

Liquid crystal droplet production in a microfluidic device

BENJAMIN D. HAMLINGTON[†], BENJAMIN STEINHAUS[†], JAMES J. FENG[‡], DARREN LINK[§],
MICHAEL J. SHELLEY[¶] and AMY Q. SHEN^{†*}

[†]Mechanical and Aerospace Mechanical Engineering, Washington University in St. Louis, St. Louis, MO 63130, USA

[‡]Chemical & Biological Engineering, University of British Columbia, Vancouver, BC V6T 1Z3, Canada

[§]Raindance Technologies, USA

[¶]Courant Institute of Mathematical Sciences, New York University, USA

(Received 28 June 2006; in final form 16 September 2006; accepted 13 November 2006)

Liquid crystal drops dispersed in a continuous phase of silicone oil are generated with a narrow distribution in droplet size in microfluidic devices both above and below the nematic-to-isotropic transition temperature. Our experiments show that the surface properties of the channels can be critical for droplet formation. We observe different dynamics in liquid crystal droplet generation and coalescence, and distinct droplet morphology on altering the microchannel surface energy. This is explained by the thermodynamic description of the wetting dynamics of the system. The effect of the nematic-to-isotropic transition on the formation of liquid crystal droplets is also observed and related to the capillary number. We also investigate how the nematic droplet size varies with the flow rate ratio and compare this behaviour with a Newtonian reference system. The effect of the defect structures of the nematic liquid crystal can lead to distinctly different scaling of droplet size in comparison with the Newtonian system. When the nematic liquid crystal phase is stretched into a thin filament before entering the orifice, different defect structures and numbers of defect lines can introduce scatter in the drop size. Capillary instabilities in thin nematic liquid crystal filament have an additional contribution from anisotropic effects such as surface gradients of bending stress, which can provide extra instability modes compared with that of isotropic fluids.

1. Introduction

Many phases of liquid crystalline materials exist, each distinguished by the spatial arrangements of the constituent liquid crystal molecules. The nematic phase is that most commonly used in commercial applications. Thermotropic liquid crystals remain in the nematic phase only within a specific temperature range; outside of this range, the material either becomes isotropic and loses its ordered structure, or assumes a much more structured phase such as the smectic phase. Liquid crystals can be engineered to have a large nematic temperature range and thereby great functionality.

Dispersions of nematic liquid crystal have unique optical and rheological properties. Examples of this are found in the interactions between water droplets dispersed in nematic liquid crystal [1], defect gels in cholesteric liquid crystals that are stabilized by particles [2] with enhanced elastic modulus, and electro-optically tunable scattering of light with polymer dispersed liquid crystals [3]. Typical methods for the generation of droplets in these dispersions result in a wide range of

droplet size and shape. When the droplets are made sufficiently uniform in size they have a strong tendency to organize into a regular packing. The regularity of the packing and uniformity of droplet size can result in a modulation of the index of refraction that is sufficiently regular to achieve interference effects with coherent light [4]. This effect has applications for the high speed electrical modulation of optical diffraction properties. However, the technology needed to generate dispersions with a precisely controlled distribution of droplet sizes is currently very limited. Several methods have been suggested for uniform emulsification of two fluids, including micromachined combs, shearing the fluid between plates [5], phase separation [6], polymerization [7] and forcing droplets through a T-junction or flow-focusing geometry [8, 9]. While each of these proposed methods can produce emulsification, obtaining uniform size in a reproducible fashion remains a challenge. It would be advantageous to have a technology capable of precisely controlling droplet size and the distribution of sizes. This would allow for the tailoring of electro-optical properties and the large scale production of materials.

Microfluidics has emerged in recent years as a method of manipulating fluid at small length-scales

*Corresponding author. Email: aqshen@me.wustl.edu