Multi-component solutions as tools to study electrospinning jet dynamics

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Electrospinning is a popular technique for producing micro- and nanoscale fibers (Figure 1a) from a wide variety of materials using an electrically-forced jet. There has been a great deal of effort dedicated to modeling[1-3] and controlling[4, 5] the jet in order to utilize electrospinning as a direct deposition fabrication process. The electrospinning jet is an elongational flow with typical strain rates of $\sim 10^5$ sec^{-1} and velocities up to ~1-10 m/sec, and is thought to produce fibers with significant molecular orientation.[3] Though the majority of current electrospinning research focuses on producing single component fibers, there is increasing interest in multi-component electrospinning. Coaxial electrospinning has been used to make hollow nanofiber tubes,[6] side-by-side bi-component electrospinning has been used to fabricate TiO_2/SnO_2 nanofiber photocatalysts,[7] and several studies have demonstrated the ability to embed particles (such as carbon nanotubes[8], quantum dots[9], and biomaterials[10, 11]) in nanofibers by using an appropriate multi-component solution. Electrospinning of multi-component systems is useful for depositing new types of composite fibers, but can also be used to learn about the fluid dynamic behavior of the electrospinning jet. For example, we have electrospun a solution of polyethylene oxide mixed with a small number of fluorescently labeled λ DNA molecules to produce fibers containing isolated, stretched DNA (Figure 1b).[12] This is not only useful for genomic analysis applications, but also indicates the flow behavior of the jet to some extent. The flow behavior of the electrospinning jet is difficult to measure, and it is not known at what point along the jet axis the DNA molecules are stretched (Figure 2). Moreover, several other parameters used to describe electrospinning jets, such as jet velocity and strain rate, have only been estimated from measurements. We propose a system to directly measure these properties along the jet axis using fluorescently labeled particles in the electrospinning solution (Figure 3). Previous work using similar techniques has measured the velocity profile in the Taylor cone that precedes an electrospinning jet.[13, 14] Jet velocity can be measured using particle image velocimetry in conjunction with a camera, or using an avalanche photodiode exposed to a field of view of known size. With more precise information about the jet velocity along the jet axis, the fluid dynamic behavior of electrospinning jets can be better understood, aiding in the development of electrospinning as a fabrication technique.

1 Y. M. Shin *et al.*, Appl. Phys. Lett. **78**, 1149 (2001).
2 Y. M. Shin *et al.*, Polymer **42**, 9955 (2001).
3 D. H. Reneker *et al.*, J. Appl. Phys. **87**, 4531 (2000).
4 J. M. Deitzel *et al.*, Polymer **42**, 8163 (2001).
5 L. M. Bellan, and H. G. Craighead, J. Vac. Sci. Technol., B **24**, 3179 (2006).
6 D. Li, and Y. Xia, Nano Lett. **4**, 933 (2004).
7 Z. Liu *et al.*, Nano Lett. (2006).
8 Y. Dror *et al.*, Langmuir **19**, 7012 (2003).
9 H. Liu *et al.*, Small **2**, 495 (2006).
10 W. Salalha *et al.*, Nanotechnology **17**, 4675 (2006).
11 A. C. Patel *et al.*, Nano Lett. **6**, 1042 (2006).
12 L. M. Bellan *et al.*, Nano Lett. **6**, 2526 (2006).
13 I. Hayati, Colloids Surf. **65**, 77 (1992).
14 S. R. Harris *et al.*, AIAA Journal **34**, 449 (1996).

