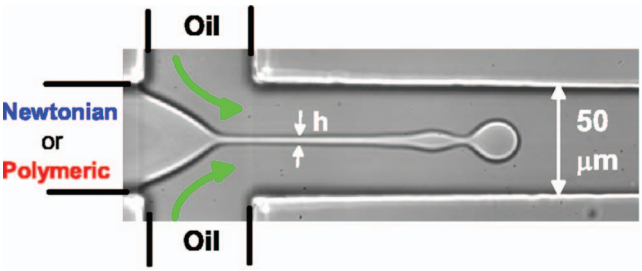

FIG. 1. (Color) Microchannel experimental setup. The device is 50 μm wide and 30 μm deep. Oil is used as the continuous phase. Newtonian or polymeric fluids are used as dispersed phases.

Polymer drop breakup in microchannels

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The addition of even small amounts of polymer to a fluid can dramatically affect the thinning and breakup of fluid filaments in microfluidic devices. Here, we compare the thinning and breakup of Newtonian and viscoelastic fluids of similar shear viscosity (0.24 Pa s) in a microchannel cross-slot geometry, where an outer oil phase enters and stretches a more slowly flowing inner aqueous phase. The device is 50 μm wide and 30 μm deep and it is molded in poly(dimethylsiloxane) using standard soft-lithography methods (Fig. 1). The continuous (outer) phase is mineral oil containing 0.1% by weight of surfactant (SPAN 80). Two types of dispersed phases (forming the filament that breaks into droplets) are used: a Newtonian fluid and a dilute viscoelastic polymeric fluid. The Newtonian fluid is a 90%-glycerin aqueous solution. The polymeric fluid is made by adding 100 ppm of flexible, high molecular weight polyacrylamide ($M_W = 18 \times 10^6$) to an 85%-glycerin aqueous solution. Fluids were designed so that both phases, oil and aqueous, have the same shear viscosity (0.24 Pa s). The aqueous and oil phases are injected into the central and side arms of the cross-channel using syringe pumps; the flow rates are 0.01 and 0.6 μl/min, respectively. The interfacial tension between the two phases is 10 mN/m. For these parameters, the Reynolds number is less than 0.01 and the capillary number is 0.2. Experiments are imaged using an inverted microscope and a fast video camera, with frame rates between 1 and 10 kHz.

The accompanying video and Fig. 2 show the evolution of filament thinning and breakup for both Newtonian and polymeric fluids. For the Newtonian case, shown in the left column, the aqueous phase is drawn into the cross-slot channel [Fig. 2(a)], and begins to elongate and collapse [Figs. 2(b)–2(d)], forming a primary drop connected by a very thin filament; later [Fig. 2(e)], the filament thins at a faster rate and breaks into a large primary drop and small satellite droplets.

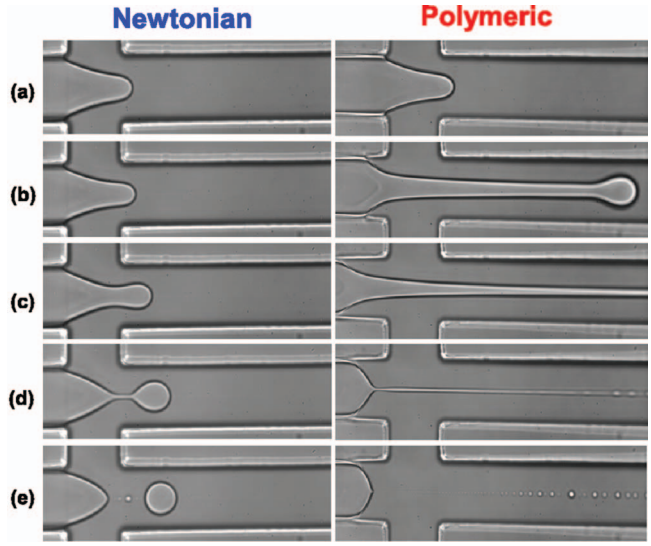

FIG. 2. (Color) Snapshots of drop formation process of both Newtonian (left column) and polymeric (right column) fluids. (Enhanced online.)

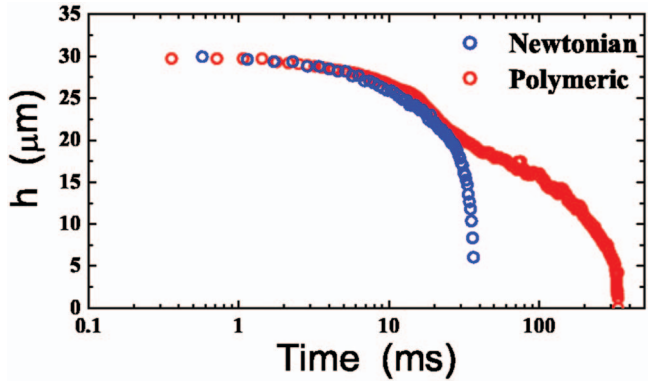

FIG. 3. (Color) Filament thickness h as a function of time for both Newtonian and polymeric fluids at the same flow rates.

The polymeric case, shown in the right column of Fig. 2, displays very different behavior. Initially [Fig. 2(a)], the morphology is similar to that of the Newtonian fluid. As the thinning progresses, the polymeric fluid develops a longer neck with a drop attached to it [Fig. 2(b)]. This filament elongates while thinning at a slower rate than in the Newtonian case [Fig. 2(c)]. Near the breakup event, the polymeric fluid shows multiple beads attached to the filament [Fig. 2(d)]. After breakup, there are many satellite drops [Fig. 2(e)].

Filament thinning is quantified by the decrease in filament diameter, $h(t)$, as a function of time (Fig. 3). At short times, the Newtonian and polymeric fluids exhibit identical initial thinning. This is indicative of their common shear viscosity but, at longer times, the two diverge with the polymeric filament lasting at least an order of magnitude longer before breakup.

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