Review of Polymer Solutions for Near-Field Electrospinning with Spatial Control

Antonio Osamu Katagiri Tanaka, Héctor Alán Aguirre Soto

Abstract

Near-field electrospinning (NFES) have demonstrated to be one of the top techniques for the fabrication of nano and micro fibers with accurate spatial control. In the attempt to create NFES has suffered a number of variations

Lorem ipsum dolor sit amet

One-dimensional (1-D) nanostructures have attracted enormous research interest due to their unique physicochemical properties and wide application potential. These 1-D nanofibers are being increasingly applied to biomedical fields owing to their high surface area-to-volume ratio, high porosity, and the ease of tuning their structures, functionalities, and properties. Many biomedical nanofiber reviews have focused on tissue engineering and drug delivery applications but have very rarely discussed their use as wound dressings. However, nanofibers have enormous potential as wound dressings and other clinical applications that could have wide impacts on the treatment of wounds. Herein, the authors review the main fabrication methods of nanofibers as well as requirements, strategies, and recent applications of nanofibers, and provide perspectives of the challenges and opportunities that face multifunctional nanofibers for active therapeutic applications.

Near field electrospinning is one of the leading techniques in accurate placement of nanofibers. This technique has evolved from using AFM tips to supply a limited volume of solution for electrospinning to nozzle-based system where a continuous stream of solution can be extruded.

The precision and accuracy of the fiber deposition has also vastly improved from simple formation of oriented fibers on a collector to precise deposition of the fiber at a specific point. Despite the progress, several intrinsic limitation or characteristic of near-field electrospinning still needs to be noted when employing this technique.

Keywords: polymer, solvent, near-field electrospinning, NFES, fibers, spatial control

Contents

Email addresses: oskatagiri@gmail.com (Antonio Osamu Katagiri Tanaka), alan.aguirre@tec.mx (Héctor Alán Aguirre Soto)

1. Introduction

Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

2. NFES

Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

Table 1: Electrospun Polymer Solutions - Solution and Process Parameters

Polymer(s)	Solvent(s)	NFES Variant	Process Parameters and Fiber Characterization	Ref.
Poly(ethylene oxide) (PEO)	Deionized water	Low-Voltage NFES	**Solution Concentration:** 1, 2, and 3 $wt\%$ PEO **Nozzle:** 27 gauge type 304; stainless steel needle **Solution deposition rate:** lower than $1\mu L/h$ **Nozzle-to-substrate distance:** $1mm$ **Substrate composition:** Pyrolyzed SU-8 carbon and Si **Applied voltage:** polymer jet initiated at 400-600 V and dispensed at 200-400 V **x-y stage velocity:** 10-40mm/s **Fiber Diameter:** 50-425nm **Distance between adjacent fibers:** *Not determined*	[1]
Poly[2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylenevinylene] (MEH-PPV) with Poly(ethylene oxide) (PEO)	acetonitrile toluene mixture (65/35); acetic acid toluene (17/83); pure toluene	Typical NFES process	**Solution Concentration:** $10mg$ of MEH-PPV in $2mL$ of toluene; $500mL$ of MEH-PPV solution with $250mg$ of PEO in $3.5mL$ of acetonitrile; $500mL$ of MEH-PPV solution with $250mg$ of PEO in $3mL$ of acetic acid / toluene (17 / 83). The resulting MEH-PPV/PEO concentration is 1:100 **Nozzle:** mm-diameter tip Tungsten spinneret in a 26 gauge needle **Solution deposition rate:** $50\mu L/h$ **Nozzle-to-substrate distance:** $500\mu m$ **Substrate composition:** SiO2/Si (oxide thickness = 800 nm) **Applied voltage:** around $1.3kV$ **x-y stage velocity:** $50cm/s$ **Fiber Diameter:** $100nm$ **Distance between adjacent fibers:** around $100\mu m$	[2]

