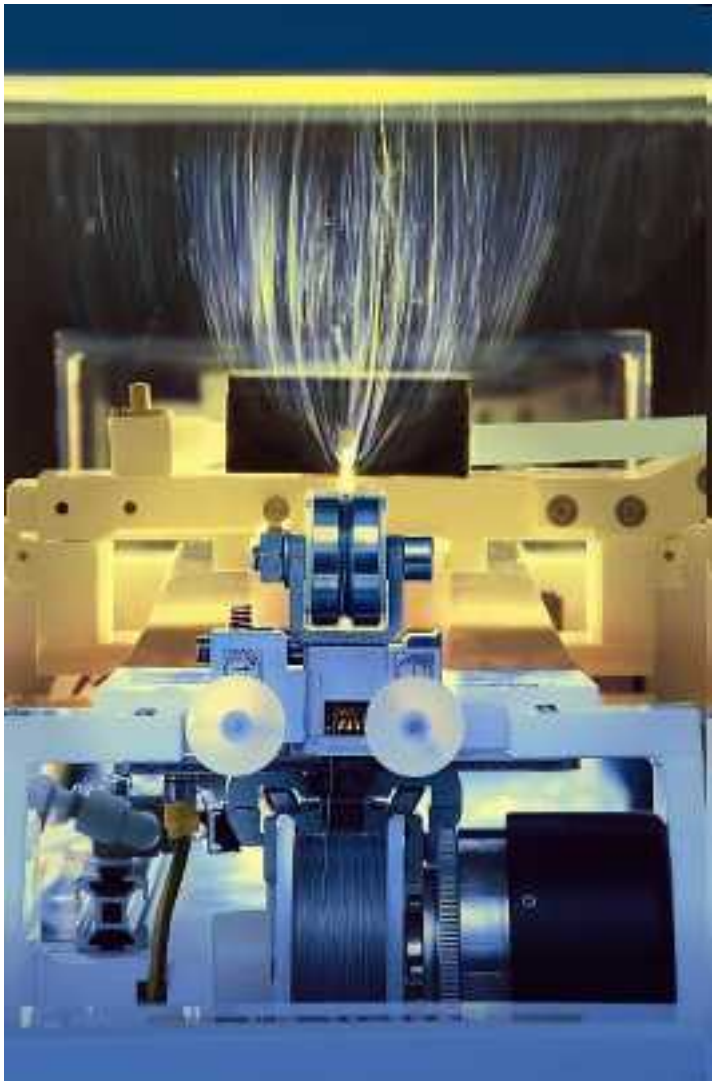


Nanospider™ - Enhanced 2Gen technology

Benefits of 2Gen technology based on stationary wire electrode system:

- Nanofiber and nanofiber web uniformity
- Low polymer and solvent consumption
- Highly volatile solvents capability
- Designed for long time shifts
- Cost effective operation

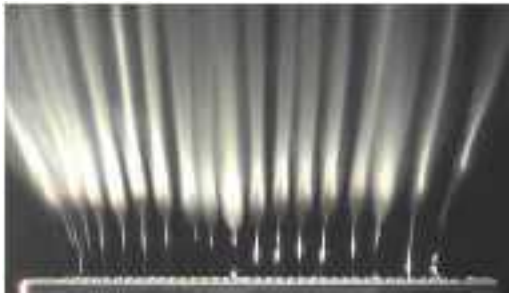




Nanospider™ - Needle-free technology

- Needless: Nature defines the distance between Taylor cones
- Simplicity of design
- Robustness against clogging of a spinneret
- Increased productivity though the simultaneous operation of numerous jets.

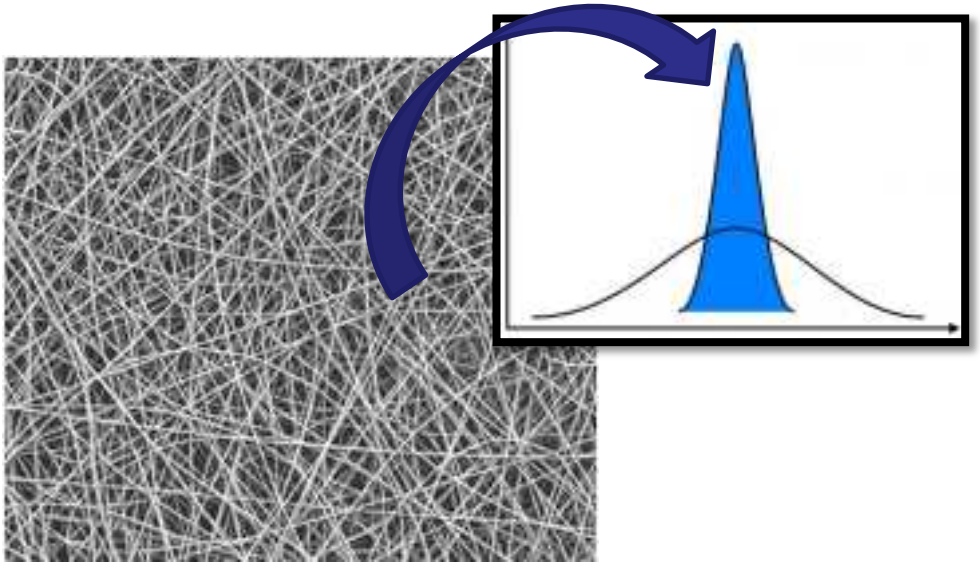
Droplet formation → Jet formation → Mass production

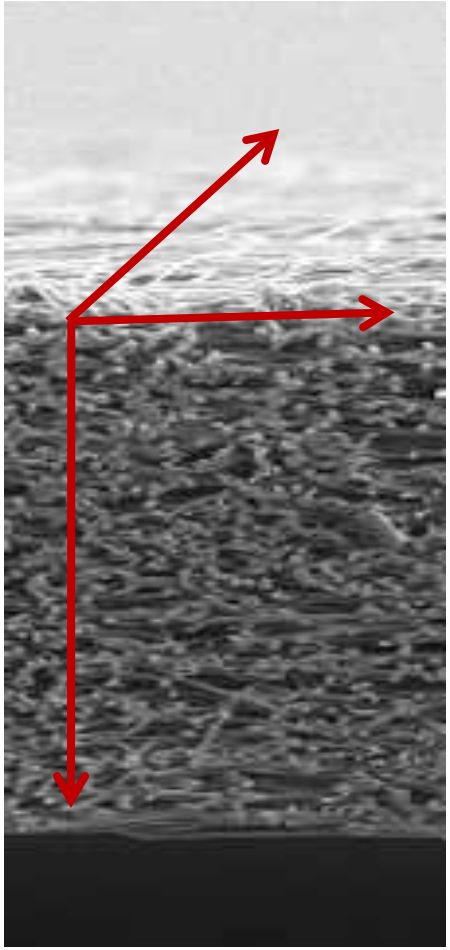


*Keith M. Forward, Gregory C. Rutledge, Chemical Engineering Journal 183 (2012)
*David Lukas, Arindam Sarkar, Pavel Pokorny, Journal of Applied Physics 103, (2008)

Nanospider™ – Quality

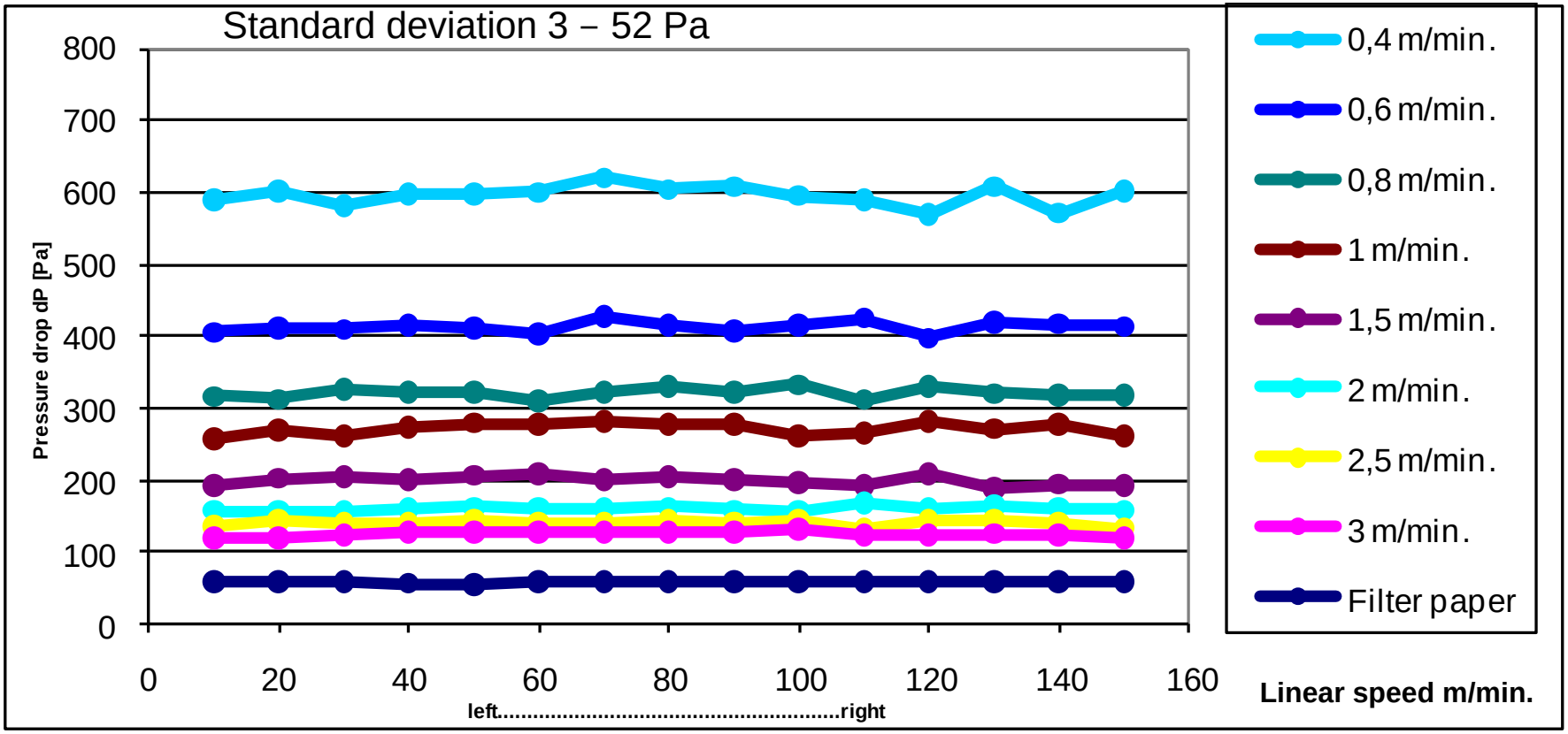
- **Uniformity** in all directions
- **Homogeneous** size distribution
- **Defect-free** structure
- **Reproducibility** (repeated results at long-term)
- **Industry-proven** technology





