Highly Controlled Deposition with Multiple Electrode Electrospinning

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Applications of electrospinning (ES) range from fabrication of biomedical devices and tissue regeneration scaffolds to light manipulation, energy conversion, and power generation, even to deposition of materials that act as growth platforms for nanoscale catalysis. One major limitation to wide adoption of electrospun materials is the ES hardware itself, which typically requires high voltage, electric isolation, and charged and flat deposition surfaces. The range of applications for electrospun materials can be further realized through control over material dimension and morphology. For instance, alignment of electrospun fibers has enabled superior crystallinity, improved cell adhesion and tissue repair,[1,2] and improved photovoltaic properties.[3,4] Weaving of polymer fabrics has enabled ES deposition of materials with superior strength and flexibility.[5] Handheld ES devices have enabled deposition onto non-charged, complex surfaces as well as deposition of conductive polymer materials that otherwise arc in a typical ES system.[6–8]

In this work, we demonstrate an ES system that contains multiple high voltage power supplies (Figure 1). COMSOL Multiphysics® software was used to model the electric field produced in this novel ES system (Figure 2). To date, this system has enabled deposition of woven fabrics, aligned fiber mats, and woven materials without the use of complex electrodes, multi-dimensional deposition surfaces, or weaving looms[5] that have been used in the past to create such structures. We demonstrate fabrication of woven fiber materials (Figure 3) and deposition of complex shapes such as figure-eight (or infinity) patterns. Time-varied sinusoidal wave inputs were used to create electrospun torus shapes (Figure 4) that have not been demonstrated with other highly-controlled ES systems. Parametric analysis was used to create a model for predicting tori dimensions. In addition, the time constant of the multiple power supply system was measured and decreased through the modification of system impedance to improve response time, further improving process controllability in our novel ES system.

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[5]Padmakumar, S., et al., 2019. *Nanomedicine: Nanotechnology, Biology and Medicine*, 15(1), pp.274-284.
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[7]Huston, L., et al., 2019. *Journal of Vacuum Science & Technology B*, 37(6), p.062002.
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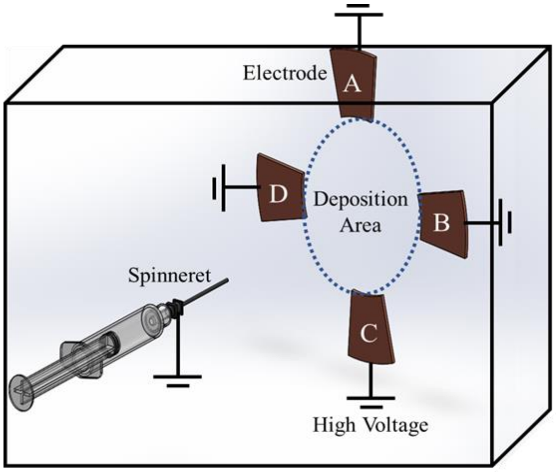

Figure 1. Graphical representation of the multiple power supply ES system. The system contains four electrodes (A-D) and a spinneret, each connected to a power supply that is independently controlled by a LabView program.

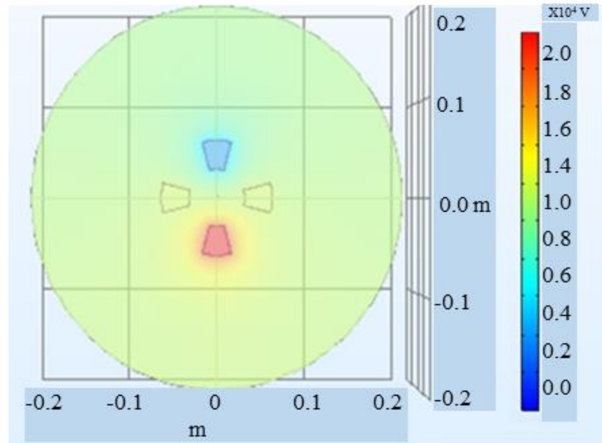

Figure 2. COMSOL Multiphysics® models representing the electric field of the multiple power supply ES system.

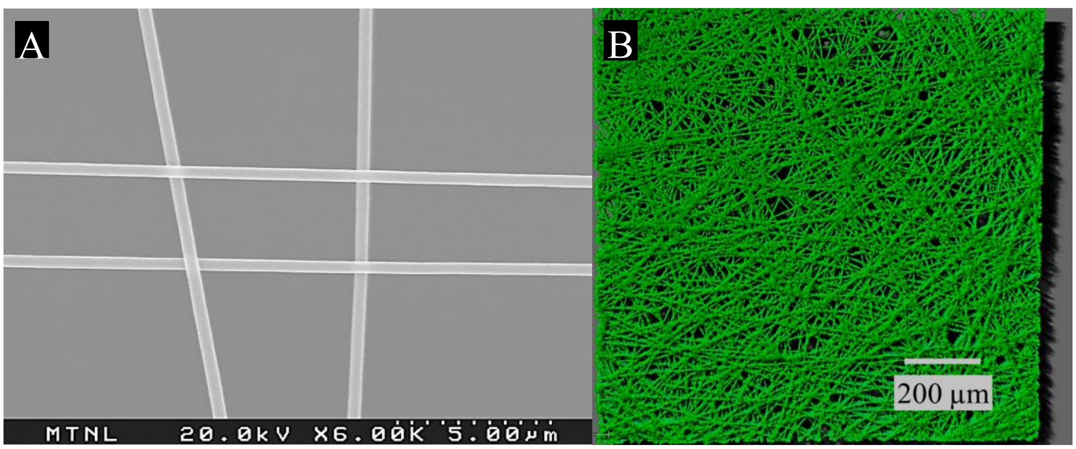

Figure 3. A Micrograph taken from a woven polymer fiber mat made with the multiple power supply ES system. Independently controlled electrodes enable woven material creation without use of complex deposition substrates or electrodes. **B** Confocal image showing a three-dimensional micrograph of a woven polymer mat

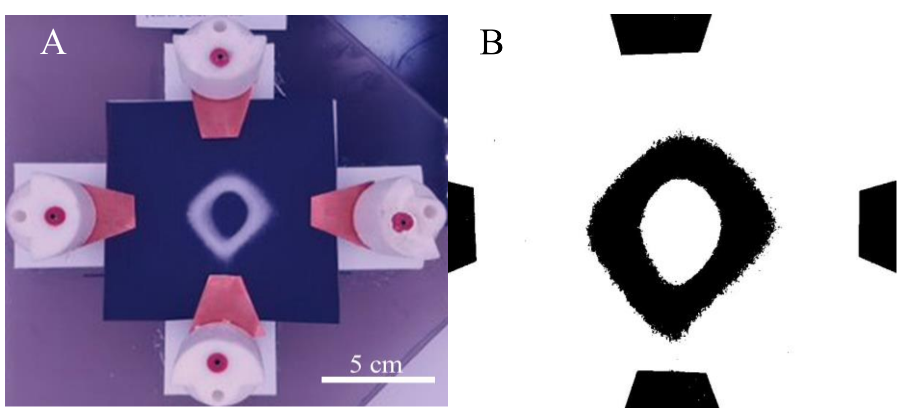

Figure 4. A Electrospun tori produced by the multiple power supply ES system. **B** Tori dimensions used for parametric analysis were determined by thresholding camera images in Image J.