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# **A Review on Nano/Micro Fiber Fabrication Methods by Near-Field Electrospinning**

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## *Abstract*

Faculty: Nanotechnology

School of Engineering and Sciences

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**keywords:** nanotechnology, nano-fiber, near-field electrospinning, NFES

# 1 Summary

TABLE 1.1: Electrospun Polymer Solutions - Solution and Process Parameters

Polymer(s):	Poly(ethylene oxide) (PEO)
Solvent(s):	Deionized water
NFES Variant:	Low-Voltage NFES
Polymer Solution and Process Properties:	<ul style="list-style-type: none"> <li>• PEO Concentration: 1, 2, and 3 <i>wt%</i></li> <li>• Rise in solution conductivity with the increase in PEO concentration</li> <li>• Solution Stirring: 24 <i>h</i> of free diffusion followed by 96 <i>h</i> of stirring at 30 <i>rpm</i></li> <li>• 3 <i>mL</i> syringe</li> <li>• 27 gauge type 304 stainless steel needle</li> <li>• Solution deposition rate: lower than 1 <math>\mu\text{L}/\text{h}</math></li> <li>• needle-to-collector distance: 1 <i>mm</i></li> <li>• Collector substrate: Pyrolyzed SU-8 carbon and Si</li> <li>• NFES process initiated by an air interference with a glass microprobe tip (1 to 3 <math>\mu\text{m}</math> tip diameter) to overcome the surface tension</li> <li>• Time to produce a stable continuous jet: 45 <i>min</i></li> <li>• Polymer jet initiated at 400-600 <i>V</i> and dispensed at 200-400 <i>V</i></li> <li>• Collector linear speed: 10-40 <i>mm/s</i></li> <li>• The voltage turned on when the solution formed a full-sized droplet of 500 <math>\mu\text{m}</math> diameter at the needle tip.</li> </ul>
Fiber Characterization:	<ul style="list-style-type: none"> <li>• Diameter: 50-425 <i>nm</i></li> </ul>
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TABLE 1.2: Electrospun Polymer Solutions - Solution and Process Parameters

Polymer(s):	Poly[2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylenevinylene] (MEH-PPV) with Poly(ethylene oxide) (PEO)
Solvent(s):	acetonitrile / toluene mixture (65 / 35); acetic acid / toluene (17 / 83); pure toluene
NFES Variant:	<i>Not determined.</i>
Polymer Solution and Process Properties:	<ul style="list-style-type: none"> <li>• Concentrations: <ul style="list-style-type: none"> <li>– MEH-PPV solution: 10 <i>mg</i> of MEH-PPV in 2 <i>mL</i> of toluene</li> <li>– 500 <math>\mu\text{L}</math> of MEH-PPV solution with 250 <i>mg</i> of PEO in 3.5 <i>mL</i> of acetonitrile / toluene (65 / 35)</li> <li>– 500 <math>\mu\text{L}</math> of MEH-PPV solution with 250 <i>mg</i> of PEO in 3 <i>mL</i> of acetic acid / toluene (17 / 83)</li> <li>– The resulting MEH-PPV/PEO concentration is 1:100</li> </ul> </li> <li>• Solution Stirring: MEH-PPV solution stirred for 4 <i>h</i>; PEO solution stirred for 8 <i>h</i>; MEH-PPV/PEO solution stirred and ultrasonically agitated</li> <li>• Collector substrate: SiO<sub>2</sub>/Si (oxide thickness = 800 <i>nm</i>)</li> <li>• needle-to-collector distance: 500 <math>\mu\text{m}</math></li> <li>• <math>\mu\text{m}</math>-diameter tip Tungsten spinneret in a 26 gauge needle</li> <li>• Solution deposition rate: 50 <math>\mu\text{L}/\text{h}</math></li> <li>• Electrostatic voltage: around 1.3 <i>kV</i></li> <li>• x-y stage velocity: 50 <i>cm/s</i></li> </ul>
Fiber Characterization:	<ul style="list-style-type: none"> <li>• Distance between adjacent fibers: around 100 <math>\mu\text{m}</math></li> <li>• Fiber diameter: around 100 <i>nm</i></li> </ul>
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TABLE 1.3: Electrospun Polymer Solutions - Solution and Process Parameters