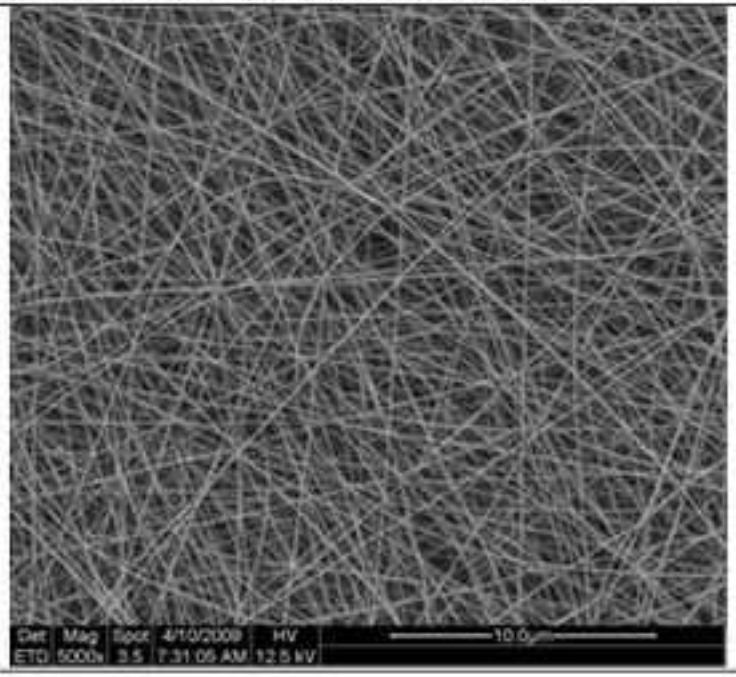
Nanospider™ - Web Uniformity

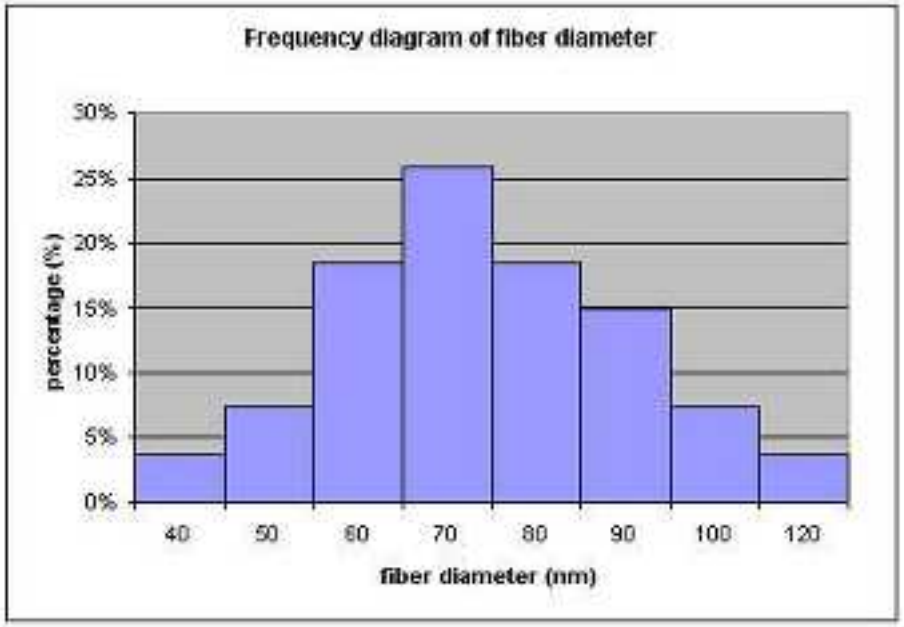
Cross profile uniformity



Nanospider™ - Fiber Uniformity

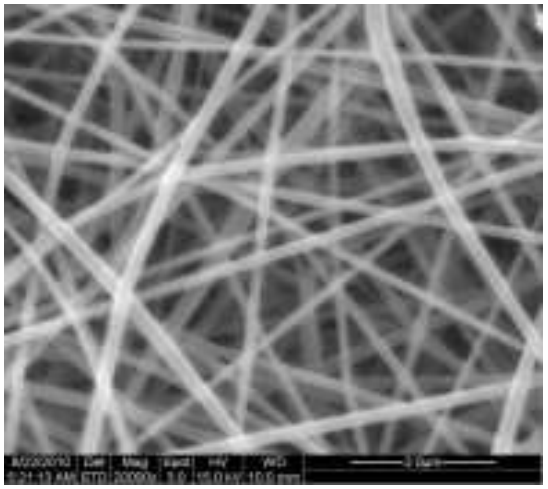
Table 1. shows SEM picture (magn. 5000 x) with PA6 nanofiber layer, frequency diagram of fiber diameter and basic statistical data

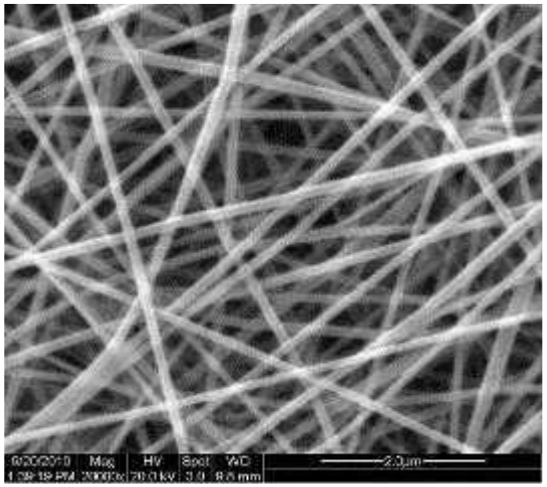


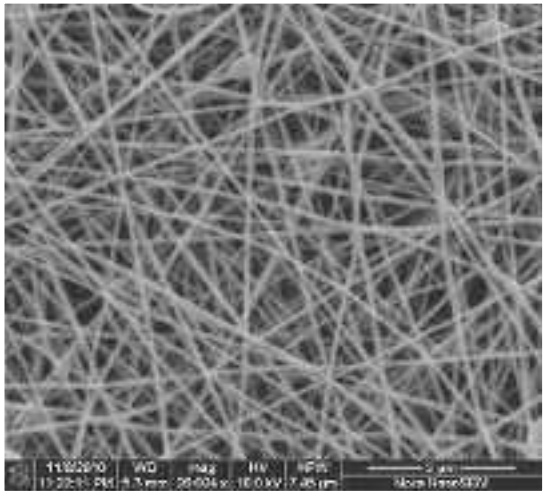


Count of fibers	80	Mean	71 nm
Standard deviation	17 nm	Coefficient of variation	24%

Tuning at industrial scale - PA6

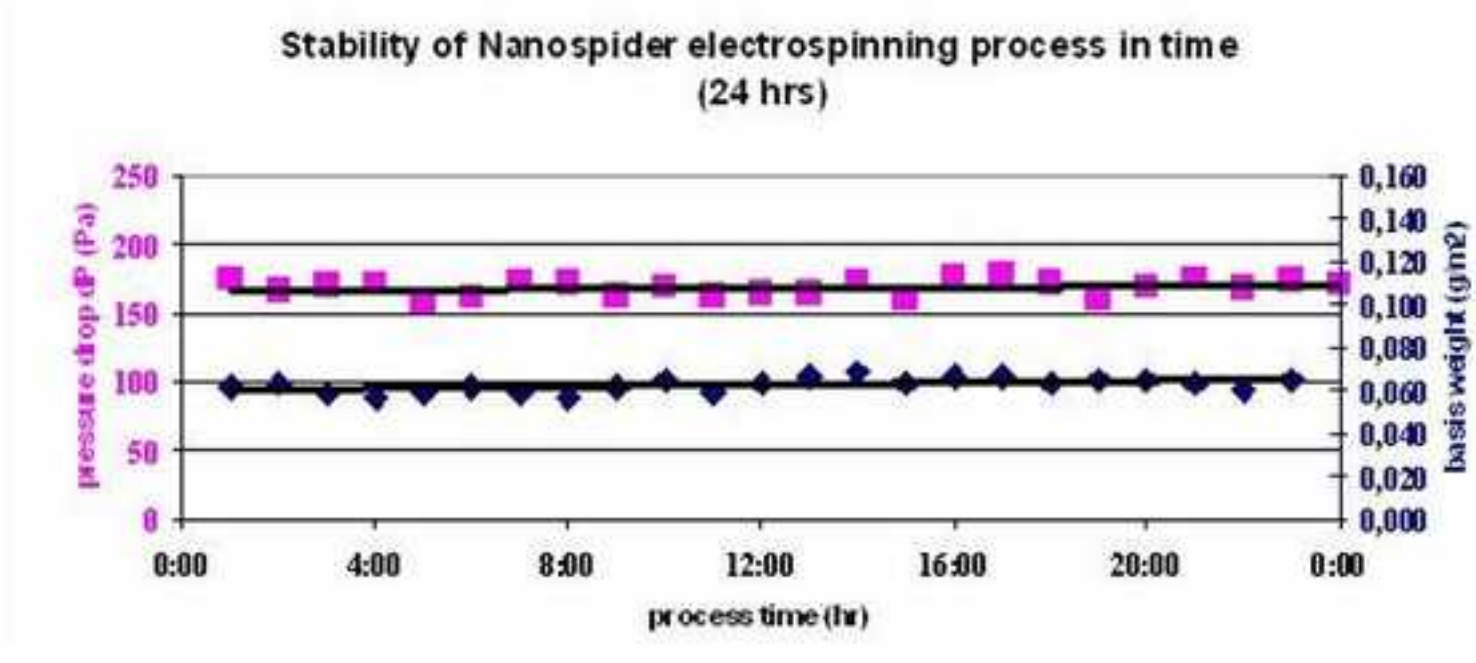






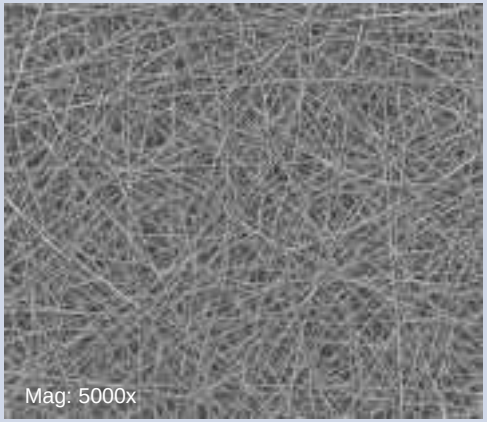
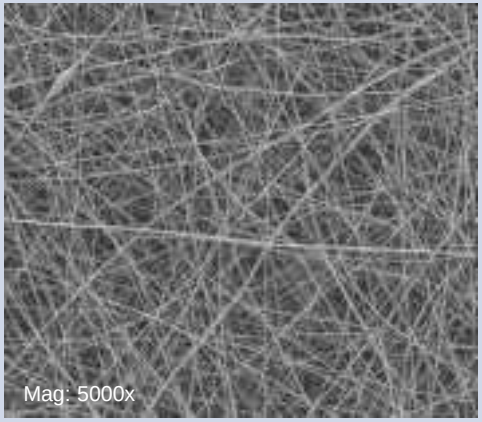
Mean fiber diameter		
147 nm	110 nm	50 nm
Average pore size		
500 nm	330 nm	165 nm

Nanospider™ - Process Stability



	mean	standard deviation	Coefficient of variation
Pressure drop*	169 Pa	6 Pa	4%
Basis weight	0,063 g/m^2	0,003 g/m^2	5%

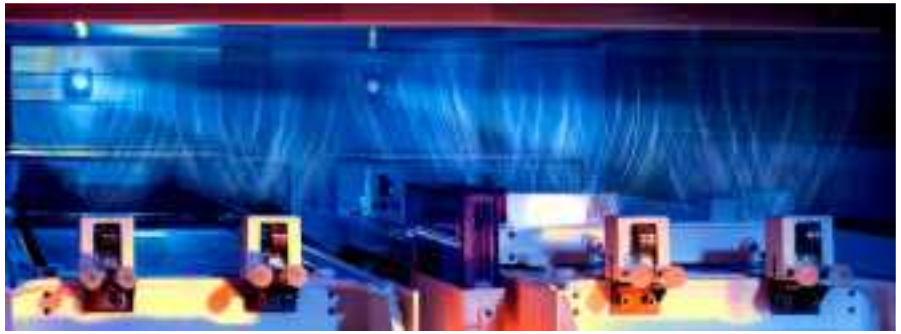
Nanospider™ - Material flexibility

Organic	Inorganic	Biopolymers
PA6, PA 6/12	TiO_2	Gelatin
Polyaramid	SiO_2	Chitosan
PUR (Polyurethane)	SnO_2	Collagen
PES (Polyethersulfone)	WO_3	Pullulan
PVA (Polyvinylalcohol)	Al_2O_3	PAA, PVA
PAN, PEO, PS, PVP, PVP-I	$Li_4Ti_5O_{12}$	PLA, PCL
PVDF, PVDF-CTFE,		
		

Selected examples only, numerous other polymer systems have been deployed

Nanofiber Production Technology – Industrial

Needle-free (Nanospider™)

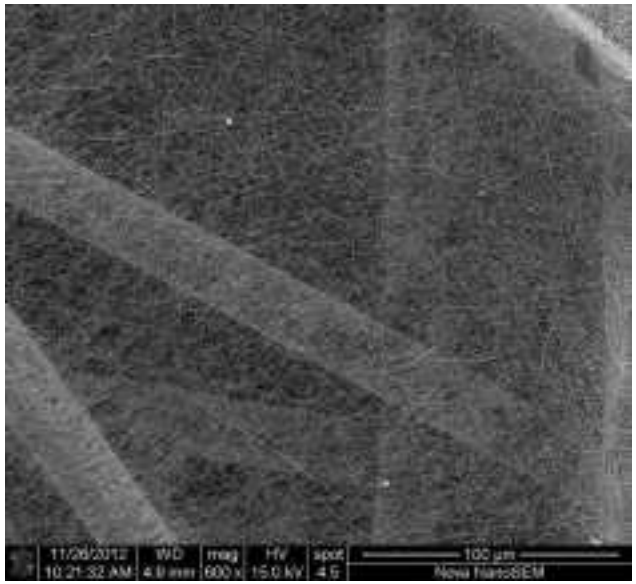


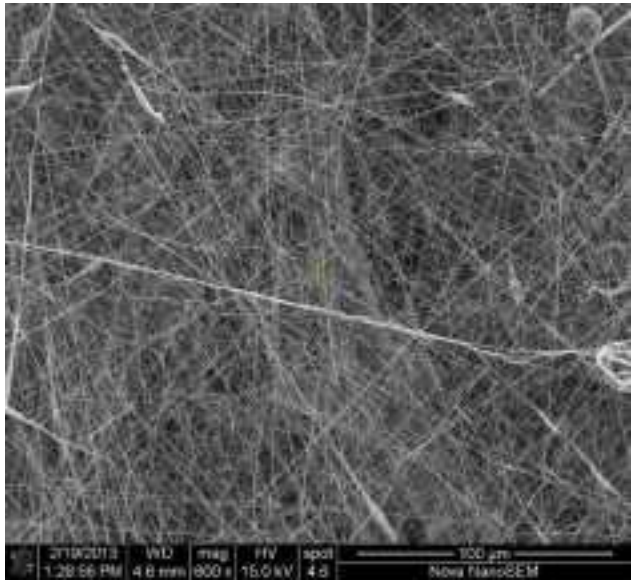
Multi-nozzle

Centrifugal

Multi-needle

Quality Comparison – PA6





Parameter	Nanospider™	Benchmark
Fiber diameter	Mean fiber diameter: 100 nm (controlling fiber diameter at industrial scale)	Mean fiber diameter: 160 nm (no fiber diameter control)
Fiber diameter distribution	Narrow: StDev: 21	Wide: StDev: 73
Defects	Defect free	Beads, droplets, discontinuous and non-uniform fibers
Uniformity (Thickness , MD and CD)	Good	Poor
Pore size	Uniform pore structure with controllable pore size	Non-uniform pore structure – no pore size control

ABOUT ELMARCO

Elmarco is the industry's first supplier of industrial scale nanofiber production equipment.