Continued on next page

Table 1 continued

Poly(ethylene oxide) (PEO)	Water	Scanning Tip Electrospinning and NFES	**Solution Concentration:** $7wt\%$ PEO **Nozzle:** Needle outer diameter of $200\mu m$ and inner diameter of $100\mu m$ **Solution deposition rate:** $0.1\mu L/h$ **Nozzle-to-substrate distance:** $500\mu m$ **Substrate composition:** *Not determined* **Applied voltage:** polymer jet initiated at 1.5 kV and dispensed at $600V$ **x-y stage velocity:** $120mm/s$ **Fiber Diameter:** $709\pm131nm$; 49-74nm when applied voltage is $800V$ **Distance between adjacent fibers:** *Not determined* **Notes:** $108m$ yield in $15min$ with a fiber diameter of $709\pm131nm$	[3]
Poly(vinylidine fluorid) (PVDF)	N,N Dimethylformamide (DMF)	Helix Electrohydrodynamic Printing (HE-printing)	**Solution Concentration:** $1.8g$ PVDF in $4.1g$ of DMF and $4.1g$ of acetone. The resulting concentration is 18% PVDF. **Nozzle:** Needle outer diameter of $510\mu m$ and inner diameter of $260\mu m$ **Solution deposition rate:** $400nL/min$ **Nozzle-to-substrate distance:** 10-50mm **Substrate composition:** Poly(dimethylsiloxane) (PDMS) on Ecoflex **Applied voltage:** 1.5–$3kV$ **x-y stage velocity:** 0-400mm/min **Fiber Diameter:** about 1.5-$3\mu m$ **Distance between adjacent fibers:** *Not determined*	[4]

Continued on next page

Table 1 continued

Polyhedral Oligomeric Silsesquioxane-Poly(Carbonate-Urea)Urethane (POSS-PCU) and Polyhedral Oligomeric Silsesquioxane Poly(Caprolactone-Poly(Carbonate-Urea)Urethane) (POSS-PCL-PCU)	Dimethyl acetamide (DMAC) and 1-Butanol	Electrohydrodynamic 3D Print-patterning or Electrohydrodynamic Jetting	**Solution Concentration:** POSS-PCU and POSS-PCL-PCU used in $20\% w/w$ concentration in DMAC **Nozzle:** needle of 750 μm in diameter **Solution deposition rate:** less than $1 \mu L/min$ **Nozzle-to-substrate distance:** about between $500 \mu m$ to $2 mm$ **Substrate composition:** *Not determined* **Applied voltage:** 8.0-10.0kV **x-y stage velocity:** $10 mm/s$ **Fiber Diameter:** 5-50μm **Distance between adjacent fibers:** $250 \mu m$	[5]
Poly(ethylene oxide) (PEO)	Distilled water	Electrohydrodynamic Writing or Mechano-electrospinning (MES)	**Solution Concentration:** $6 wt\%$ PEO **Nozzle:***Not determined* **Solution deposition rate:** $1200 nL/min$ **Nozzle-to-substrate distance:** $7.5 mm$ **Substrate composition:** *Not determined* **Applied voltage:** polymer jet initiated at 2 kV and dispensed at 0.8-1kV **x-y stage velocity:** around $400 mm/s$ **Fiber Diameter:** 200-350nm **Distance between adjacent fibers:** $5 \mu m$	[6]

Continued on next page

Table 1 continued

Poly(ethylene oxide) (PEO)	Deionized water and the ethanol with a volume ratio of 3:1	Airflow-assisted Electrohydrodynamic Direct-writing (EDW)	**Solution Concentration:** $8wt\%$ PEO **Nozzle:** Outer airflow passage diameter: $1mm$ Airflow gas pump pressure: $25kPa$ Inner liquid passage diameter: $0.21mm$ **Solution deposition rate:** $30\mu L/h$ **Nozzle-to-substrate distance:** $2mm$ **Substrate composition:** Silicon **Applied voltage:** about $2kV$ **x-y stage velocity:** 1-$20mm/s$ **Fiber Diameter:** $3.73 \pm 1.37\mu m$ **Distance between adjacent fibers:** $5.13 \pm 6.67\mu m$	[7]
Poly(Vinylidene Fluoride) (PVDF)	Acetone and Dimethyl Sulfoxide (DMSO)	3D Electrospinning	**Solution Concentration:** $17wt\%$ PVDF; $1.7g$ of PVDF, $5g$ of acetone, $0.5g$ of Capstone FS-66, $5g$ of DMSO **Nozzle:** Needle inner diameter of $100\mu m$ **Solution deposition rate:** $14\ nL/min$ **Nozzle-to-substrate distance:** $750\mu m$ **Substrate composition:** A4 size commercial printing paper (Double A) **Applied voltage:** $1.9kV$ **x-y stage velocity:** $10mm/s$ **Fiber Diameter:***Not determined* **Distance between adjacent fibers:** *Not determined*	[8]