Polymer(s):	Poly(ethylene oxide) (PEO)
Solvent(s):	Water
NFES Variant:	Scanning Tip Electrospinning and NFES
Polymer Solution and Process Properties:	<ul style="list-style-type: none"> <li>• 7 wt % PEO aqueous solution</li> <li>• Under room temperature at 1 <i>atm</i></li> <li>• needle-to-collector distance: 500 <math>\mu\text{m}</math></li> <li>• needle diameter: outer: 200 <math>\mu\text{m}</math>; inner: 100 <math>\mu\text{m}</math></li> <li>• applied voltage for jet initiation: 1.5 <i>kV</i></li> <li>• applied voltage for fiber deposition: 600 <i>V</i></li> <li>• Mechanical drawing is applied by using a tungsten probe with 1 <math>\mu\text{m}</math> tip diameter to poke inside the meniscus.</li> <li>• The probe is then rapidly pulled away from the polymer droplet to activate the continuous electrospinning process</li> <li>• polymer jet diameter: 3 <math>\mu\text{m}</math></li> <li>• polymer feed rate: 0.1 <math>\mu\text{L}/\text{h}</math></li> <li>• x-y stage velocity: 120 <i>mm/s</i></li> </ul>
Fiber Characterization:	<ul style="list-style-type: none"> <li>• 108 <i>m</i> yield in 15 <i>min</i> with a fiber diameter of <math>709 \pm 131</math> <i>nm</i></li> <li>• Fiber diameter: around 49-74 <i>nm</i> when applied voltage is 800 <i>V</i></li> </ul>
Ref:	[3]

TABLE 1.4: Electrospun Polymer Solutions - Solution and Process Parameters

Polymer(s):	Poly( $\epsilon$ -Caprolactone) (PCL)
Solvent(s):	<i>Not applicable.</i>
NFES Variant:	Melt Electrospinning Writing (MEW)
Polymer Solution and Process Properties:	<ul style="list-style-type: none"> <li>• Collector substrate: NCO-sP(EO-stat-PO)-coated glass slide surfaces</li> <li>• Accelerating voltage 2.0–10.0 kV</li> <li>• Collector distance: 1–10 mm</li> <li>• Heating temperature: 80–120 °C</li> <li>• Feeding air pressure 0.5–4.0 bar</li> <li>• Spinneret diameters: 21, 23, 25, 27, 30, and 33 G</li> <li>• Axis velocity: 1000–9000 mm/min</li> <li>• Fibre spacing: 100 <math>\mu</math>m</li> </ul>
Fiber Characterization:	<ul style="list-style-type: none"> <li>• Filament surface is smooth and homogeneous</li> <li>• The crystalline regions formed perpendicular to the filament</li> <li>• Fiber diameter: <math>817 \pm 165</math> nm</li> </ul>
Ref:	[4]

TABLE 1.5: Electrospun Polymer Solutions - Solution and Process Parameters

Polymer(s):	Poly(vinylidene fluoride) (PVDF)
Solvent(s):	N,N-dimethylformamide (DMF)
NFES Variant:	Helix Electrohydrodynamic Printing (HE-printing)
Polymer Solution and Process Properties:	<ul style="list-style-type: none"> <li>• 1.8 g PVDF in 4.1 g of DMF and 4.1 g of acetone to obtain a concentration of 18%</li> <li>• Solution kept at 35 °C for about 6 h until the solution was homogeneous.</li> <li>• Collector substrate: Poly(dimethylsiloxane) (PDMS) on Ecoflex</li> <li>• Solution feed rate: 400 nL/min</li> <li>• Needle diameter: inner 260 <math>\mu\text{m}</math>; external 510 <math>\mu\text{m}</math></li> <li>• Applied voltage: 1.5–3 kV</li> <li>• Nozzle-to-collector distance: 10–50 mm</li> <li>• x-y stage velocity: 0–400 mm/min</li> <li>• At room temperature and 35–45% humidity</li> </ul>
Fiber Characterization:	<ul style="list-style-type: none"> <li>• Stretchable serpentine structures with specific wavelength and amplitude.</li> <li>• Wavelength: about 100–2000 <math>\mu\text{m}</math></li> <li>• Fiber diameter: about 1.5–3 <math>\mu\text{m}</math></li> </ul>
Ref:	[5]