Elmarco - Company Profile

Elmarco - Global support and service

Liberec, Czech Republic
Global HQ, Sales, Service - Europe,
Corporate R&D, Equipment production

Raleigh, NC, USA –
Sales, Service, Americas, Showroom

Tokyo, Japan –
Sales, Service, Asia-Pacific Showroom

Elmarco - Milestones

2004 – 2006	2007 – 2009	2010	2011	2012	2013	2014

Elmarco's Nanofiber division was formed in 2004

- 2007: first industrial Nanospider™ line was installed
- 2Gen Nanospider™ technology introduced

- First installation of 2Gen NS Line 1600
- 2Gen lab tool introduced

100 Nanospider™ machines sold

- Air filtration reference product development

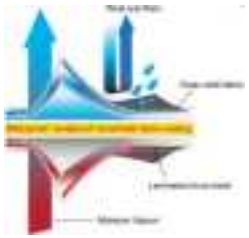
- First Nanospider™ lab prototype developed for water soluble polymers
- First Nanospider™ equipment for solvent-based polymers developed

- First Nanospider™ line installed in cleanroom facility

150 Nanospider™ machines sold

- New World-class Technology Center in Liberec and supporting offices in the US and Japan was opened

- High perform. Nanospider™ technology for NF membranes



2004 – 2006	2007 – 2009	2010	2011	2012	2013	2014

Elmarco, an Innovator
- Top High-tech Company in Czech Republic

A visit of

Mr. Vaclav Klaus, President of Czech republic

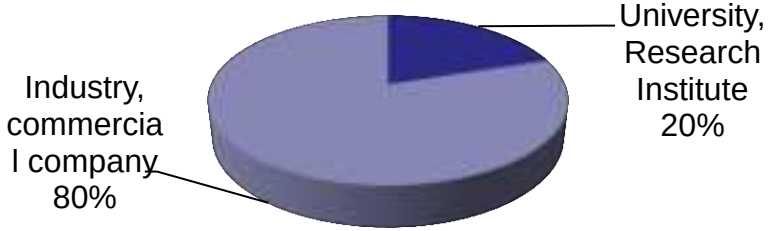
to Elmarco HQ in Czech republic on Wednesday, April. 20, 2011

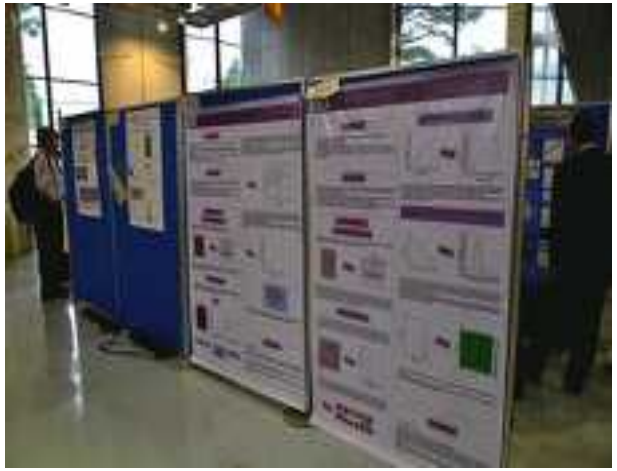
ELMARCO
NANO FOR LIFE

www.nanofibers2012.com

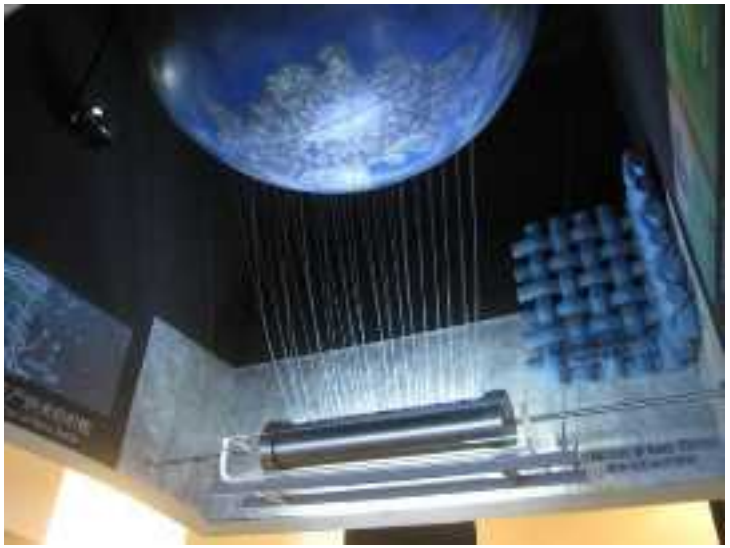
From which field?

The total number of participants: 340





Elmarco, an Innovator - EXPO 2010, Shanghai



Elmarco NanoSpider Model In Czech Pavilion at EXPO 2010

Nanofiber Technical Seminar At Elmarco Day, Oct. 2010

Movie

Movie

Elmarco - Tokyo Showroom

Since February 2011

Nanospider™ - Product portfolio

Lab Products	Production Lines		
NS LAB	**NS 1S500U**	**NS 4S1000U**	**NS 8S1600U** **Elmarco's flagship product**
0.3 m width Single electrode	0.5 m width Single electrode	1.0 m width	1.6 m width
Standalone spinning unit	Standalone spinning unit (line)	Standalone spinning unit (line)	Scalable up to 4 units in line
Designed for the academic and basic research market	Optimized for the rigors of industrial labs and corporate R&D		Targeted towards reliable 24/7/365 production




Nanospider™ - NS 8S1600U

Technical data

- Stationary wire principle electrodes
- 8 spinning electrodes per unit
- 1,6 m spinning electrode width
- Scalability up to 4 units (32 spinning electrodes) in line

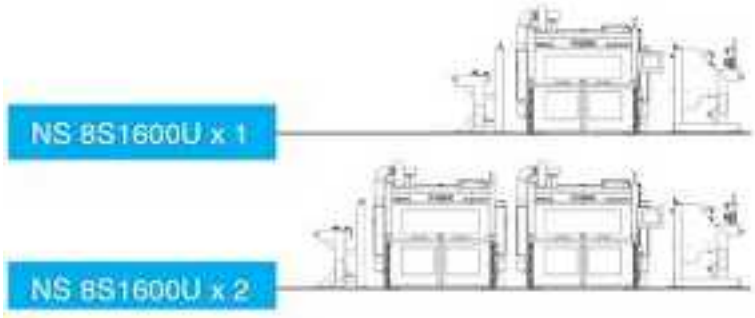
Benefits

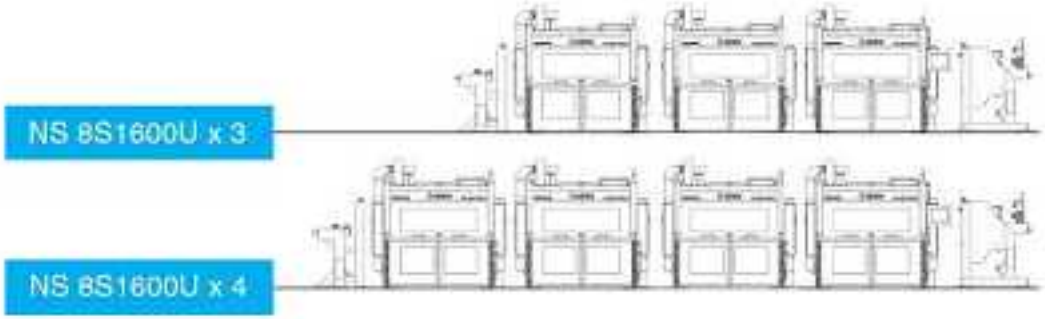
- Optimized for non water soluble polymers
- High throughput per unit
- High nanofiber web and fiber uniformity
- Low volume polymer system with reduced solvent & polymer consumption

Nanospider™ - NS 8S1600U

Production volume scalability

- 1, 2, 3 or 4 spinning units in line
- 8, 16, 24 or 32 spinning electrodes in line
- Start with one unit and scale up by addition of spinning units
- Centralized process control
- Optional peripheral equipment

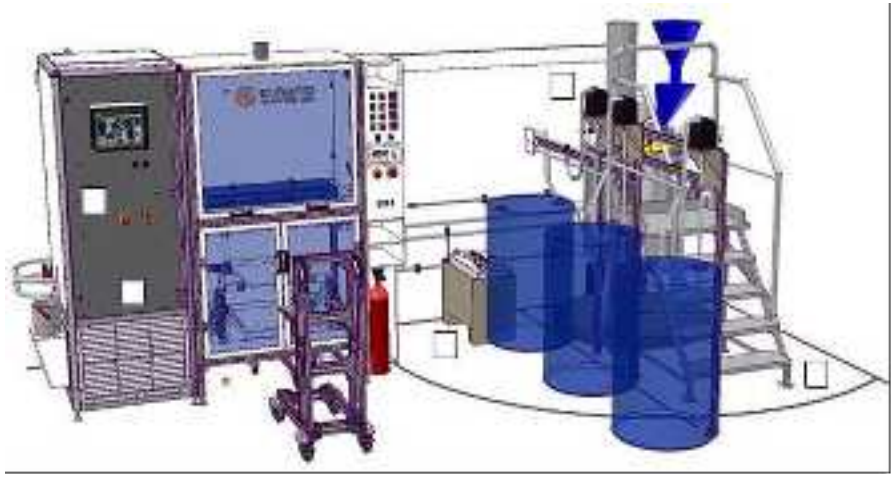




NS8S1600U Major Peripheral Equipment

elmarco NANO FOR LIFE

Filling & Cleaning Station + Polymer Mix Station



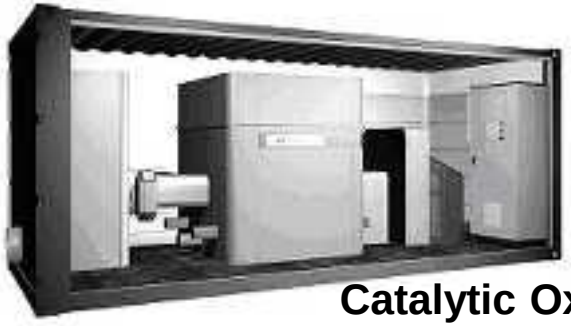
Precise Air Conditioning Unit

Adhesion Module

Hot Air Dryer

Solvent (Waste Air) Treatment System

Scrubber Type



Catalytic Oxidization Type

Production Layout Example – NS8S1600U

Nanospider™ - NS 4S1000U

Technical data

- Stationary wire principle electrodes
- 4 spinning electrodes
- 1,0 m spinning electrode width (configurable between 0,3 – 1,0 m)

Benefits

- Optimized for non water soluble polymers
- High nanofiber web and fiber uniformity
- Cost effective equipment for early stage manufacturing

Nanospider™ - NS 1S500U

Technical data

- 500 mm spinning electrode width
- Run time per batch approx. 60 min, (depends on polymer / solvent solution)
- Integrated unwind / rewind with low substrate speed capabilities for thick membrane materials preparation
- Process data tracking for PC analysis

Benefits

- Full time shit operation enabled by peristaltic pump for continuous feeding of polymer solution
- Easy to switch between production and experimental work
- Enabled for higher gsm and composite samples preparation
- Easy set up and operation

Movie

Nanospider™ - NS LAB

Technical data

- Spinning electrode width: 300 mm
- Run time per batch: 30 - 80 min (depends on polymer / solvent solution)
- Volume of solution per batch: 40 ml
- Substrate speed: 0 - 5000 mm/min
- Spinning voltage: 0 - 80 kV
- Integrated substrate unwind / rewind

Benefits

- Designed for experimental work
- Compact and affordable research tool
- Easy to scale up to industrial technology
- Time saving experimental work
- Safety door locks and shut off switches

Nanospider™ - NS LAB

Basic research and development

- Robust platform for creating a uniform nanofiber membrane for materials science, technical textile and membrane experimental work
- Designed for experimentation and product development in academic, research and industrial spheres

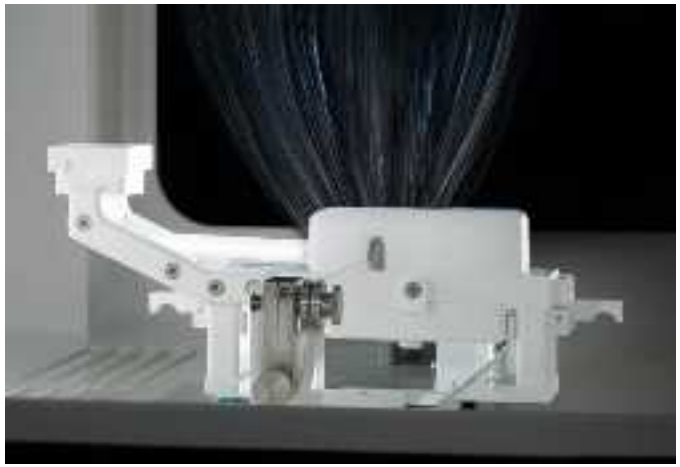
Basic application exploration

- Ideal for exploratory research in membrane, air filtration, liquid filtration, medical, and many other areas
- Designed to enable basic materials science exploration such as process parameters and new material development