Continued on next page

Table 1 continued

Poly(9-Vinyl Carbazole) (PVK)	Styrene	Typical NFES process	**Solution Concentration:** 3.96wt% PVK in styrene **Nozzle:** Needle inner diameter of 100μm **Solution deposition rate:** 500nL/min **Nozzle-to-substrate distance:** around 2.5mm **Substrate composition:** Si/SiO2 **Applied voltage:** 3-4kV x-y stage velocity: 13.3cm/s **Fiber Diameter:** $289.26 \pm 35.37nm$ **Distance between adjacent fibers:** 50μm **Notes:** 15m yield in 2min	[9]
Polystyrene (PS)	1,2,4-Trichloro benzene	Electrohydro-dynamic (EHD) jet printing	**Solution Concentration:** 1 to 5wt% PS **Nozzle:** Glass nozzle inner diameter of 2μm and outer diameter of 2.66μm **Solution deposition rate:** Si **Nozzle-to-substrate distance: 20, 30, 40**μm **Substrate composition:** **Applied voltage:** 500 to 400V in 25V increments **x-y stage velocity:** 0.01-10mm/s **Fiber Diameter:** about 60-170μm **Distance between adjacent fibers:** *Not determined*	[10]
Poly(ethylene oxide) (PEO)	*Not determined*	Typical NFES process	**Solution Concentration:** 3wt% PEO **Nozzle:***Not determined* **Solution deposition rate:** *Not determined* **Nozzle-to-substrate distance:** 500μm **Substrate composition:** Si **Applied voltage:** 1000V **x-y stage velocity:** 20cm/s **Fiber Diameter:** 300nm **Distance between adjacent fibers:** 25μm	[11]

Continued on next page

Table 1 continued

Poly(ethylene oxide) (PEO)	Distilled water	Multinozzle NFES	**Solution Concentration:** $5wt\%$ **Nozzle:** four-nozzle and six-nozzle array with needle spacing changes from $1.5mm$ to $3.5mm$ **Solution deposition rate:** 1-$3\mu L/min$ **Nozzle-to-substrate distance:** $2mm$ **Substrate composition:***Not determined* **Applied voltage:** 1.7-$2.7kV$ **x-y stage velocity:** *Not determined* **Fiber Diameter:** $5.47\mu m$ **Distance between adjacent fibers:** 3-5 mm	[12]
Poly(ethylene oxide) (PEO)	Distilled water	Multinozzle NFES	**Solution Concentration:**$5wt\%$ **Nozzle:** Dual-28G-needle array with needle inner diameter of $0.18mm$ and outer diameter of $0.36mm$; with needle spacing changes from $2.0mm$ to $3.0mm$ **Solution deposition rate:** $0.2\mu L/min$ **Nozzle-to-substrate distance:** 3.0-$4.0mm$ **Substrate composition:** *Not determined* **Applied voltage:** 2.0-$3.0kV$ **x-y stage velocity:** $20mm/s$ **Fiber Diameter:** *Not determined* **Distance between adjacent fibers:** 218-$326\mu m$	[13]

Continued on next page

Table 1 continued

Poly(ethylene oxide) (PEO)	Distilled water	Multinozzle NFES	**Solution Concentration:**5 $wt\%$ **Nozzle:** Dual-28G-needle array with needle inner diameter of 180μm and outer diameter of 360μm; with needle spacing changes of 2.0mm **Solution deposition rate:** 0.2$\mu L/min$ **Nozzle-to-substrate distance:** 4.0mm **Substrate composition:** chromium-plated glass **Applied voltage:** 2.5kV **x-y stage velocity:** 20mm/s **Fiber Diameter:** *Not determined* **Distance between adjacent fibers:** 2.3002-2.7224mm	[14]
Poly(ethylene oxide) (PEO)	*Not determined*	Typical NFES process	**Solution Concentration:** 2$wt\%$ **Nozzle:** G30 needle with inner diameter of 0.15mm **Solution deposition rate:***Not determined* **Nozzle-to-substrate distance:** 1-3mm **Substrate composition:** Silicon **Applied voltage:** 1250V **x-y stage velocity:** *Not determined* **Fiber Diameter:** *Not determined* **Distance between adjacent fibers:** 20μm	[15]