TABLE 1.6: Electrospun Polymer Solutions - Solution and Process Parameters

Polymer(s):	Polyhedral Oligomeric Silsesquioxane-Poly(Carbonate-Urea)Urethane (POSS-PCU) and Polyhedral Oligomeric Silsesquioxane-Poly(Caprolactone-Poly(Carbonate-Urea)Urethane) (POSS-PCL-PCU)
Solvent(s):	Dimethylacetamide (DMAC) and 1-Butanol
NFES Variant:	Electrohydrodynamic 3D Print-patterning or Electrohydrodynamic Jetting
Polymer Solution and Process Properties:	<ul style="list-style-type: none"> <li>• Solution concentration: POSS-PCU and POSS-PCL-PCU used in 20% w/w concentration in DMAC</li> <li>• Needle diameter: 750 <math>\mu m</math></li> <li>• Applied voltage: 8.0-10.0 kV</li> <li>• Solution flow rate: less than 1 <math>\mu L/min</math></li> <li>• Needle-to-collector distance: about between 500 <math>\mu m</math> to 2 mm</li> <li>• x-y stage velocity: 10 mm/s</li> <li>• Ethanol-coated substrate</li> </ul>
Fiber Characterization:	<ul style="list-style-type: none"> <li>• Distance between adjacent fibers: 250 <math>\mu m</math></li> <li>• Fiber diameter: 5-50 <math>\mu m</math></li> </ul>
Ref:	[6]

TABLE 1.7: Electrospun Polymer Solutions - Solution and Process Parameters

Polymer(s):	Poly(ethylene oxide) (PEO)
Solvent(s):	Distilled water
NFES Variant:	Electrohydrodynamic Writing or Mechano-electrospinning (MES)
Polymer Solution and Process Properties:	<ul style="list-style-type: none"> <li>• Polymer solution weight concentration: 6 wt% PEO</li> <li>• Needle-to-collector distance: 7.5 mm</li> <li>• Applied voltage to initiate the jet: 2 kV</li> <li>• Applied voltage during deposition: 0.8-1 kV</li> <li>• Under the room temperature and relative humidity of about 25%.</li> <li>• x-y stage velocity: around 400 mm/s</li> <li>• Solution flow rate: 1200 nL/min</li> </ul>
Fiber Characterization:	<ul style="list-style-type: none"> <li>• Distance between adjacent fibers: 5 <math>\mu m</math></li> <li>• Fiber diameter: 200-350 nm</li> </ul>
Ref:	[7]



TABLE 1.8: Electrospun Polymer Solutions - Solution and Process Parameters

Polymer(s):	Poly(ethylene oxide) (PEO)
Solvent(s):	Deionized water and the ethanol with a volume ratio of 3:1
NFES Variant:	Airflow-assisted Electrohydrodynamic Direct-writing (EDW)
Polymer Solution and Process Properties:	<ul style="list-style-type: none"> <li>• Concentration: 8 <i>wt%</i> PEO</li> <li>• Outer airflow passage diameter: 1 <i>mm</i></li> <li>• Airflow gas pump pressure: 25 <i>kPa</i></li> <li>• Inner liquid passage diameter: 0.21 <i>mm</i></li> <li>• Silicon substrate</li> <li>• Needle-to-collector distance: 2 <i>mm</i></li> <li>• Solution flow rate: 30 <math>\mu\text{L}/\text{h}</math></li> <li>• Applied voltage: about 2 <i>kV</i></li> <li>• x-y stage velocity: between 1-20 <i>mm/s</i></li> </ul>
Fiber Characterization:	<ul style="list-style-type: none"> <li>• Fiber deposition position accuracy: <math>5.13 \pm 6.67 \mu\text{m}</math></li> <li>• Fiber diameter: <math>3.73 \pm 1.37 \mu\text{m}</math></li> </ul>
Ref:	[8]