Nanospider™ - NS LAB

Stationary wire electrode system

- The same industrial-proven technology as found in industrial NS production lines
- High throughput
- High nanofiber diameter uniformity
- High nanofiber web homogeneity
- Easy to scale up to NS production lines



Nanospider™ - NS LAB 200, NS LAB 500

Technical data

- Interchangeable spinning electrode
- 500 or 200 mm spinning electrode width
- Run time per batch up to 20 min
  (depends on polymer / solvent solution)
- Scalable volume polymer system
- Built in roll-to-roll capabilities for substrates

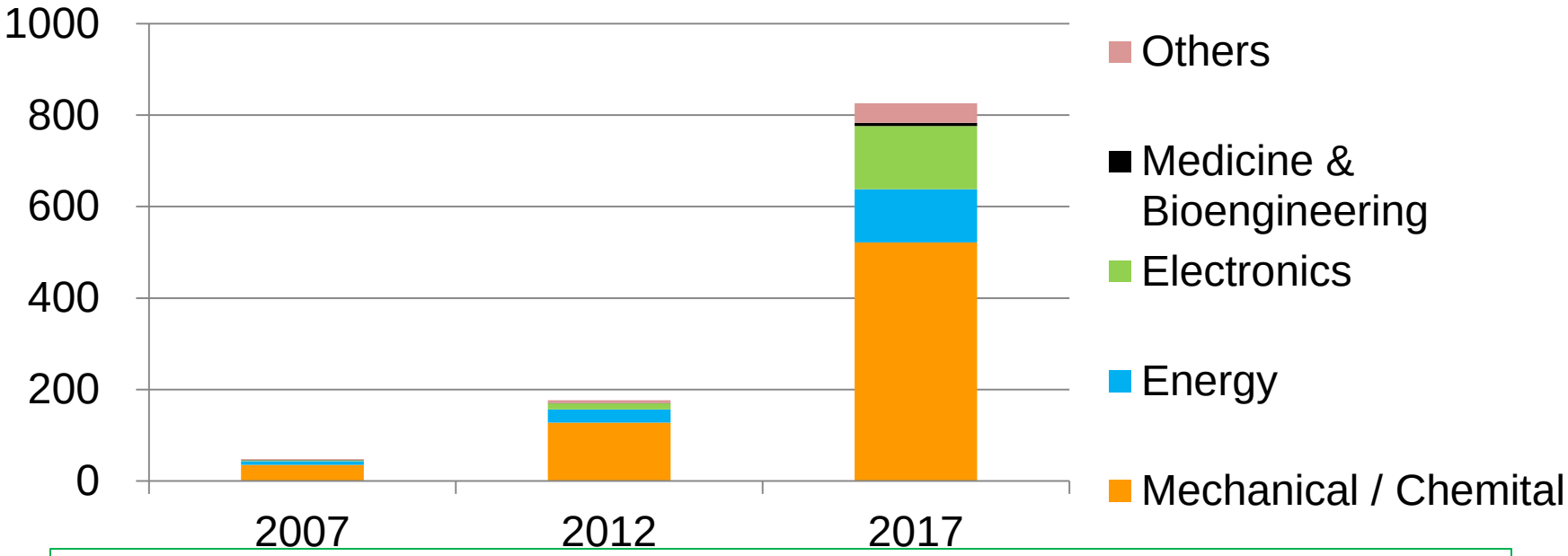
Benefits

- Designed for experimental work
- Easy to scale up to industrial technology
- Capable of spinning variety of polymers
- Coat numerous substrates, including cellulose, synthetics and fiberglass
- Time saving experimental work

Discontinued

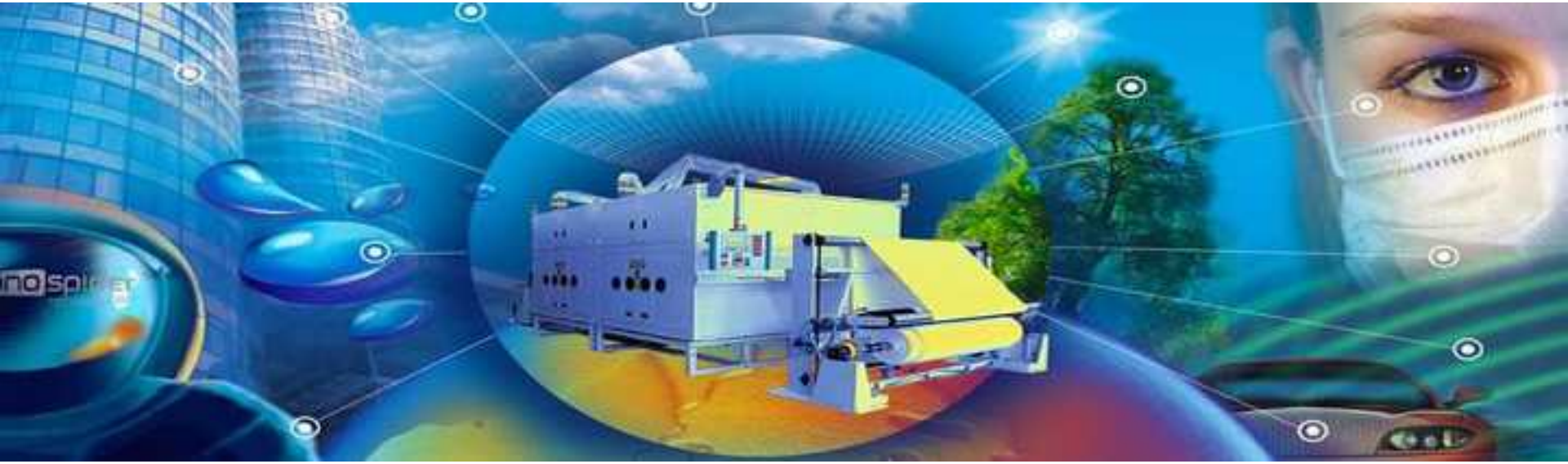
Global Market of Nanofibers – Market Research Report

FORECAST (2017) – NANOFIBER GLOBAL REVENUES BY APPLICATION, ($ MILLION)



A company who has mass production electrospinning technology will be the winner !!!

Source: BBC Research



Nanofibers Applications

APPLICATIONS BY INDUSTRY

Environment

- •Air filtration
- •Water filtration
- •Photocatalysts
- •Ion exchange systems
- •Noise absorption

Electronics

- •Flat panel displays
- •Hard disk drives
- •Optical waveguides
- •Optoelectronic devices
- •Piezoelectric devices

Energy

- •Lithium Batteries
- •Solar cells
- •Fuel cells
- •Supercapacitors

Defense

- •Warfare protection
- •Bulletproof uniforms
- •Anti-counterfeiting devices

Health

- •Wound care materials
- •Tissue engineering
- •Barrier garments
- •Respirators
- •Drug delivery materials

Automotive

- •Noise absorption
- •Filters
- •Batteries
- •Electro-static discharge

Building

- •Thermal insulation
- •Sound insulation
- •Solar panels

Consumer

- •High-tech textiles
- •Biodegradable packaging
- •Personal care

Nanofiber applications – Ready for commercialization

Air filtration

- Industrial HVAC
- Engine air Intake
- Cleanroom (HEPA, ULPA)
- Gas turbines
- Dust collectors

Acoustic materials

- Transportation
- Room acoustics
- Home appliances
- Industrial equipment

Healthcare

- Wound care
- Tissue engineering
- Drug release
- Surgical drapes
- Face masks

Liquid filtration

- Drinking water preparation
- Fuel and oil filtration
- Processing filtration
- Waste water treatment
- Seawater treatment

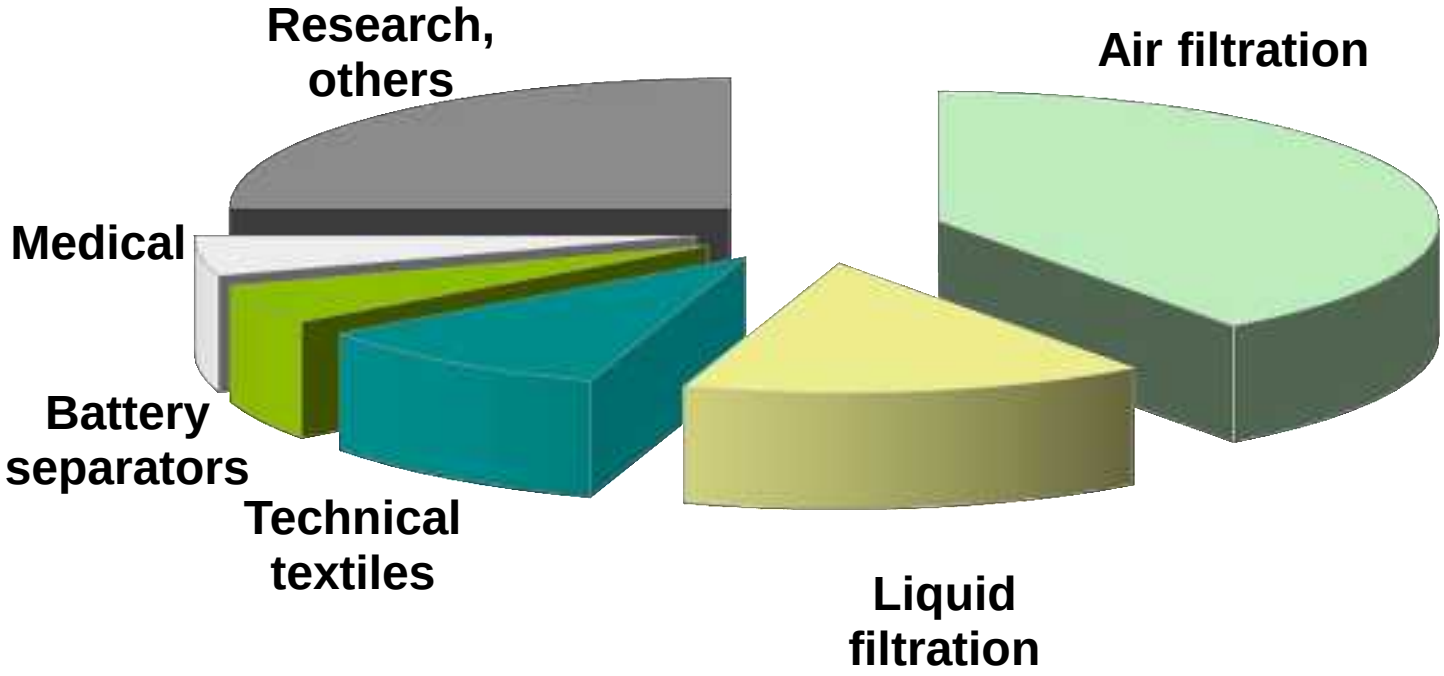
Lithium-ion batteries

- Battery separators
- Battery electrodes

Performance apparel

- Outdoor sportswear
- Protective clothing
- Footwear

Applications by Elmarco Nanospider™ Production Line customers

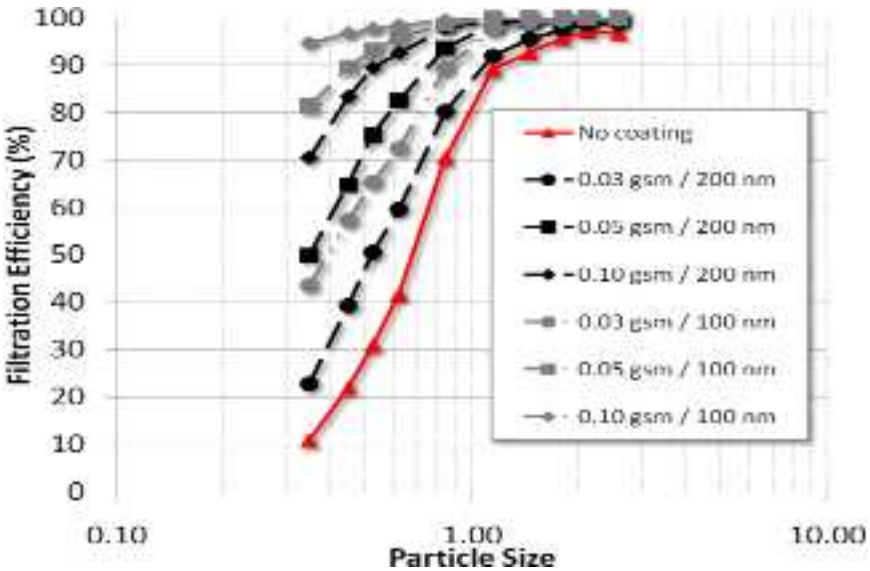


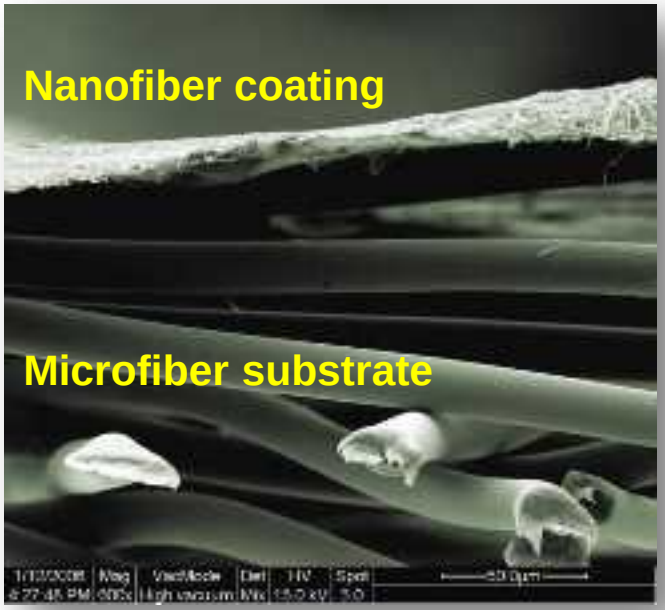
Note: Figures valid as of May 2013

FILTRATION

Nanofibrous filter media has enabled new levels of filtration performance in several diverse applications within a broad range of environments, with improved filter life, increased contaminate holding capacity and enhanced filtration efficiency.

