Chip-based microfabricated electrospinning nozzles

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We have used microfabricated nozzles with inner diameters as small as 5 microns to produce electrospinning jets. Because the electrospinning process uses an electrically forced fluid jet to produce micro- or nanofibers from solution, both the nozzle material and geometry can play an important role in defining the fluidic cone and jet. As the field of electrospinning grows, there is increased interest in investigating the effects of nozzle geometry on both the behavior of the electrospinning jet and the properties of the resulting fibers. Typical electrospinning systems utilize a standard syringe needle to provide a constant supply of solution to an electrically formed fluid cone at the sharp end of the needle. Other systems have used solid sharp tips to which a small droplet of solution is applied;[1] though a constant supply of solution is not practical with such designs, they are useful for quick deposition of a small number of fibers. Several multi-jet systems have been described that allow for increased mass throughput.[2-4] However, there has been little investigation into the limits of a nozzle-based design.

We have used the robotic NanoMate system (Advion Biosciences) typically used to introduce samples into mass spectrometry systems using electrospray ionization (ESI-MS)[5] to produce an electrospinning jet. The Advion ESI-chip used in this system was fabricated from single crystal silicon using standard microfabrication techniques. Lithography and Deep Reactive Ion Etching (DRIE) were used to create the nozzle feature and a channel through the wafer to a liquid reservoir etched into the backside of the wafer. The nozzles were etched on a 1.125mm pitch, resulting in 400 nozzles per ESI-chip (Figure 1). Using the NanoMate system, we were able to produce polymeric nanofibers with various geometries, including beads-on-a-string, straight continuous fiber, and fibers that had broken in flight (Figure 2). To our knowledge, this is the smallest electrospinning source demonstrated that incorporates a nozzle, allowing a continuous feed of solution.

Fibers were collected both on a stationary substrate and on a substrate that was rotated through the jet to help isolate the fibers. In several situations, while examining the resulting fibers, we observed short isolated lengths of fiber (Figure 2c) as well as the typical single non-woven mat (Figure 2a). When the collecting substrate was stationary, instead of observing the typical circular mat produced by standard electrospinning systems, we often observed a starburst pattern due to short isolated sections of fiber being deposited radially at the perimeter of the mat. We believe this is due to the accumulated charge in the deposited mat radially deflecting the path of a broken section of the jet in flight.

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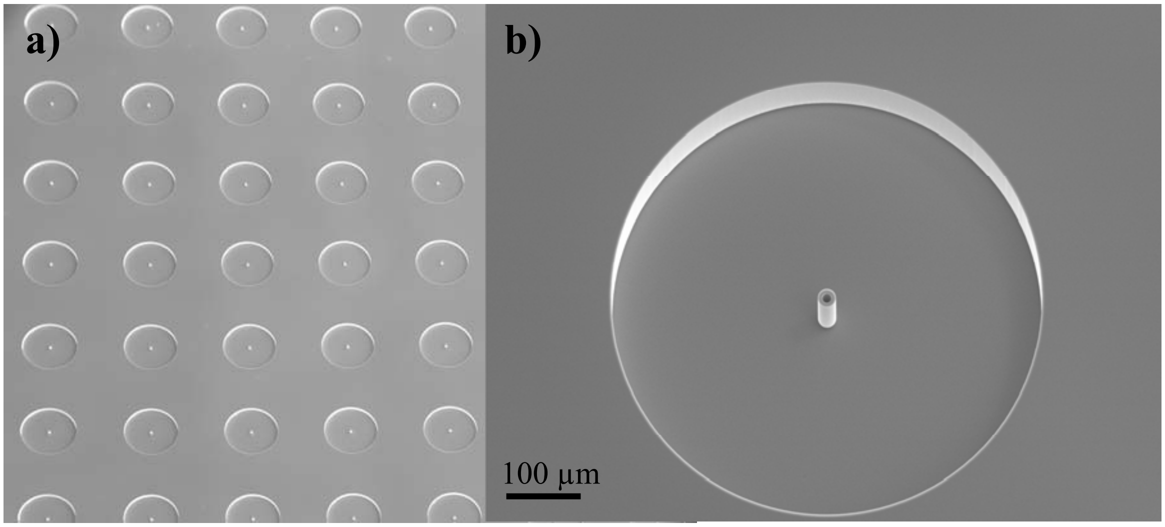