Continued on next page

Table 1 continued

Gelatin (porcine skin)	Acetic Acid and Ethyl Acetate	Typical process	NFES	**Solution Concentration:** $11wt\%$ gelatin, $30wt\%$ water, $35.4wt\%$ acetic acid, $23.6wt\%$ ethyl acetate **Nozzle:** 19G needle tip with outer diameter of $1.08mm$ **Solution deposition rate:** *Not determined* **Nozzle-to-substrate distance:** $1.25mm$ **Substrate composition:** Poly(Dimethylsiloxane) (PDMS) films **Applied voltage:** $1000V$ **x-y stage velocity:** *Not determined* **Fiber Diameter:** around 2-$3\mu m$ **Distance between adjacent fibers:** $40\mu m$	[16]
Poly(ethylene oxide) (PEO)	Water/Ethanol (v/v = 60/40)	Typical process	NFES	**Solution Concentration:** PEO concentrations of 16% adn 18% **Nozzle:** $40\mu m$ **Solution deposition rate:** **Nozzle-to-substrate distance:** $1mm$ **Substrate composition:** Planar silicon **Applied voltage:** $1.7kV$ **x-y stage velocity:** $0.36m/s$ **Fiber Diameter:** $5.15\mu m$ **Distance between adjacent fibers:** *Not determined*	[17]

Continued on next page

Table 1 continued

Poly(ethylene oxide) (PEO)	Water/Ethanol (v/v = 3/1)	Electrohydrodynamic Direct-Write (EDW)	**Solution Concentration:** 14wt% PEO **Nozzle:** Stainless needle with inner diameter of 210μm and outer diameter of 400μm **Solution deposition rate:** 50$\mu L/h$ **Nozzle-to-substrate distance:** 2mm **Substrate composition:** Poly(ethylene terephthalate) (PET) **Applied voltage:** 3kV **x-y stage velocity:** 700mm/s **Fiber Diameter:** 15-35μm **Distance between adjacent fibers:** 70μm	[18]
Poly(ethylene oxide) (PEO)	Deionized water	Mechano-Electrospinning	**Solution Concentration:** 3wt% PEO **Nozzle:** Stainless steel nozzle with inner diameter of 160μm and outer diameter of 310μm **Solution deposition rate:** 50nL/min **Nozzle-to-substrate distance:** 2-5mm **Substrate composition:** Silicone **Applied voltage:**polymer jet initiated at 2kV and dispensed at 1kV **x-y stage velocity:** 200-400mm/s **Fiber Diameter:** from 344±32 to 214±27nm **Distance between adjacent fibers:** *Not determined*	[19]

Continued on next page

Table 1 continued

Poly(co-Glycolic) acid (PLGA)	Dimethyl Carbonate (DMC)	Tethered Pyro-Electrohydrodynamic Spinning (TPES)	**Solution Concentration:** *Not determined* **Nozzle:** nozzle-free **Solution deposition rate:** The drop reservoir is placed directly on a flat substrate **Nozzle-to-substrate distance:** Taylor's cone is focused and put in direct contact with the collector **Substrate composition:** Poly(tetrafluoroethylene) (PTFE) coated glass slide **Applied voltage:** pyro-electric field of between 2.7 $x10^7\ V/m$ and $5.5x10^7\ V/m$ **x-y stage velocity:** *Not determined* **Fiber Diameter:** $304.7nm$ **Distance between adjacent fibers:** *Not determined*	[20]
Poly(ethylene oxide) (PEO) with Tetrabutylammonium tetrafluoroborate (TBF) and SU-8 2002	N,N Dimethylformamide (DMF)	Typical NFES process	**Solution Concentration:** SU-8/PEO/TBF blend with $0.75wt\%$ PEO, $1wt\%$ TBF; the blend is diluted with $30vol\%$ DMF **Nozzle:** needle inner diameter of $533\mu m$ and outer diameter of $710\mu m$ **Solution deposition rate:** *Not determined* **Nozzle-to-substrate distance:** *Not determined* **Substrate composition:** Brass disk with a diameter of $38mm$ **Applied voltage:** $980V$ **x-y stage velocity:** *Not determined* **Fiber Diameter:** *Not determined* **Distance between adjacent fibers:** *Not determined*	[21]