BENEFITS OF NANOFIBROUS FILTER MEDIA





BENEFITS OF NANOFIBERS

- Relatively straightforward way to upgrade low cost, low performance media to high end media at a lower or competitive cost.
- Often best performance combination metrics available (i.e. high efficiency, low pressure drop, longer life).
- Flexible and universal media design platform with wide variety of materials.

HEPA – Grade

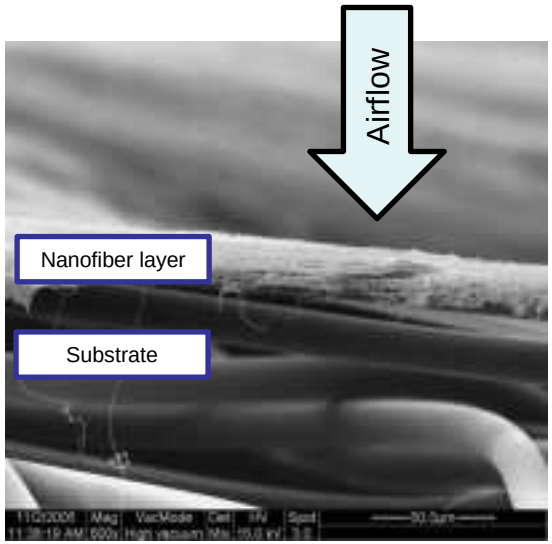
EN 779:2012			EN 1822:2009		
Course Filters	Medium Filters	Fine Filters	Aerosol Filters		
G1-G4	M5-M6	F7-F9	E10-E12	H13-H14	U15-U17
Average arrestance (Am) of synthetic dust %	Average efficiency (Em) for 0.4 µm particles %	Minimum efficiency (ME) for 0.4 µm particles %	Integral efficiency MPPS	Integral and Local efficiency MPPS	

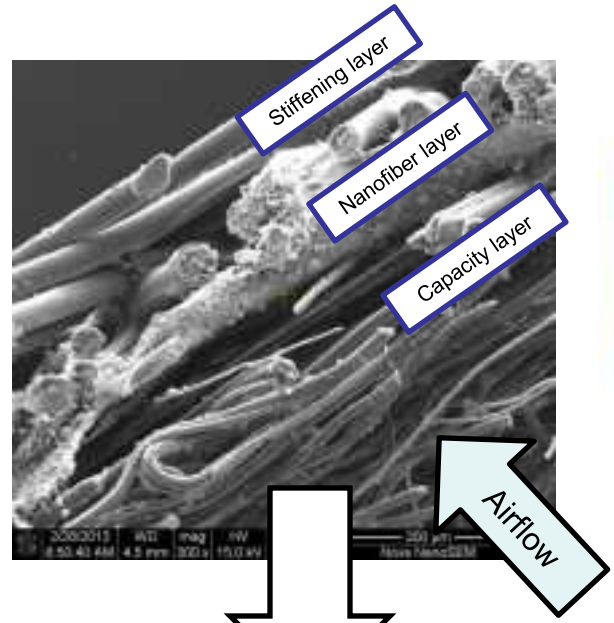
Nanofibers not relevant | Commercial Solution | Development

Nanofiber Depth Filter Media

Nanofibers for surface filtration

Nanofibers for depth filtration

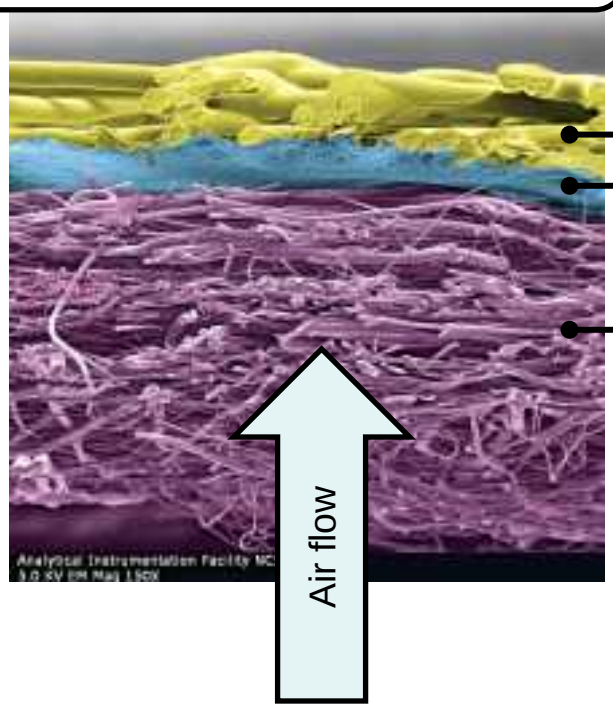


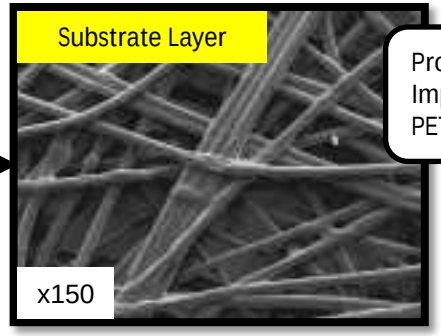


A synthetic nanofiber filter media which meets high mechanical efficiency, low pressure drop and high dust loading capacity

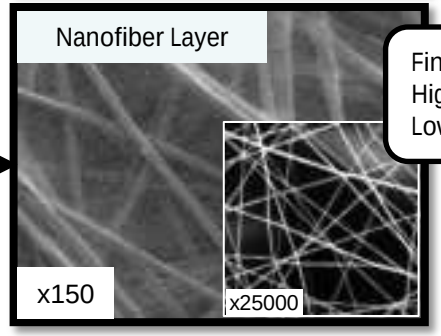
Gradient Media Design

Traditional media provides a coarse pre-filter upstream to enhance dust holding capacity and a nanofiber layer with finer pore structure and smaller fiber diameter downstream for high particulate filtration efficiency

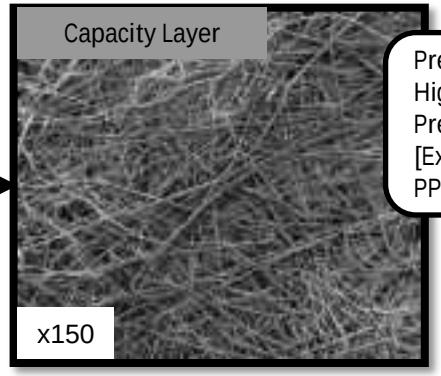




Protecting nanofibers
Improving rigidness [for pleating]
PET spunbond



Fine filtration (small particulates)
High filtration efficiency
Low pressure drop



Pre-filtration (large particulates)
High dust holding capacity
Prevents clogging of nanofibers
[Extends filter life]
PP meltblown

Nanospider™ - NS 8S1600U

Features

- **8 spinning electrodes per unit**
- **1,6 m spinning electrode width**
- **Scalability up to 4 units (32 spinning electrodes) in line**

Performance

	English	Metric
Type	High efficiency mini-pleat V-bank filter	
Nominal dimensions (H x W x D)	24 x 24 x 12 (inches)	610 x 610 x 305 (mm)
Media area	172 ft^2	16 m^2
Nominal face velocity	492 fpm	2.5 m/s
Initial pressure drop	0.33 in wg	82 Pa
Efficiency Rating per ASHRAE 52.2: 2007	MERV 15 @ 1968 cfm >95%	F9 @ 0,944 m^3/s >95%
Efficiency Rating per ASHRAE 52.2: 2007 Appendix J	MERV 15A (F9) @ 1968 cfm >95%	
Dust holding capacity	300 g @ 1.5 in wg	300 g @ 375 Pa

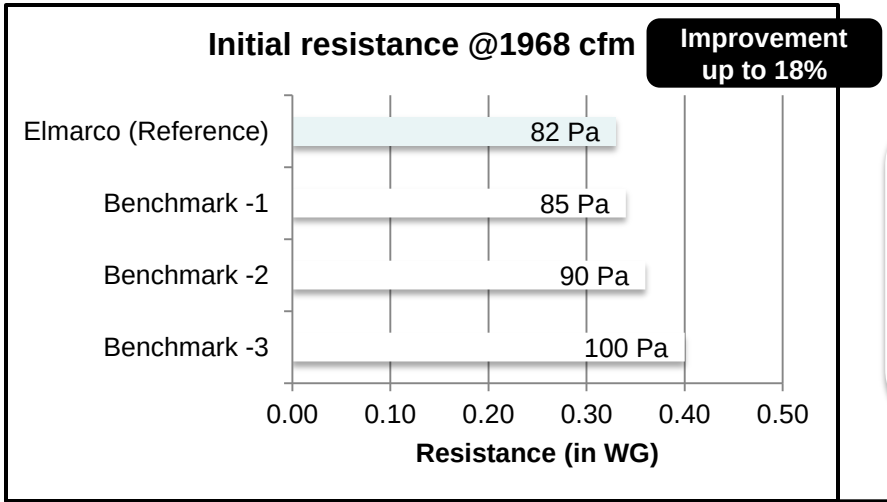
Typical Applications

- Commercial buildings
- Hospitals
- Educational facilities
- Manufacturing facilities
- Research facilities

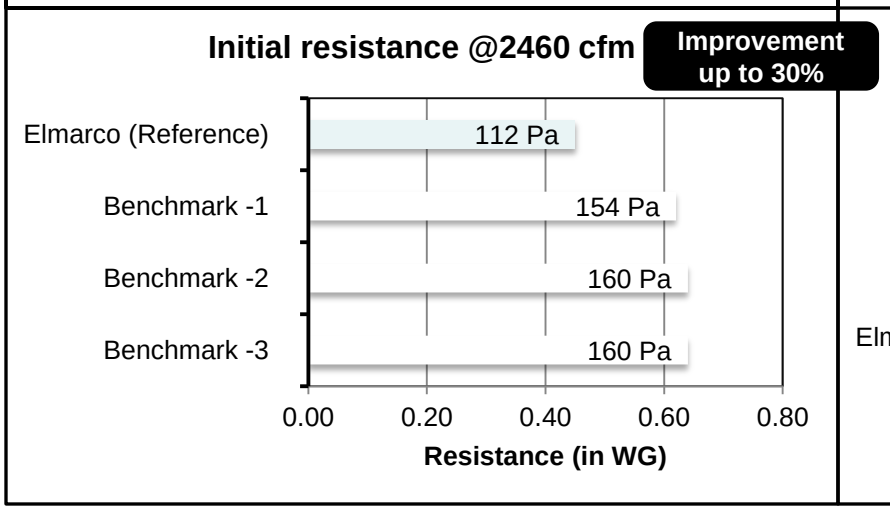
Min. Composite Efficiency (%) after KCL conditioning	
E1 - A (0.3 - 1.0 µm)	89
E2 - A (1.0 - 3.0 µm)	98
E3 - A (3.0 - 10 µm)	100

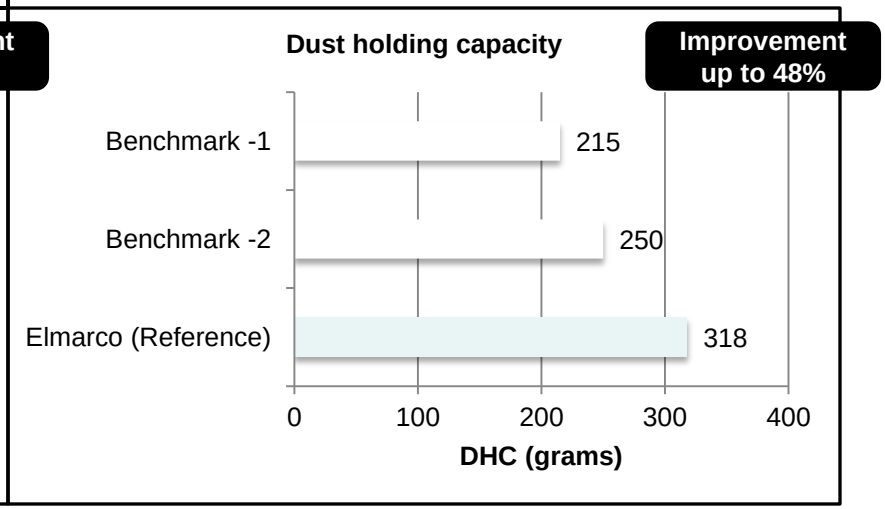
In accordance with ASHRAE 52.2:2007 Appendix J, an independent lab testing has certified the reference filter at **MERV 15A**