Figure 1- a,b) SEM images of ESI-chip nozzles on which we form electrospinning jets. The chip containing the nozzle array is mounted in the NanoMate robot to supply solution to the back of individual nozzles

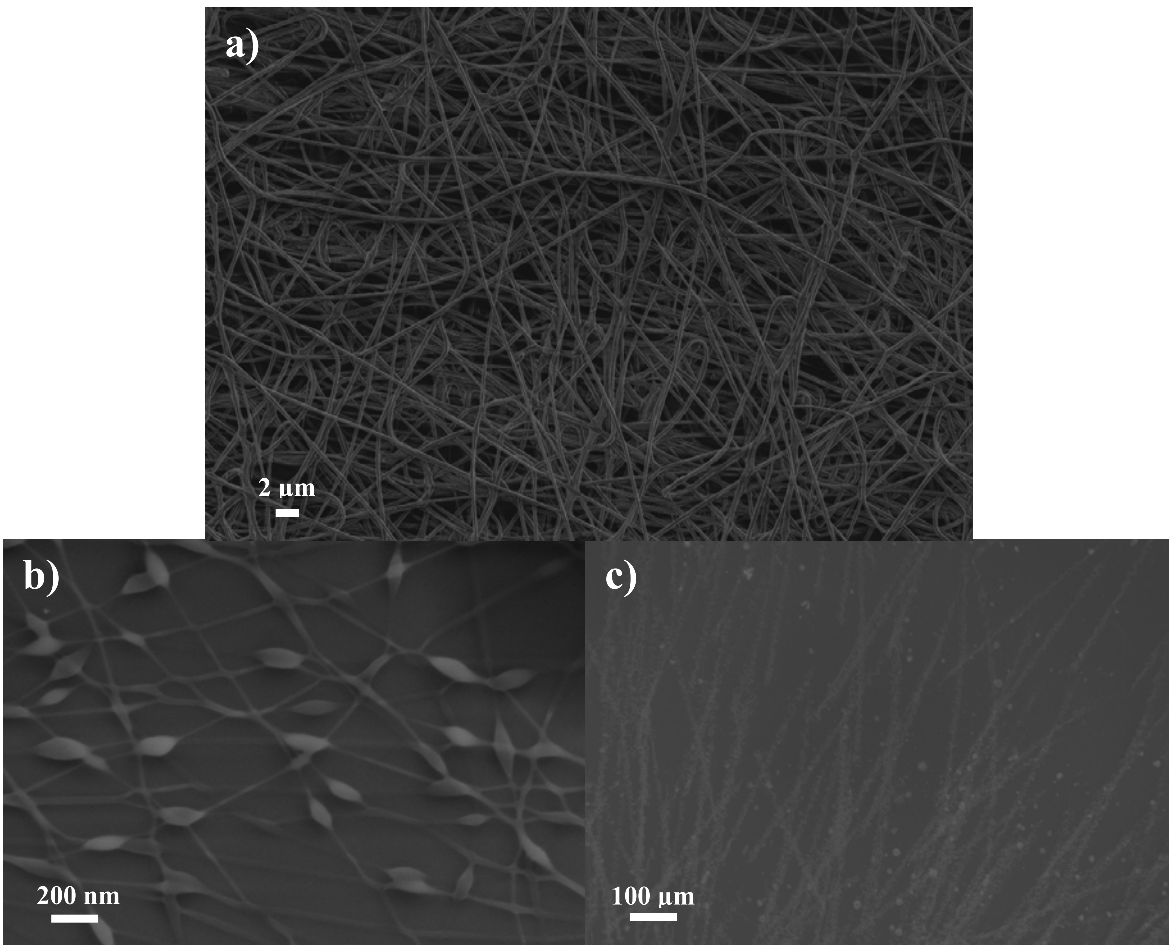

Figure 2- SEM images of fibers produced by electrospinning PMMA solutions. Image a) shows a standard non-woven mat of PMMA nanofibers. Fibers in image b) are of the "beads-on-a-string" geometry, with "string" sections of sub-50nm diameter. Several of the fibers in image c) are terminated on both sides, indicating that the jet broke in flight.