Continued on next page

Table 1 continued

Poly(ethylene oxide) (PEO)	Water:Ethanol (3:2)	Suspension NFES	**Solution Concentration:** $14wt\%$ PEO **Nozzle:** stainless steel needle (25 G) with inner diameter of $0.25mm$ **Solution deposition rate:** $3nL/s$ **Nozzle-to-substrate distance:** between 0.5 and $10mm$ with $0.5mm$ increments **Substrate composition:** Planar silicon electrodes **Applied voltage:** $1.6kV$ **x-y stage velocity:** 50, 150, and $250mm/s$ **Fiber Diameter:** $300nm$ **Distance between adjacent fibers:** 0.1 and $0.5mm$	[22]
Poly(ethylene oxide) (PEO)	Deionized water		**Solution Concentration:** $10wt\%$ PEO **Nozzle:** 32G metal needle **Solution deposition rate:** (Jet impact speed of $5mm/s$) **Nozzle-to-substrate distance:** $0.5mm$ **Substrate composition:** p-type silicon wafer **Applied voltage:** $400V$ **x-y stage velocity:** $5mm/s$ **Fiber Diameter:** **Distance between adjacent fibers:** $50\mu m$	[23]

Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

3. Polymer Solution and Process Parameters

4. Applications

5. Fiber Characterization

6. Conclusion

References

[1] G. S. Bisht, G. Canton, A. Mirsepassi, L. Kulinsky, S. Oh, D. Dunn-Rankin, M. J. Madou, Controlled Continuous Patterning of Polymeric Nanofibers on Three-Dimensional Substrates Using Low-Voltage Near-Field Electrospinning, Nano Letters 11 (4) (2011) 1831–1837. doi:10.1021/nl2006164.

[2] D. D. Camillo, V. Fasano, F. Ruggieri, S. Santucci, L. Lozzi, A. Camposeo, D. Pisignano, Near-field electrospinning of conjugated polymer light-emitting nanofibers, Nanoscale 5 (2013) 11637–11642. doi:10.1039/C3NR03094F.

[3] C. Chang, K. Limkrailassiri, L. Lin, Continuous near-field electrospinning for large area deposition of orderly nanofiber patterns, Appl Phys Lett (2008) 3doi:10.1063/1.2975834.

[4] Y. Duan, Y. Ding, Z. Xu, Y. Huang, Z. Yin, Helix Electrohydrodynamic Printing of Highly Aligned Serpentine Micro/Nanofibers., Polymers 9 (9) (sep 2017). doi:10.3390/polym9090434.

[5] A. Gupta, A. M. Seifalian, Z. Ahmad, M. J. Edirisinghe, M. C. Winslet, Novel Electrohydrodynamic Printing of Nanocomposite Biopolymer Scaffolds, Journal of BIOACTIVE AND COMPATIBLE POLYMERS 22 (2007). doi:10.1177/0883911507078268.

[6] Y. Huang, Y. Duan, Y. Ding, N. Bu, Y. Pan, N. Lu, Z. Yin, Versatile, kinetically controlled, high precision electrohydrodynamic writing of micro/nanofibers, Scientific Reports 4 (1) (2015) 5949. doi:10.1038/srep05949.

[7] J. Jiang, X. Wang, W. Li, J. Liu, Y. Liu, G. Zheng, J. Jiang, X. Wang, W. Li, J. Liu, Y. Liu, G. Zheng, Electrohydrodynamic Direct-Writing Micropatterns with Assisted Airflow, Micromachines 9 (9) (2018) 456. doi:10.3390/mi9090456.

[8] J. Kim, B. Maeng, J. Park, Characterization of 3D electrospinning on inkjet printed conductive pattern on paper, Micro and Nano Systems Letters 6 (1) (2018) 12. doi:10.1186/s40486-018-0074-1.

[9] S.-Y. Min, T.-S. Kim, B. J. Kim, H. Cho, Y.-Y. Noh, H. Yang, J. H. Cho, T.-W. Lee, Large-scale organic nanowire lithography and electronics, Nature Communications 4 (1) (2013) 1773. doi:10.1038/ncomms2785.