Performance Benchmarking

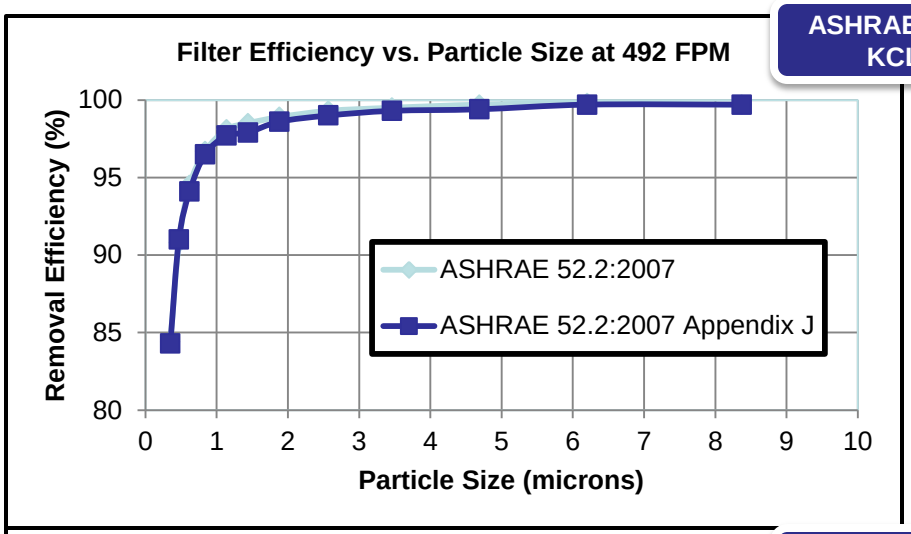


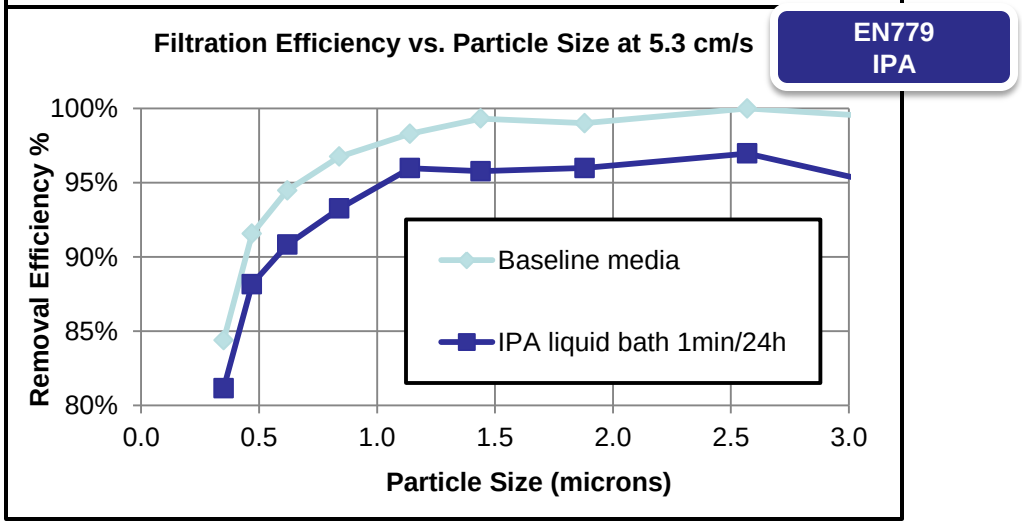
Performance benchmarking with industry leading products. Nanofiber coating provides higher dust holding capacity with better mechanical filtration efficiency and lower pressure drop.



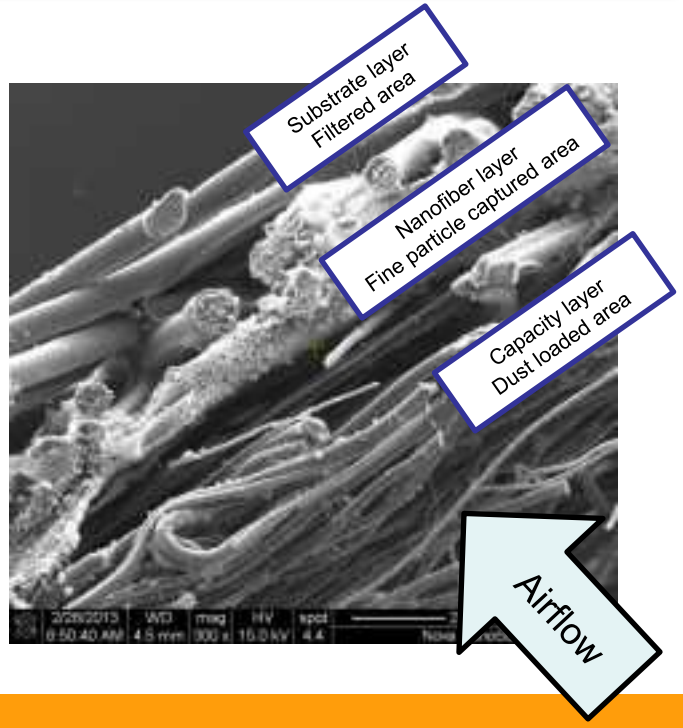


Discharge Durable Nanofibers

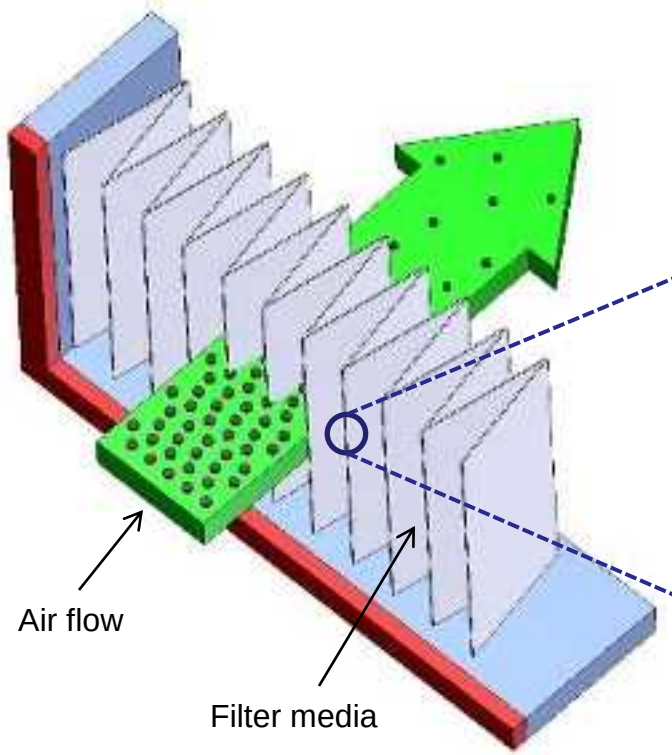




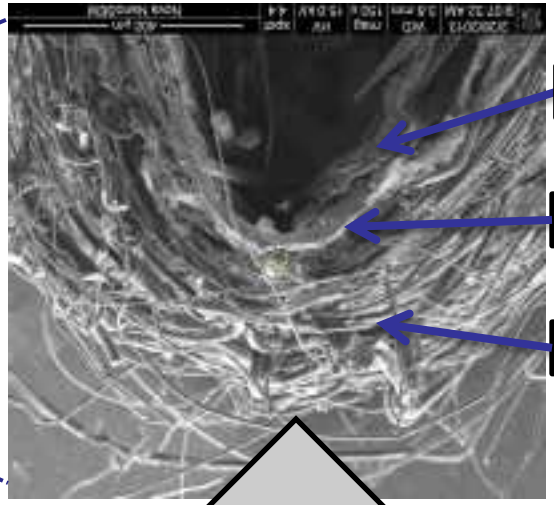
- ✓ *No efficiency drop after discharge procedure*
- ✓ *Proven durability of nanofibers*
- ✓ *High mechanical filter efficiency*
- ✓ *Industry leading low pressure drop*



Mechanically Durable Nanofibers



No damage after pleating & assembling



Substrate layer

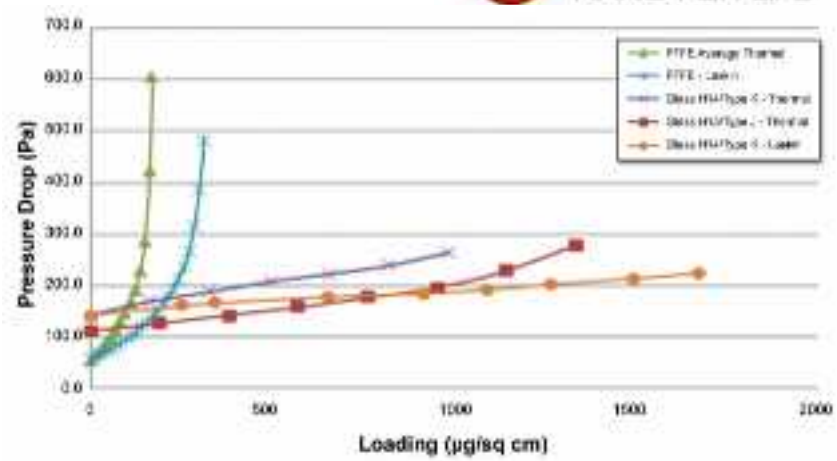
Nanofiber layer

Capacity layer

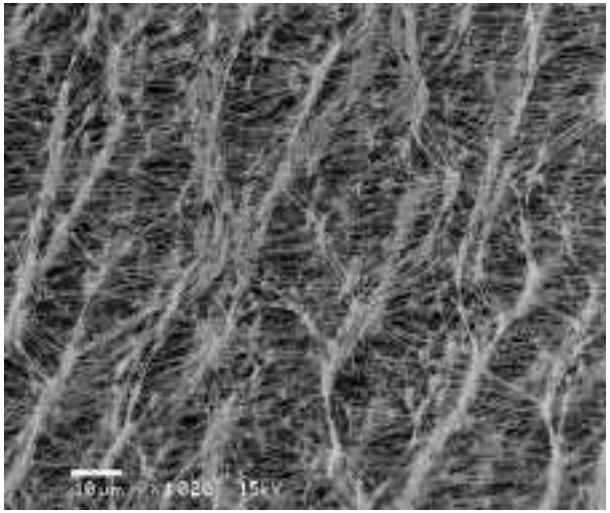
Air flow

HEPA Media

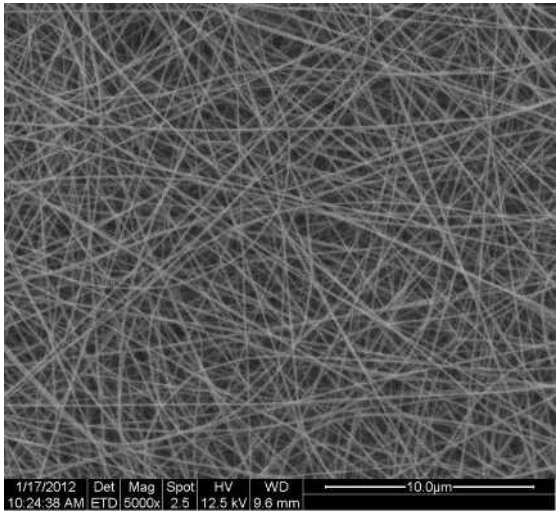
- Glass fiber is the industry standard for HEPA filters. Inexpesive
- Despite low initial pressure drop of e-PTFE filter the rate of increase in pressure drop with PAO loading is substantially higher than microfiber glass media filter.