TABLE 1.9: Electrospun Polymer Solutions - Solution and Process Parameters

Polymer(s):	Poly(Vinylidene Fluoride) (PVDF)
Solvent(s):	Acetone and Dimethyl Sulfoxide (DMSO)
NFES Variant:	3D Electrospinning
Polymer Solution and Process Properties:	<ul style="list-style-type: none"> <li>• Capstone FS-66 used as an anionic surfactant.</li> <li>• Solution concentration: 17 <i>wt%</i> PVDF <ul style="list-style-type: none"> <li>– 1.7 g of PVDF added to 5 g of acetone and dispersed for 30 <i>min</i></li> <li>– 0.5 g of Capstone FS-66 was added to 5 g of DMSO and dispersed</li> <li>– then both solutions are mixed for more than 1 <i>h</i></li> </ul> </li> <li>• Collector substrate: A4 size commercial printing paper (Double A)</li> <li>• Needle inner diameter: 100 <math>\mu m</math></li> <li>• x-y stage velocity: 10 <i>mm/s</i></li> <li>• Solution flow rate: 14 <i>nL/min</i></li> <li>• Needle-to-collector distance: 750 <math>\mu m</math></li> <li>• Applied voltage: 1.9 <i>kV</i></li> </ul>
Fiber Characterization:	<ul style="list-style-type: none"> <li>• A stack of fibers was produced, but fiber diameter is not reported.</li> </ul>
Ref:	[9]

TABLE 1.10: Electrospun Polymer Solutions - Solution and Process Parameters

Polymer(s):	Polycaprolactone
Solvent(s):	Chloroform
NFES Variant:	Direct-Write Electrospinning
Polymer Solution and Process Properties:	<ul style="list-style-type: none"> <li>• Needle inner diameter: 200 <math>\mu m</math></li> <li>• Ground electrode to collector plate distance: 50 <math>\mu m</math></li> <li>• Solution concentration: 8.8 <i>wt%</i> Polycaprolactone</li> <li>• Solution stirred for 120 <i>min</i></li> <li>• Applied voltage: 25 <i>kV</i></li> <li>• Needle-to-collector distance: 70 <i>mm</i></li> <li>• Solution flow rate: 0.1 <i>mL/h</i></li> <li>• Electrospun at 23 °C and relative humidity between 54 and 57 %</li> <li>• x-y stage velocity: 2-200 <i>mm/s</i></li> </ul>
Fiber Characterization:	<ul style="list-style-type: none"> <li>• Fiber diameter: 400 <i>nm</i> to 950 <math>\mu m</math></li> </ul>
Ref:	[10]

TABLE 1.11: Electrospun Polymer Solutions - Solution and Process Parameters

Polymer(s):	Poly(Vinylidene Fluoride) (PVDF)
Solvent(s):	Dimethyl Sulfoxide (DMSO) <ul style="list-style-type: none"> <li>Acetone and surfactant (ZONYL UR) were applied to improve the evaporation rate and to reduce the surface tension.</li> </ul>
NFES Variant:	Hollow Cylindrical Near-Field Electrospinning (HCNFES)
Polymer Solution and Process Properties:	<ul style="list-style-type: none"> <li>Solution concentration: 16, 18, and 20 <i>wt%</i> PVDF <ul style="list-style-type: none"> <li>DMSO:acetone concentration is 1:1</li> <li>Surfactant amount: 0.2 <i>g</i></li> </ul> </li> <li>Solution preparation: <ul style="list-style-type: none"> <li>PVDF-acetone stirred for 30 <i>min</i></li> <li>sufractant-DMSO stirred for 30 <i>min</i></li> <li>Both solutions stirred for 60 <i>min</i></li> </ul> </li> <li>Needle-to-collector distance: 0.5 <i>mm</i></li> <li>Applied voltage: 10-16 <i>kV</i></li> <li>Tube collector rotational velocity: 900-1900 <i>rpm</i> <ul style="list-style-type: none"> <li>Tangential speed: 942.3-1989.3 <i>mm/s</i></li> </ul> </li> <li>Collector substrate: Poly(ethylene terephthalate) (PET)</li> </ul>
Fiber Characterization:	<ul style="list-style-type: none"> <li>a</li> </ul>
Ref:	[11]

TABLE 1.12: Electrospun Polymer Solutions - Solution and Process Parameters

Polymer(s):	
Solvent(s):	
NFES Variant:	
Polymer Solution and Process Properties:	<ul style="list-style-type: none"> <li>1</li> </ul>
Fiber Characterization:	<ul style="list-style-type: none"> <li>a</li> </ul>
Ref:	[1]

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