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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:	• PEO Concentration: 1, 2, and 3 $wt\%$ • Rise in solution conductivity with the increase in PEO concentration • Solution Stirring: 24 h of free diffusion followed by 96 h of stirring at 30 rpm • 3 mL syringe • 27 gauge type 304 stainless steel needle • Solution deposition rate: lower than 1 $\mu L/h$ • needle-to-collector distance: 1 mm • Collector substrate: Pyrolyzed SU-8 carbon and Si • NFES process initiated by an air interference with a glass microprobe tip (1 to 3 μm tip diameter) to overcome the surface tension • Time to produce a stable continuous jet: 45 min • Polymer jet initiated at 400-600 V and dispensed at 200-400 V • Collector linear speed: 10-40 mm/s • The voltage turned on when the solution formed a full-sized droplet of 500 μm diameter at the needle tip.
Fiber Characterization:	• Diameter: 50-425 nm
Ref:	[1]

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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:	*Not determined.*
Polymer Solution and Process Properties:	• Concentrations: – MEH-PPV solution: 10 mg of MEH-PPV in 2 mL of toluene – 500 μL of MEH-PPV solution with 250 mg of PEO in 3.5 mL of acetonitrile / toluene (65 / 35) – 500 μL of MEH-PPV solution with 250 mg of PEO in 3 mL of acetic acid / toluene (17 / 83) – The resulting MEH-PPV/PEO concentration is 1:100 • Solution Stirring: MEH-PPV solution stirred for 4 h; PEO solution stirred for 8 h; MEH-PPV/PEO solution stirred and ultrasonically agitated • Collector substrate: SiO2/Si (oxide thickness = 800 nm) • needle-to-collector distance: 500 μm • μm-diameter tip Tungsten spinneret in a 26 gauge needle • Solution deposition rate: 50 $\mu L/h$ • Electrostatic voltage: around 1.3 kV • x-y stage velocity: 50 cm/s
Fiber Characterization:	• Distance between adjacent fibers: around 100 μm • Fiber diameter: around 100 nm
Ref:	[2]

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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:	• 7 wt % PEO aqueous solution • Under room temperature at 1 atm • needle-to-collector distance: 500 μm • needle diameter: outer: 200 μm; inner: 100 μm • applied voltage for jet initiation: 1.5 kV • applied voltage for fiber deposition: 600 V • Mechanical drawing is applied by using a tungsten probe with 1 μm tip diameter to poke inside the meniscus. • The probe is then rapidly pulled away from the polymer droplet to activate the continuous electrospinning process • polymer jet diameter: 3 μm • polymer feed rate: 0.1 $\mu L/h$ • x-y stage velocity: 120 mm/s
Fiber Characterization:	• 108 m yield in 15 min with a fiber diameter of 709 $\pm$ 131 nm • Fiber diameter: around 49-74 nm when applied voltage is 800 V
Ref:	[3]

TABLE 1.4: Electrospun Polymer Solutions - Solution and Process Parameters

Polymer(s):	Poly(ε-Caprolactone) (PCL)
Solvent(s):	*Not applicable.*
NFES Variant:	Melt Electrospinning Writing (MEW)
Polymer Solution and Process Properties:	• Collector substrate: NCO-sP(EO-stat-PO)-coated glass slide surfaces • Accelerating voltage 2.0–10.0 kV • Collector distance: 1–10 mm • Heating temperature: 80–120 $^{\circ}C$ • Feeding air pressure 0.5–4.0 bar • Spinneret diameters: 21, 23, 25, 27, 30, and 33 G • Axis velocity: 1000–9000 mm/min • Fibre spacing: 100 μm
Fiber Characterization:	• Filament surface is smooth and homogeneous • The crystalline regions formed perpendicular to the filament • Fiber diameter: 817 ± 165 nm
Ref:	[4]

