Electromechanical Spinning (EMS) a New Nanomanufacturing Option

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Background:

Fabrication of functional polymeric nanofibers has attracted considerable attention from researchers in academia and industry due to a wide variety of applications of such fibers in the fields of sensors and actuators [1-4], energy storage [5, 6], smart textiles [7-10], optoelectronics [11, 12], tissue engineering [13-16], prosthetics [17], drug delivery [18, 19], micro resonators [20], and piezoelectric energy generators [21]. However, widespread success of these applications is impeded by the limited capabilities of presently available fabrication techniques to accurately control the physical properties and positioning (patterning) of the nanofibers in a reliable and economical way. Techniques analogous to Electron-Beam Lithography (EBL) and Dip-Pen Lithography do allow controlled writing of nanofibers but face stiff economical or technical challenges in scale-up. Electrospinning on the other hand has emerged as a successful method to fabricate various types of polymeric nanofibers on a large scale [22]. This technique, also known as Far-Field Electrospinning (FFES), involves the application of a high voltage (10-15kV) to bias a polymer solution in a syringe against a grounded substrate with the syringe tip separated from the substrate by a distance of 10 to 15cm. The grounded substrate then electrostatically pulls onto the droplet at the tip of the syringe to induce flow of charge in the form of a polymeric jet that undergoes stretching and whipping motion in situ by the electric field leading to the generation of nanofibers that land onto the substrate. However, FFES is hard to control due to the electric instabilities that are inherent in the electrospinning process [23-25]. Although the alignment of nanofibers along a preferred direction has been accomplished through the use of a rotating drum collector [26-29], and by using electrical field manipulation [23, 30-32], precise 2D and 3D patterning is still very difficult to achieve. Generally speaking, current state-of-the-art fabrication methods for polymeric nanofibers fail to deliver precise, inexpensive, fast and continuous patterning capability.

Electromechanical Spinning:

A technology developed by our team that alleviates most of the listed problems is called Electromechanical Spinning (EMS). It offers a key advance in electrostatic fabrication of functional nanofibers by lowering of the operating voltage by several orders of magnitude and an attendant increase in patterning control compared to FFES. The EMS technology uses a superelastic polymer based carrier ink that can be utilized in conjunction with functional materials to pattern a range of versatile nanofibers with desired properties. Figure 1 shows a schematic of our setup with the perturbation free polymeric jet emanating out of the Taylor cone to generate nanofibers by electro-mechanical stretching. These nanofibers are generated continuously and targeted with precision on 2D or 3D substrates. 3D micropost arrays were wired together with the electrospun nanofibers as shown in Figure 2. The major difference between FFES and EMS technology is the ability to tightly control bending instabilities as demonstrated in Figure 3, which is found to be enabled by the low operating voltage and the viscoelastic properties of the carrier ink. The ability to operate in the low voltage regime also improves control over thickness of the nanofibers directly by controlling the applied voltage and can be further fine-tuned by relative stage speed with respect to the nozzle as evidenced in Figure 4. We have successfully demonstrated patterning of nanofibers across a wide range of diameters from a few microns to sub 20nm. Preliminary results were published in the April 2011 [33] issue of Nano Letters.

In this contribution we will detail the work reported there and additional results obtained from 2011 to 2014.

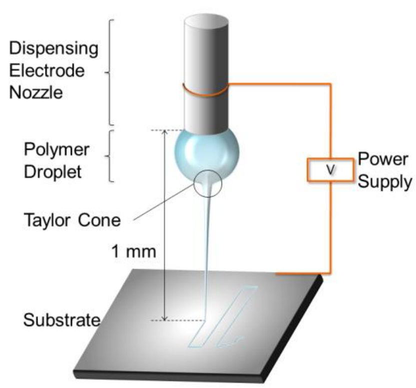

Figure 1. The EMS setup

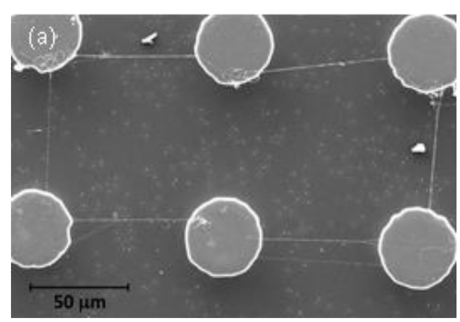

Figure 2. Direct wiring of 3D micropost structures with EMS.

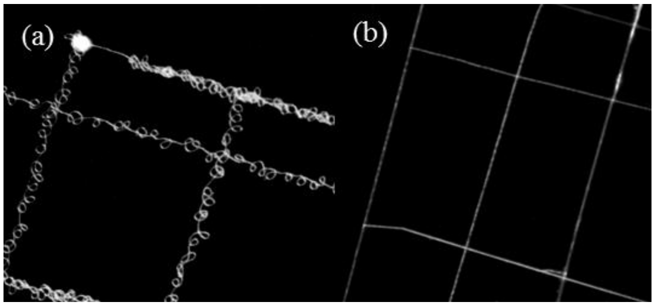

Figure 3. Transition from an unstable nanofiber jet at 600V (a) to a stable controlled jet at 300V (b) allows easy patterning

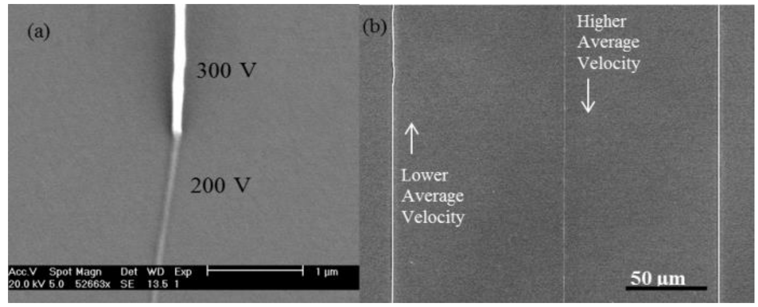

Figure 4. Applied voltage and stage speed are used to control nanofiber thickness in the EMS technology

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