Microglass fiber



ePTFE

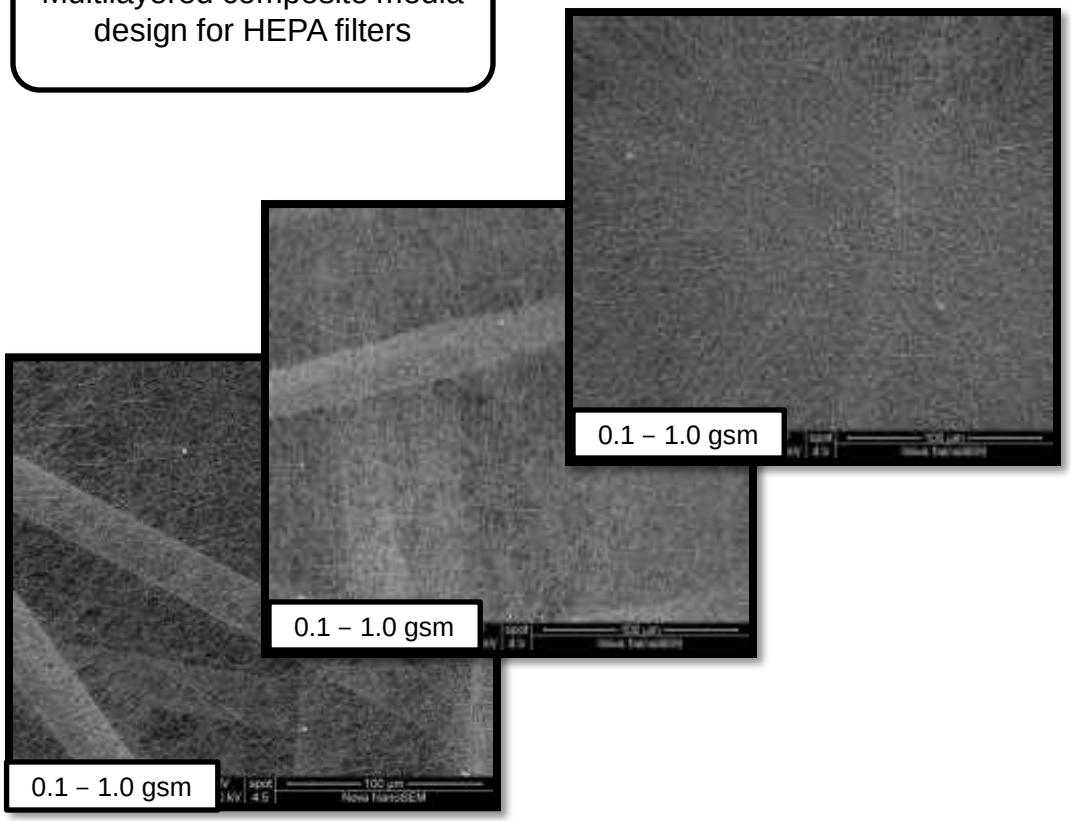


eSpun PA6

Pharmaceutical Engineering, Jan/Feb 2013, vol 33, No1

HEPA Media Design

Multilayered composite media design for HEPA filters



- ✓Fully synthetic composite media with high quality nanofibers
- ✓Not fragile, flexible and easy to handle [Robust materials that perform better than wetlaid glass in materials handling.]
- ✓Lower pressure drop than traditional wetlaid glass media

HEPA FILTER MEDIA made by PA6 Nanofibers

Sample dispatch note	Sample No. Order No.

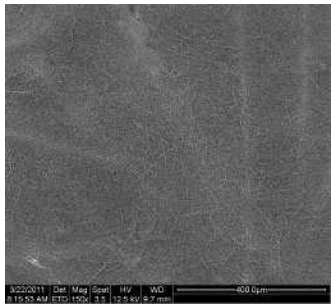
SAMPLE DETAILS

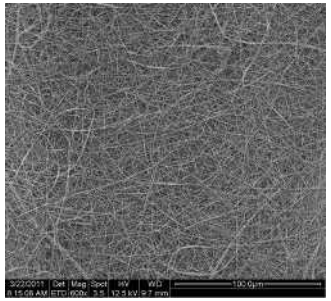
Polymer	PA6	**Substrate**	Filtration Paper
Defects	no		

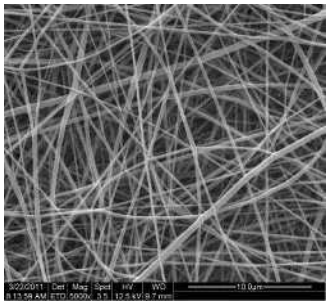
Measuring parameters

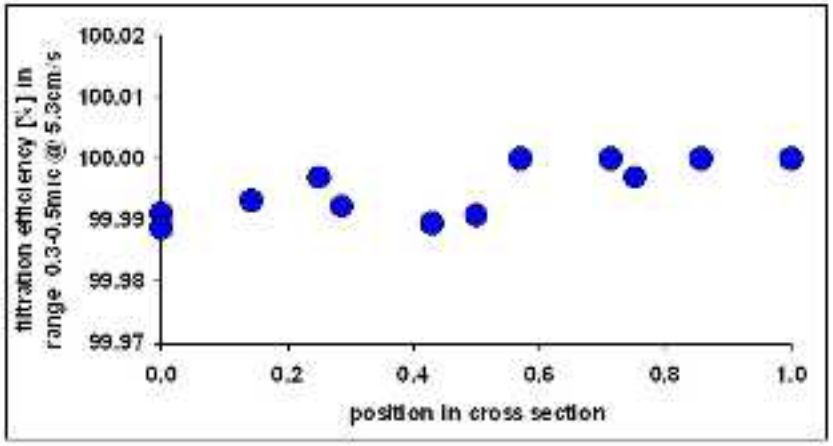
Properties	Measured value	Unit	coeff. of variation	Number of measurements	Timing of measurements	Value	Result	Method description
Pressure drop	200	Pa	± 8	25	end of sample	200	OK	testing area 20cm2; airspeed 5.3cm/s - Textest 3300
Fiber diameter	195	nm	± 51	60	end of sample		OK	SEM picture analysis
Adhesion	good adhesion of dry sample, no spontaneous delamination observed after wetting by water						OK	finger test, wetting test
Filtration efficiency	99.995	%	± 0.005	13	end of sample	99.97%	OK	SEM picture analysis
Sample volume	12	m					OK	

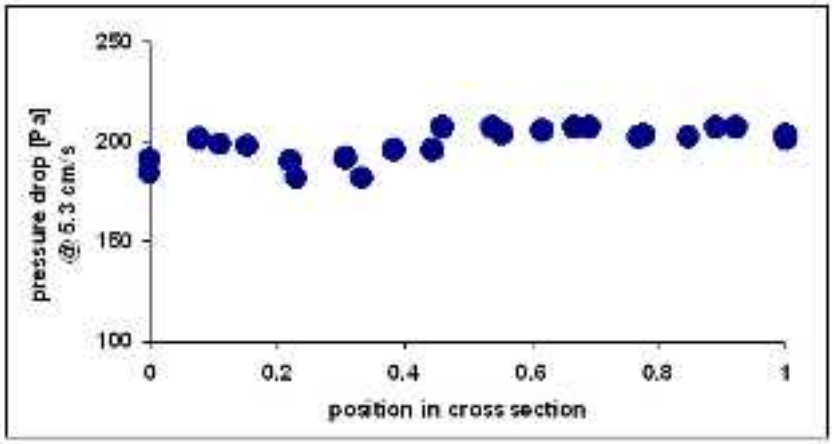
SAMPLE IMAGE











Applications

HVAC

- Commercial buildings
- Hospitals
- Universities
- Schools
- Airports
- Manufacturing facilities
- Hotel
- Entertainment complexes
- Research facilities

Automotive

- Cabin air intake
- Engine intake

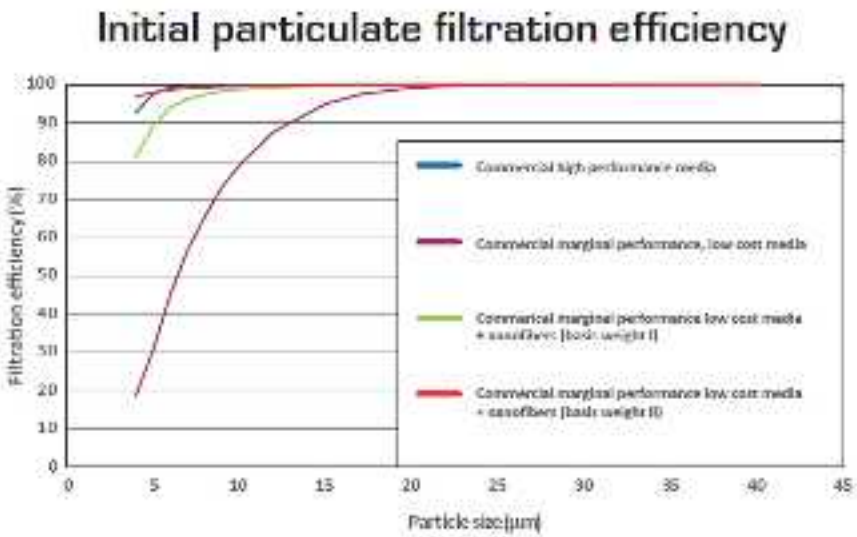
Air Purifier & Vacuum Cleaner

- HEPA

Nanofiber applications – Liquid filtration

Key features of nanofibers:

- High porosity
- Small pore size
- Interconnected pore structure
- Unique physical and mechanical performance
- Design flexibility for chemical / /physical surface functionalization



Inexpensive substrate + thin nanofiber coating =
= superior filtration performance at a lower cost

Nanofibrous filtering media could be used for filtration of water, beverages, bio-pharma materials, blood, chemicals, oils, diesel, petrol, etc

LIQUID FILTER MEDIA made by PA6 Nanofibers

Sample dispatch note	Sample No. Order No.

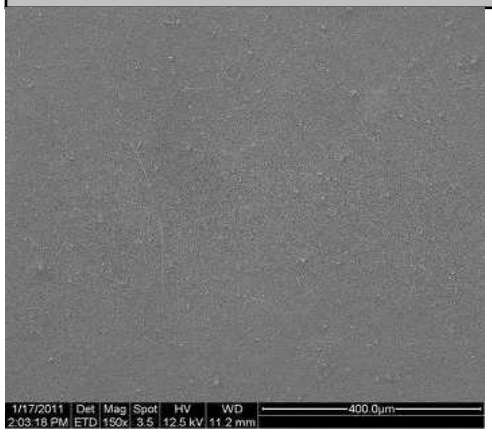
SAMPLE DETAILS

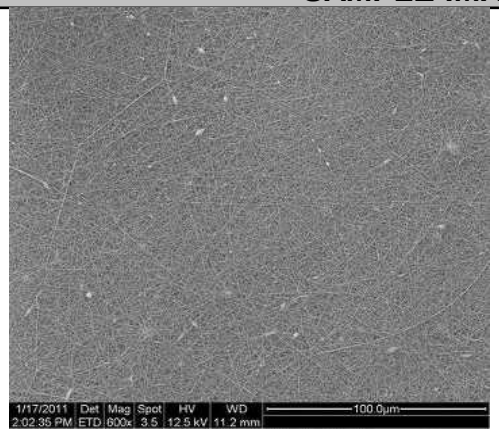
Polymer	PA6	**Substrate**	PA meltblown

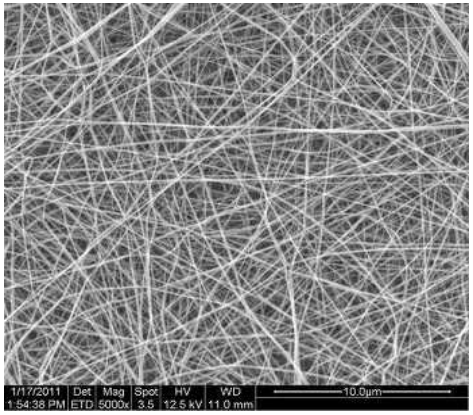
Measuring parameters

Properties	Measured value	Unit	coeff. of variation	Number of measurements	Timing of measurements	Result	Method description
Basis weight	2.13	gsm	± 3.1%	6	start/end	OK	peeling and weighting material
Fiber diameter	100	nm	± 18.0%	4x;>50	start/end	OK	SEM picture analysis
Bubble point	185.2	kPa	± 3.6%	9	start/end	OK	PMI Capilary flow porometer

SAMPLE IMAGE

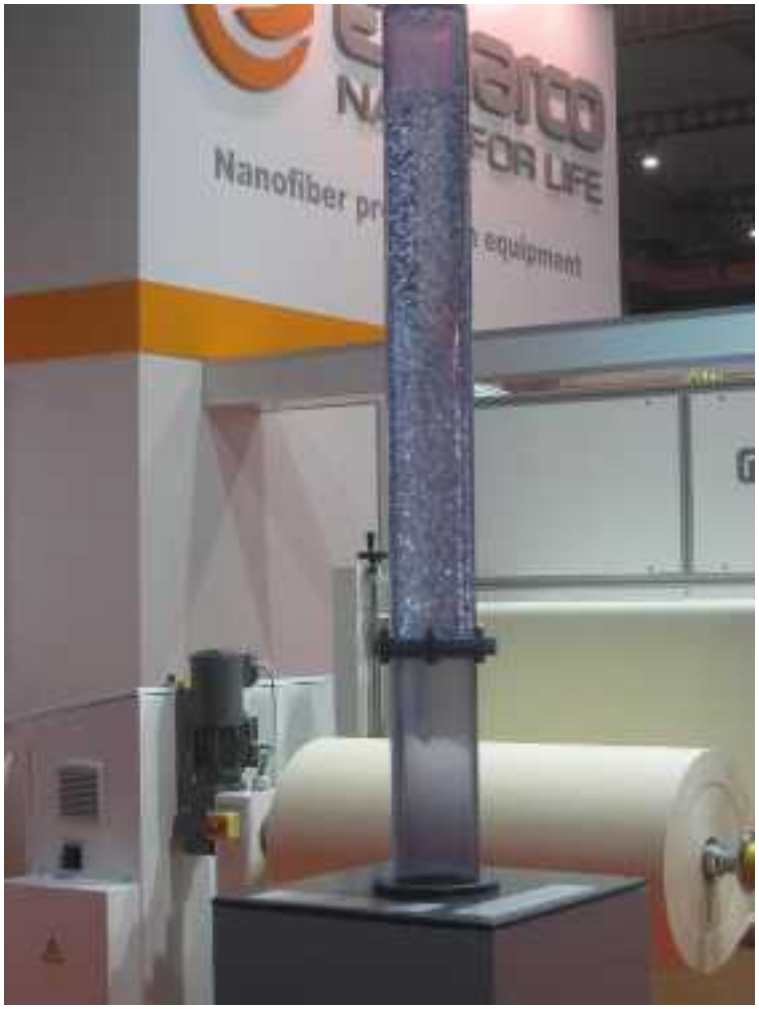






PERFORMANCE APPAREL

Movie



Nanofiber applications – Performance apparel

Electrospun nanofiber webs can be engineered with a desired porous structure and a range of polymers. Manufacturers are able to optimize the performance of the composite material by the unique combination of nanofiber web properties:

