Lithography via Aligned Electrospun Fibers

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Electrospun materials have been used to enhance efficiency of physical filters, modify material properties of composites, and provide drug delivery functions. Another less-explored use of electrospun fibers is as a masking material in lift-off and lithography processes.[1-4] As with traditional lithography methods feature shape, size, and position are critical in the patterning layers. Electrospinning is being examined as a process for creating large areas of aligned fibers that can be used as masking materials for subsequent processes. Electrospinning deposition control has been achieved through the movement of the collector during the process of melt-electrospinning.[5] Deposition control can also be achieved through the manipulation of the electric field used in the deposition process. Ring electrodes have been used to lengthen the stability region of the electrospun fiber.[6] The focus of this work is to develop the methods, hardware, and expertise required for electrospinning to become a viable lithography method for the scientific community.

Aligned electrospun fibers are deposited on a substrate and then used as a mask for subsequent processes (see Figure 1). Fiber alignment is controlled through electric field manipulation during fiber creation and deposition. The electrospinning equipment contains two electrodes placed on opposite sides of a collection plate. By changing the relative voltage applied to each electrode the electrostatic field is modified creating a higher electrostatic field gradient on one electrode (see Figure 2). This asymmetric electrostatic field initiates preferential deposition toward the corresponding electrode. Two high voltage power supplies (HVPSs) along with a custom commutator are used to control applied electrode voltage. Typical HVPSs used in electrospinning use diode charge pumps and are limited to switching speeds on the order of 1 Hz. It is therefore advantageous to use an alternative method of switching. This work demonstrates a 10x increase is switching frequency with an electromechanical commutator (see Figure 3).

The switching speed of the HVPSs must be matched to the deposition speed of the polymer with an ideal switching speed producing highly aligned fibers between the electrodes without either fiber stretching or surface accumulation. To match the deposition speed of the polymer two methods were compared: (1) a volumetric method and (2) the stage velocity method. The volumetric method considers the volume of dispersed polymer, fiber deposition time, and average fiber diameter to calculate the polymer jet speed. In the stage velocity method, highly-aligned fibers are created when the lateral displacement velocity of the collection plate matches the polymer jet speed.[7] Fiber alignment is quantified by a two-dimensional FFT method.[8] Resultant fiber arrays were found to have an alignment factor of 0.482 and 0.383 (see Figure 4).

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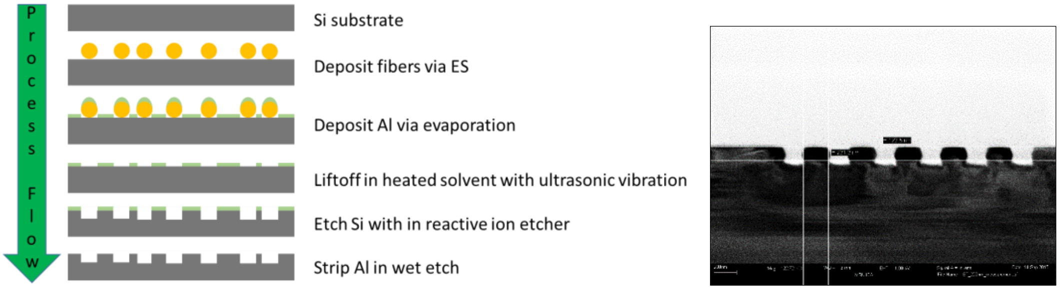

Figure 1: Side profile sketch (left) of the lithography process using electrospun fibers as a masking material and TEM (right) of the substrate after the lithography process.

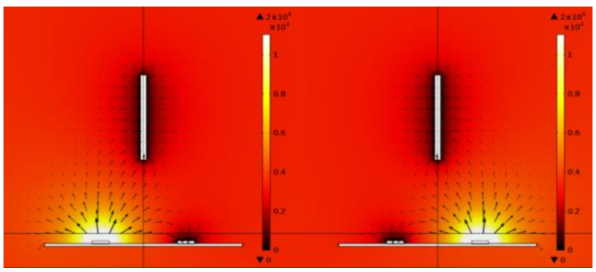

Figure 2: Electrostatic field between two electrodes and the capillary. The field strength changes as one electrode is set to a higher potential which causes the fiber to preferentially deposit to the electrode with the higher potential.

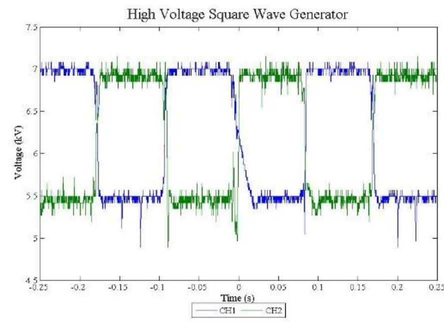

Figure 3: The mechanical commutator generates a square-wave signal from two DC voltages. The two signals that are generated are 180° out of phase. This signal is used to raster the electrospun fiber across the Si substrate.

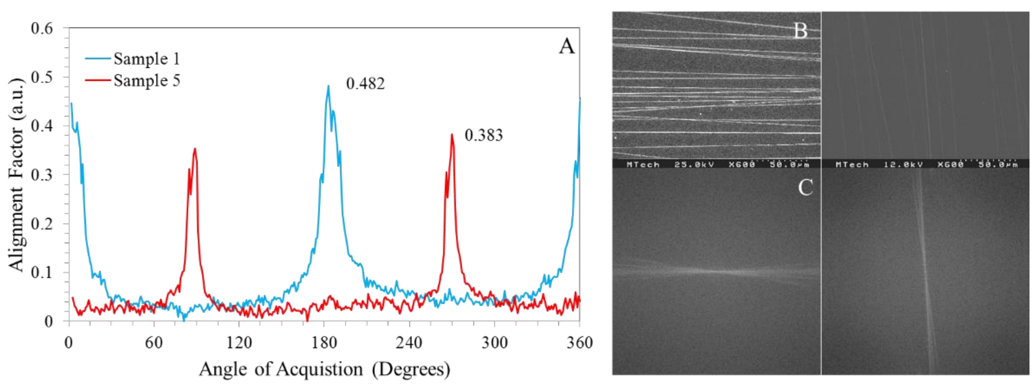

Figure 4: (A) Plot of 2D FFT measuring fiber alignment. (B) Scanning electron micrographs of aligned electrospun fibers with Sample 1 (left) and Sample 5 (right). (C) FFT image processing for the electrospun samples.