TABLE 1.5: Electrospun Polymer Solutions - Solution and Process Parameters

Polymer(s):	Poly(vinylidine fluorid) (PVDF)
Solvent(s):	N,N-dimethylformamide (DMF)
NFES Variant:	Helix Electrohydrodynamic Printing (HE-printing)
Polymer Solution and Process Properties:	• 1.8 g PVDF in 4.1 g of DMF and 4.1 g of acetone to obtain a concentration of 18% • Solution kept at 35 $^{\circ}C$ for about 6 h until the solution was homogeneous. • Collector substrate: Poly(dimethylsiloxane) (PDMS) on Ecoflex • Solution feed rate: 400 nL/min • Needle diameter: inner 260 μm; external 510 μm • Applied voltage: 1.5–3 kV • Nozzle-to-collector distance: 10-50 mm • x-y stage velocity: 0-400 mm/min • At room temperature and 35–45% humidity
Fiber Characterization:	• Stretchable serpentine structures with specific wavelength and amplitude. • Wavelength: about 100-2000 μm • Fiber diameter: about 1.5-3 μm
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:	• Solution concentration: POSS-PCU and POSS-PCL-PCU used in 20% w/w concentration in DMAC • Needle diameter: 750 μm • Applied voltage: 8.0-10.0 kV • Solution flow rate: less than 1 $\mu L/min$ • Needle-to-collector distance: about between 500 μm to 2 mm • x-y stage velocity: 10 mm/s • Ethanol-coated substrate
Fiber Characterization:	• Distance between adjacent fibers: 250 μm • Fiber diameter: 5-50 μm
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 Mechanoelectrospinning (MES)
Polymer Solution and Process Properties:	• Polymer solution weight concentration: 6 $wt\%$ PEO • Needle-to-collector distance: 7.5 mm • Applied voltage to initiate the jet: 2 kV • Applied voltage during deposition: 0.8-1 kV • Under the room temperature and relative humidity of about 25%. • x-y stage velocity: around 400 mm/s • Solution flow rate: 1200 nL/min
Fiber Characterization:	• Distance between adjacent fibers: 5 μm • Fiber diameter: 200-350 nm
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:	• Concentration: 8 $wt\%$ PEO • Outer airflow passage diameter: 1 mm • Airflow gas pump pressure: 25 kPa • Inner liquid passage diameter: 0.21 mm • Silicon substrate • Needle-to-collector distance: 2 mm • Solution flow rate: 30 $\mu L/h$ • Applied voltage: about 2 kV • x-y stage velocity: between 1-20 mm/s
Fiber Characterization:	• Fiber deposition position accuracy: 5.13 $\pm$ 6.67 μm • Fiber diameter: 3.73 $\pm$ 1.37 μm
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:	• Capstone FS-66 used as an anionic surfactant. • Solution concentration: 17 $wt\%$ PVDF – 1.7 g of PVDF added to 5 g of acetone and dispersed for 30 min – 0.5 g of Capstone FS-66 was added to 5 g of DMSO and dispersed – then both solutions are mixed for more than 1 h • Collector substrate: A4 size commercial printing paper (Double A) • Needle inner diameter: 100 μm • x-y stage velocity: 10 mm/s • Solution flow rate: 14 nL/min • Needle-to-collector distance: 750 μm • Applied voltage: 1.9 kV
Fiber Characterization:	• A stack of fibers was produced, but fiber diameter is not reported.
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:	• Needle inner diameter: 200 μm • Ground electrode to collector plate distance: 50 μm • Solution concentration: 8.8 $wt\%$ Polycaprolactone • Solution stirred for 120 min • Applied voltage: 25 kV • Needle-to-collector distance: 70 mm • Solution flow rate: 0.1 mL/h • Electrospun at 23 $^{\circ}C$ and relative humidity between 54 and 57 % • x-y stage velocity: 2-200 mm/s
Fiber Characterization:	• Fiber diameter: 400 nm to 950 μm
Ref:	[10]

TABLE 1.11: Electrospun Polymer Solutions - Solution and Process Parameters

Polymer(s):	Poly(Vinylidene Fluoride) (PVDF)
Solvent(s):	Dimethyl Sulfoxide (DMSO) • Acetone and surfactant (ZONYL UR) were applied to improve the evaporation rate and to reduce the surface tension.
NFES Variant:	Hollow Cylindrical Near-Field Electrospinning (HCNFES)
Polymer Solution and Process Properties:	• Solution concentration: 18 $wt\%$ PVDF – DMSO:acetone concentration is 1:1 – Surfactant amount: 0.2 g • Solution preparation: – PVDF-acetone stirred for 30 min – sufractant-DMSO stirred for 30 min – Both solutions stirred for 60 min – Placed in a vacuum chamber for 15 min to remove bubbles • Needle-to-collector distance: 0.5 mm • Applied voltage: 14 kV • Tube collector rotational velocity: 1900 rpm – Tangential speed: 1989.3 mm/s • Collector substrate: Poly(ethylene terephthalate) (PET)
Fiber Characterization:	• Fiber diameter: around 1.2 μm
Ref:	[11]

TABLE 1.12: Electrospun Polymer Solutions - Solution and Process Parameters

Polymer(s):	
Solvent(s):	Electrohydrodynamic Organic Nanowire printing (ONP)
NFES Variant:	
Polymer Solution and Process Properties:	• 1
Fiber Characterization:	• a
Ref:	[12]

TABLE 1.13: Electrospun Polymer Solutions - Solution and Process Parameters

Polymer(s):	
Solvent(s):	
NFES Variant:	
Polymer Solution and Process Properties:	• 1
Fiber Characterization:	• a
Ref:	[1]

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