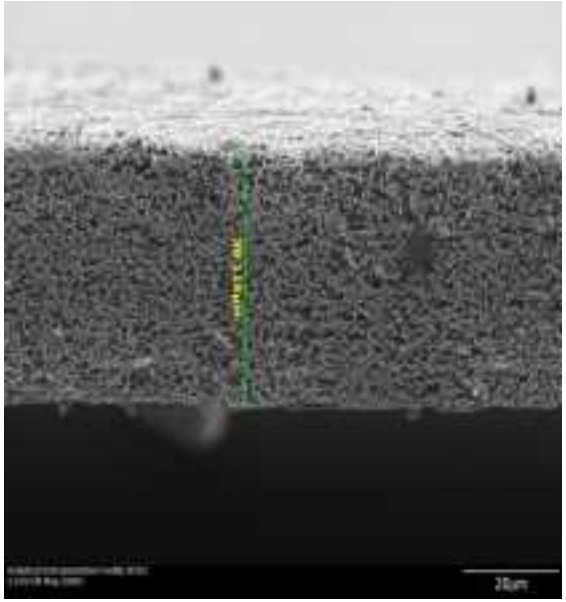
- High specific surface area
- Low basis weight
- Small fibre diameter
- Porous structure with high permeability
- Potential to incorporate active chemistry

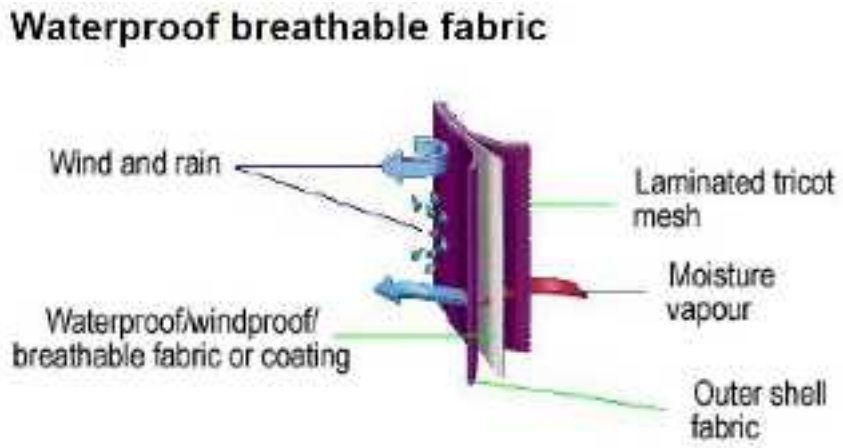
Performance apparel fabrics are evaluated on the performance of the composite material. Attributes most frequently evaluated include:

- Water resistance
- Breathability
- Water vapor transmission
- Windproof
- Resistance to wear

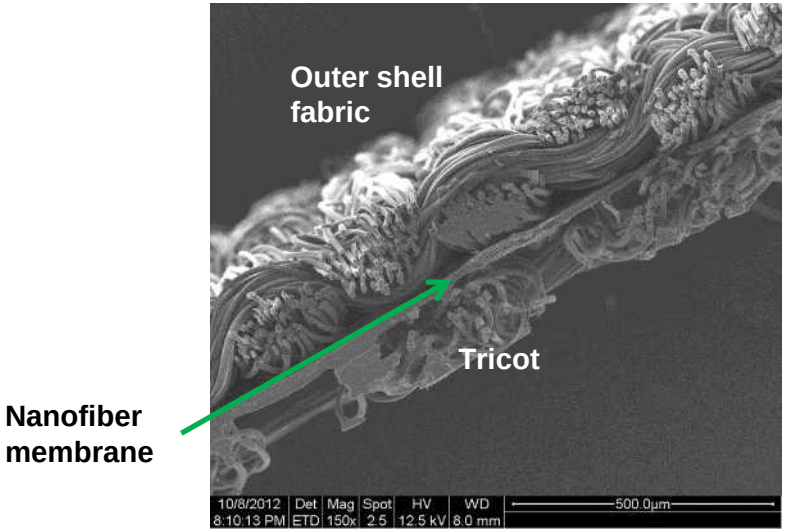
Waterproof breathable nanofiber membrane

- Porous structure with high permeability
- Low basis weight
- Small fibre diameter
- High specific surface area
- Potential to incorporate active chemistry

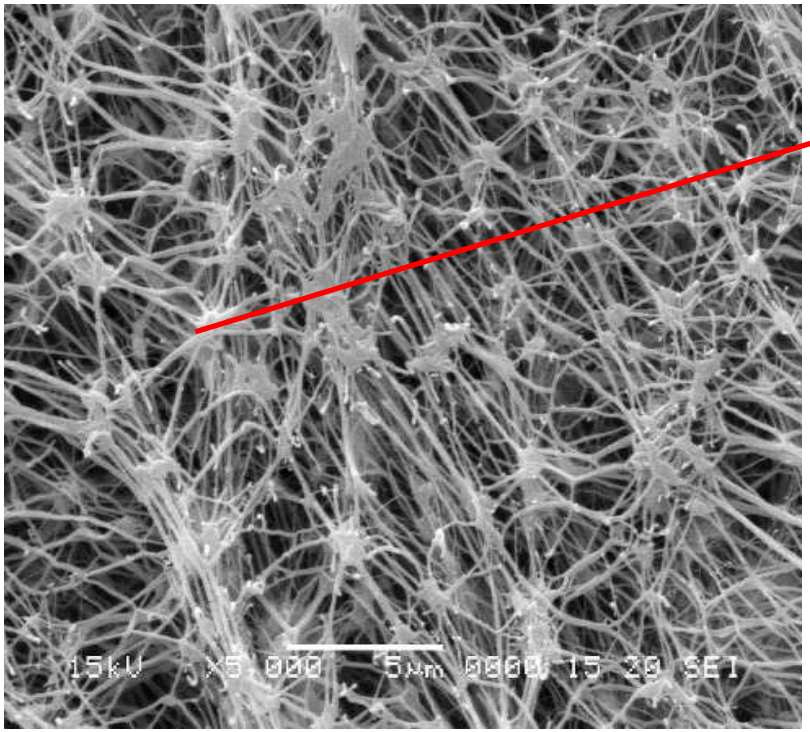




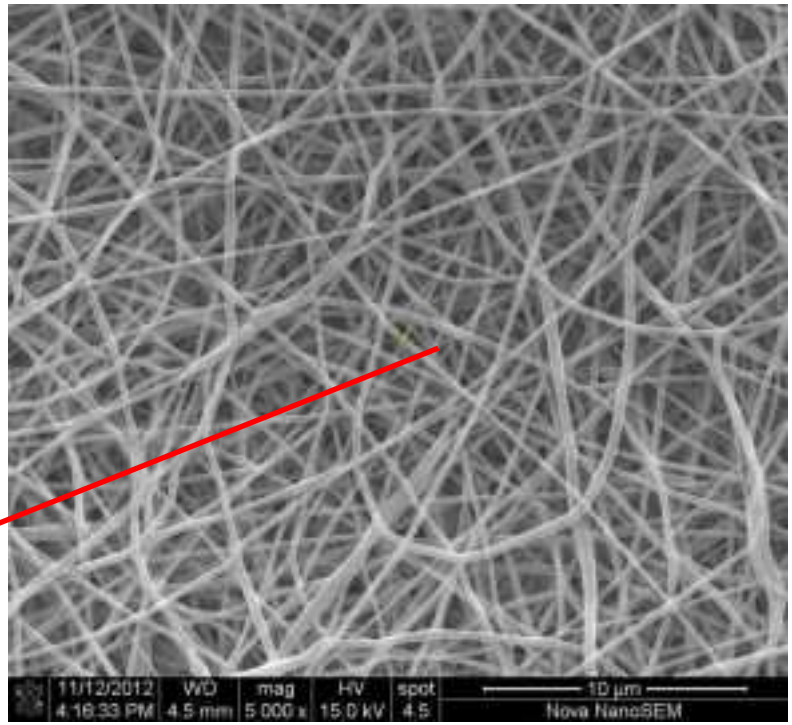
Waterproof breathable fabric with nanofiber membrane



PTFE *vs*. Nanofiber

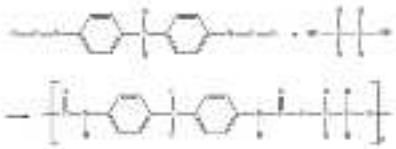


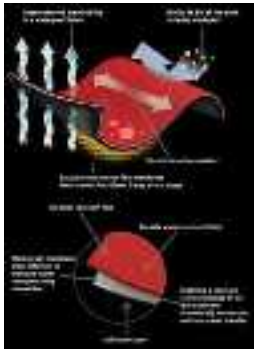
Air permeability is relatively low due to the nodules which interrupt air flow.



Air permeability is excellent due to the high porosity and interconnected pore structure.

Performance Apparel: Nanofibers Composite Recipe



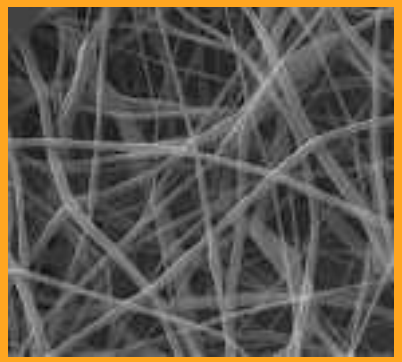


Polymer	Nanospider™	Post-Processing	NF Composite
Use hydrophobic NF Layer Potential use of additives	NS4S1000U and NS8S1600U To produce 5 – 10 gsm layer of NF on baking paper for delamination	Use calendar to compress the NF layer Other coatings to improve water barrier	1. Outer layer provides tear and abrasion resistance 2. NF Layer for water barrier 3. Soft inner layer for comfort

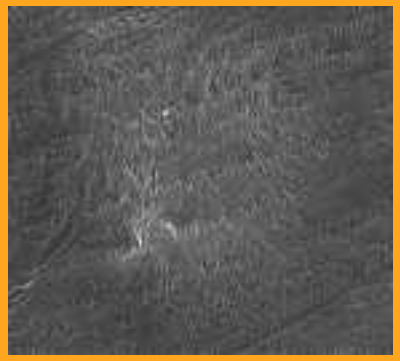
Nanofiber applications – Battery separators

Nanofiber separators characteristics

- Chemical stability
- Thermal stability
- Thickness
- Porosity (greater than 40%)
- Dimensional stability
- Pore and pore size distribution
- Tensile strength



PVDF-HFP electrospun membrane
(Magnification 5000x)



Conventional battery separator
(Magnification 5000x)

Battery with superior parameters

- Lower consumption of polymer material due to lower basis weight of the membrane
- Significant increase of battery power density
- Higher charge and discharge rate
- Increase in battery life

Nanofiber applications – Healthcare

Nanofiber benefits for WOUND CARE

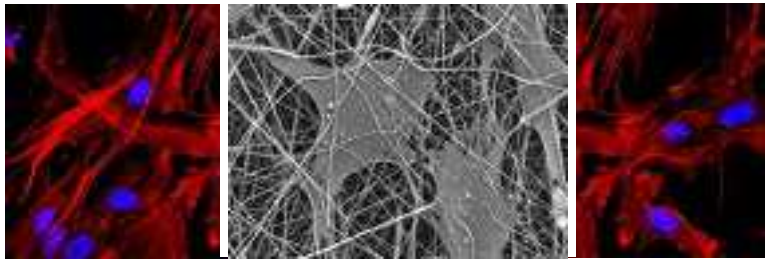
- Promote healing
- Protection from infection
- Providing soft and moist environment
- Anti adhesive effect to the derma
- Ease pain

Nanofiber benefits for DRUG RELEASE

- Slower drug release over a longer period
- Reduction of the first pass effect
- Higher initial drug concentration
- Lower overall drug consumption

Nanofiber benefits for TISSUE ENGINEERING

- Cell growth
- Proliferation
- Differentiation
- Ability to mimic the extracellular matrices



Potential Applications of PLA Nanofibers

- ❑Implant medical devices
- ❑Scaffolds for tissue engineering
- ❑Drug delivery devices
- ❑Hygiene products
- ❑Biosensor
- ❑Membrane for filtration
- ❑Catalysis
- ❑Food packaging