[10] C. Song, J. A. Rogers, J.-M. Kim, H. Ahn, Patterned polydiacetylene-embedded polystyrene nanofibers based on electrohydrodynamic jet printing, Macromolecular Research 23 (1) (2015) 118–123. doi:10.1007/s13233-015-3024-2.

[11] D. Sun, C. Chang, S. Li, L. Lin, Near-Field Electrospinning (2006). doi:10.1021/nl0602701.

[12] H. Wang, S. Huang, F. Liang, P. Wu, M. Li, S. Lin, X. Chen, Research on Multinozzle Near-Field Electrospinning Patterned Deposition, Journal of Nanomaterials 2015 (2015) 1–8. doi:10.1155/2015/529138.

[13] Z. Wang, X. Chen, J. Zeng, F. Liang, P. Wu, H. Wang, Controllable deposition distance of aligned pattern via dual-nozzle near-field electrospinning, AIP Advances 7 (3) (2017) 035310. doi:10.1063/1.4974936.

[14] Z. Wang, X. Chen, J. Zhang, Y.-J. Lin, K. Li, J. Zeng, P. Wu, Y. He, Y. Li, H. Wang, Fabrication and evaluation of controllable deposition distance for aligned pattern by multi-nozzle near-field electrospinning, AIP Advances 8 (7) (2018) 075111. doi:10.1063/1.5032082.

[15] J. Xu, M. Abecassis, Z. Zhang, P. Guo, J. Huang, K. Ehmann, J. Cao, Accuracy Improvement of Nano-fiber Deposition by Near-Field Electrospinning, International Workshop on Microfactories IWMF2014 (9th) (2014).

[16] N. Xue, X. Li, C. Bertulli, Z. Li, A. Patharagulpong, A. Sadok, Y. Y. S. Huang, Rapid Patterning of 1-D Collagenous Topography as an ECM Protein Fibril Platform for Image Cytometry, PLoS ONE 9 (4) (2014) e93590. doi:10.1371/journal.pone.0093590.

[17] G. Zheng, W. Li, X. Wang, D. Wu, D. Sun, L. Lin, Precision deposition of a nanofibre by near-field electrospinning, Journal of Physics D: Applied Physics 43 (41) (2010) 415501. doi:10.1088/0022-3727/43/41/415501.

[18] J.-Y. Zheng, H.-Y. Liu, X. Wang, Y. Zhao, W.-W. Huang, G.-F. Zheng, D.-H. Sun, Electrohydrodynamic Direct-Write Orderly Micro/Nanofibrous Structure on Flexible Insulating Substrate, Journal of Nanomaterials 2014 (2014) 1–7. doi:10.1155/2014/708186.

[19] N. Bu, Y. Huang, X. Wang, Z. Yin, Materials and Manufacturing Processes Continuously Tunable and Oriented Nanofiber Direct-Written by Mechano-Electrospinning Continuously Tunable and Oriented Nanofiber Direct-Written by Mechano-Electrospinning (2012). doi:10.1080/10426914.2012.700145.

[20] S. Coppola, V. Vespini, G. Nasti, O. Gennari, S. Grilli, M. Ventre, M. Iannone, P. A. Netti, P. Ferraro, Tethered Pyro-Electrohydrodynamic Spinning for Patterning Well-Ordered Structures at Micro-and Nanoscale, Chem. Mater 26 (2014) 3360. doi:10.1021/cm501265j.

[21] A. Cisquella-Serra, M. Magnani, Álvaro Gual-Mosegui, S. Holmberg, M. Madou, M. Gamero-Castaño, Study of the electrostatic jet initiation in near-field electrospinning, Journal of Colloid and Interface Science 543 (2019) 106–113. doi:10.1016/J.JCIS.2019.02.041.

[22] A. R. Nagle, C. D. Fay, Z. Xie, G. G. Wallace, X. Wang, M. J. Higgins, A direct 3D suspension near-field electrospinning technique for the fabrication of polymer nanoarrays, Nanotechnology 30 (19) (2019) 195301. doi:10.1088/1361-6528/ab011b.

[23] D. Shin, J. Kim, J. Chang, Experimental study on jet impact speed in near-field electrospinning for precise patterning of nanofiber, Journal of Manufacturing Processes 36 (2018) 231–237. doi:10.1016/J.JMAPRO.2018.10.011.