ABSTRACT

Sub-micron polymethylmethacrylate (PMMA) filaments shaped by hydrodynamic forces were fabricated in a very simple sheath flow fluidic device. The sheathing of the core polymer solution is guided by straight or chevron-shaped grooves on the channel's top and bottom walls; sheath fluid flowing through the grooves wraps around the core stream containing the solubilized PMMA. Different sizes of the filaments were obtained by changing the flow ratios between the sheath and core solutions.

KEYWORDS: fluidic, hydrodynamic, sheath flow system, micron/nano filament,

INTRODUCTION

Extrusion of polymers using microfluidic devices has been used to form micron-diameter fibers [1-3]. However, the shape and size of the particles/filaments are usually dictated by the geometry of the nozzle used to introduce the prepolymer into a fluid of a different phase or by interfacial effects. In our fluidic system, slanted straight grooves or chevron-shaped grooves are incorporated strategically on both the top and bottom surfaces of the channel to wrap the sheath solution around the PMMA-containing core after both streams are introduced into the main channel via standard intersecting channels (Figure 1 A, B). Only a single sheath stream is required to ensheathe the PMMA solution [4, 5] using the slanted grooves system while two streams of sheath solution are used in chevron-based design

EXPERIMENTAL

The sheath flow devices are fabricated as two mirror-image halves in Teflon using a CNC milling machine. The two halves are then assembled and clamped with aluminum pieces on which the fluidic connection ports are machined. The flow channels are 3.2 mm wide and 1 mm high. The sheath solution is introduced from the inlet that allows the solution to reach the sheathing features first (Figure 1.)

The filament fabrication is demonstrated using solubilized PMMA (dissolved in acetone: $\mu \sim 130$ cP) and a fructose solution ($\mu \sim 550$ cP) as the core and sheath fluid, respectively. The PMMA hardens as the acetone diffuses into the fructose. The outlet of fluidic device is submerged in a beaker filled with water and the solution falls to the bottom of the beaker (Figure 1C). Once the fructose is dispersed, the PMMA filament floats on the surface of the water. The fluid flow ratio is varied by changing the flow rate of the core solution to study the effect of the flow ratio on the size of filaments.
RESULTS AND DISCUSSION

With the PMMA-fructose system, the PMMA solidification starts immediately after the PMMA is ensheathed as the acetone diffuses into the sheath fluid. Different sizes of the filaments were obtained by adjusting the flow rate ratio of the monomer and sheath fluids (Figure 2). The filament diameter decreases as the flow ratio is increased. PMMA filaments as small as 550 nm have been achieved with this method.

The resulting PMMA filaments are continuous unless the flow is interrupted. The internal structure of the filaments is porous (not shown). Since the sheathing solution is water-based, the reaction is very fast along the outer shell of the PMMA solution. This can cause deformation of the filaments cross section as the outer shell can collapse toward the center of the filament for filaments that are larger than a certain threshold size, typically 10 µm in diameter for the current system. There is also some non-uniformity in the filament diameter within each experiment caused by the instability of the syringe pump. A new pumping scheme is under development to
overcome this problem and also to enable further reduction of the size of the filament by increasing the flow ratio.

![Figure 3: Size and shape of monomer fluid as a function of the flow ratio for a design with 4 pairs of chevrons: (A) Predicted cross-sections, (B-C) Corresponding experimental cross-sections for two flow ratios. Chevron design uses two streams of sheath solution with one core monomer stream [6].](image)

An important advantage of this sheath flow system is the ability to fabricate particles/filaments with desired cross sectional features by either varying the core-to-sheath flow ratio, using multiple sheath streams, or changing the number of grooves or chevrons (Figure 3) [6].

**CONCLUSIONS**

A simple sheath flow device with integrated groove structures was used to fabricate sub-micron-diameter PMMA filaments. The hydrodynamic forces generated by the structures imbedded in the channel form the desired cross-sectional shape of the filaments.

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