Figures

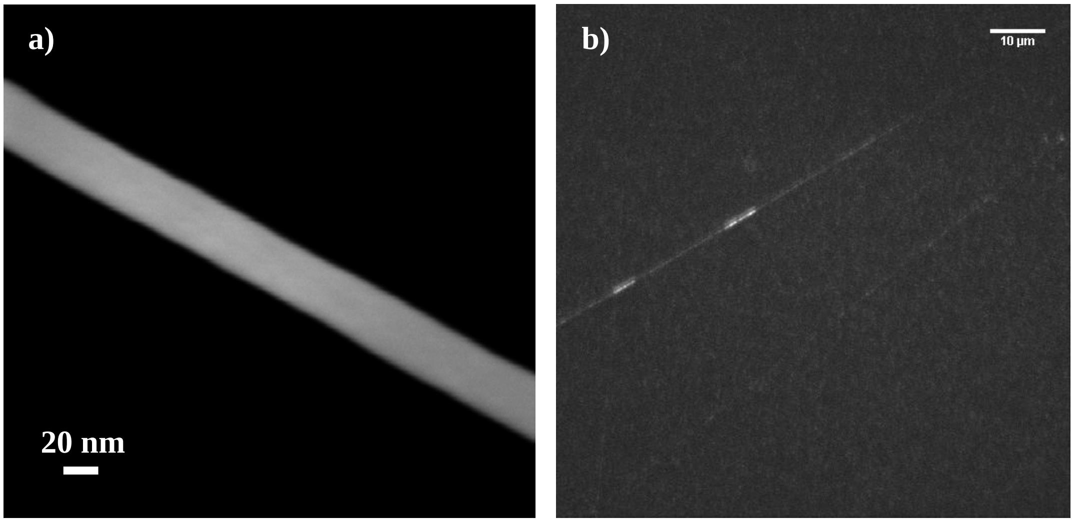

Figure 1-a) SEM image of electrospun DNA fiber b) fluorescence microscope image of stretched DNA molecules embedded in an electrospun polyethylene oxide nanofiber

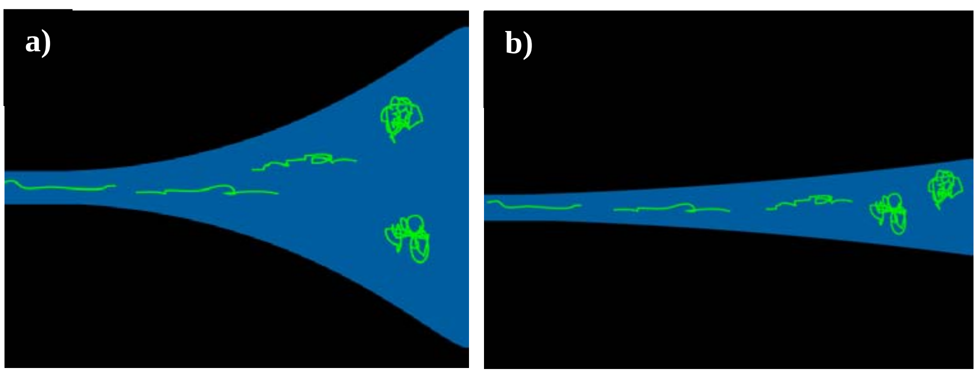

Figure 2- Illustration of DNA stretching in a) cone at electrospinning source and b) elongational flow in jet

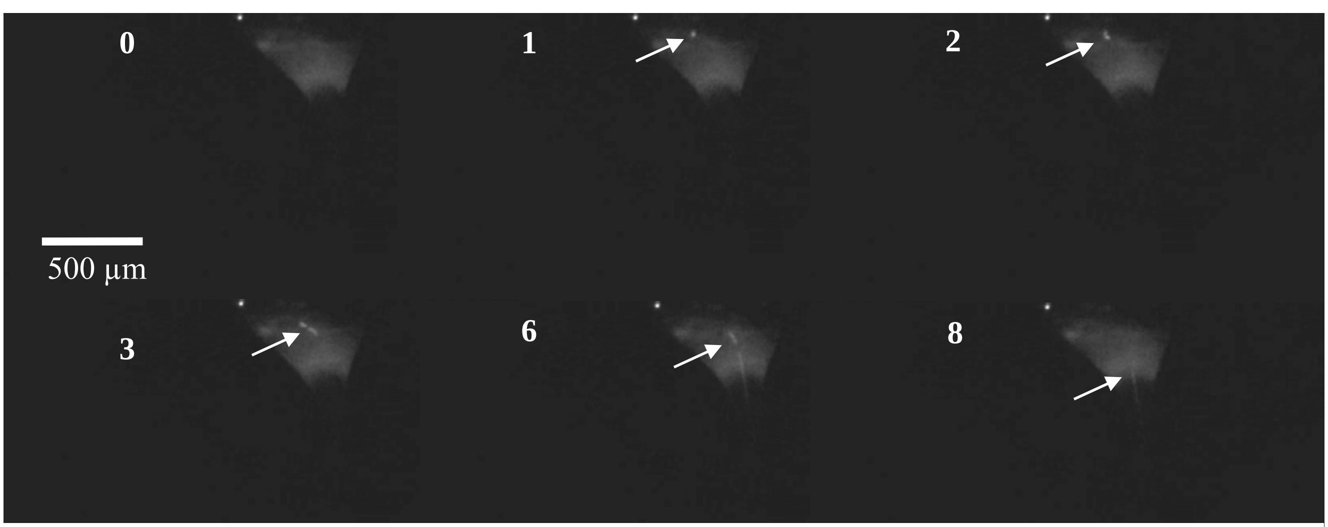

Figure 3-Time progression of fluorescent particle imaged at the beginning of the electrospinning jet. Numbers indicate frame number; the video was taken at 30 fps.