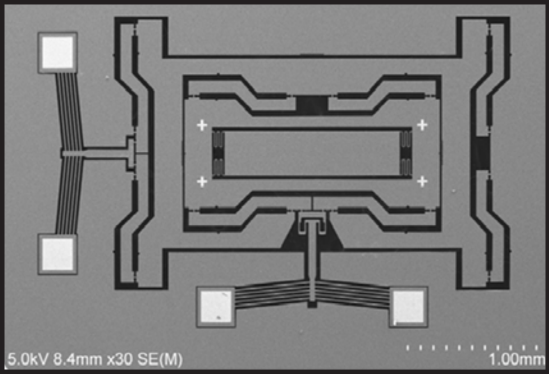
Micro-rheometry

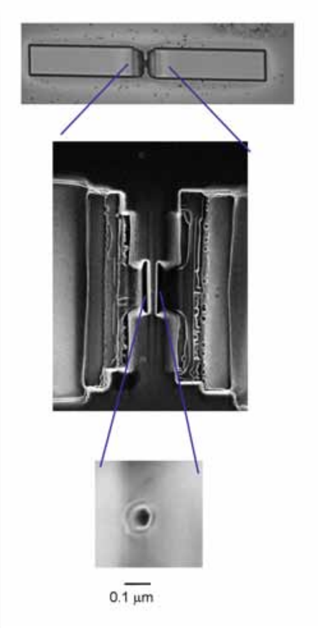
Objective

Our goal is to develop micro and nano-fluidic tools that measure rheological properties of quantity-limited complex fluids and that probe the regime where the fluid's structural length scales are comparable to that of the flow. These tools are especially needed by the pharmaceutical, polymers, and medical testing industries to probe rheological properties of fluids which are difficult and expensive to produce.



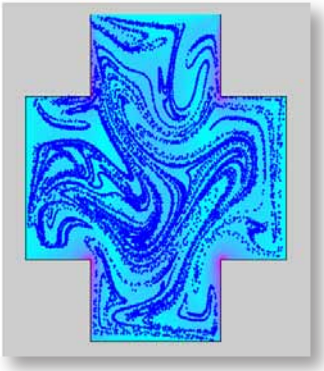
Impact and Customers

- Our micro and nano-fluidic devices will be the next generation of tools to measure rheology and processing operations and provide critical tests of theories of polymer confinement in channels.
- We are developing a polymer processing laboratory on a chip with capabilities of multisample rheological measurements, lamellar stacking and blending operations in a volume at least 1000 smaller than other processing equipment. This enables processing studies on highly controlled samples of limited quantity.
- We have developed a micro-fluidic platform with unprecedented control over the flow, and the ability to generate droplets with interfacial compatibilizers. The industrially relevant flow fields enable realistic studies of droplet aging during processing.
- We have discovered a new family of structures in polymer blends that are sheared under conditions of strong confinement (strings, chains, and layering) – these structures are expected to be prominent in micro-injection and microfluidics.
- Our customers include Stanford University (ring polymers), Michigan State University (nanocomposites), University of Maryland (photoactive polymers) and MedImmune (protein therapeutics)



Approach

Our approach to the development of micro and nano-fluidic devices is to start with existing concepts and geometries of rheometry and to then "think small." This approach ensures that we are measuring fundamental materials properties rather than quantities that are experiment and geometry specific. Examples include:

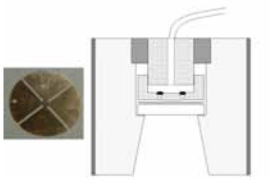


- Development of microfluidic devices that generate well defined flow fields to probe interfacial properties such as interfacial tension and interfacial viscosity.
- Development of a multisample capillary rheometer that is based on a traditional rheometer but uses approximately 1000 times less material.
- New measurements of the hemadynamics within microcapillaries to explore the flow structures that occur when the red blood cells are confined by the capillaries.
- Development of a dynamic rheometer for solution characterization that uses traditional oscillating parallel plates, but is constructed on a MEMS platform.

POLYMERS

Accomplishments

Polymer Melt Microfluidics
We are developing a new platform for polymer processing operations and rheological measurements that operates on the microlength scale and utilizes at least 1000 times less material than traditional instruments. The platform is based on flow through shim slits and is easily reconfigurable so that it can emulate a capillary rheometer, a microinjection molder, a blender, or an ABAB lamellar stacker. The goal is to enable faster and more efficient testing of the processing behavior of new materials, and to speed the development of new processing operations.



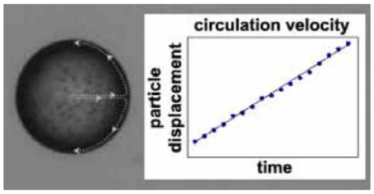
Multisample micro-rheometer (M2R)

In the Multi-Sample Micro-slit Rheometer configuration, the instrument is inherently simple, as the flow is generated by external gas pressure, and the shear rate is measured through optical tracking of the flow front; it has no moving parts. The required mass of each sample is approximately 20 mg, significantly less than traditional rheometers, and it measures four samples simultaneously. It covers eight orders of magnitude in viscosity and six orders of magnitude in shear rate over a wide range of temperatures.

In the lamellar stacking configuration a 2^n split-and-recombine mixer has been demonstrated. For completely immiscible polymers, the thickness of the layers decreases to approximately one micron; after that, a droplet morphology is formed. Processing configurations of this class allow for simple tests of complex operations.

The Polymer Melt Microfluidic Platform in a lamellar ABAB stacking configuration

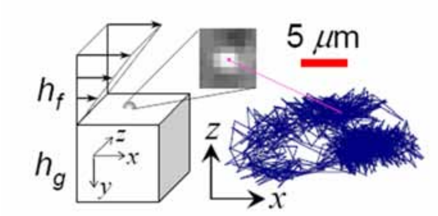
Multi-Component Liquid Flow
Multiphase liquid systems are essential to everyday life, e.g., foods, pharmaceuticals, cosmetics, paints, oil recovery, etc. The morphology and stability of such systems depend on dynamic interfacial properties and processes. Using a microfluidic approach, we have developed a means to measure dynamic structure and kinetics in multiphase systems that utilizes drop sizes comparable to those encountered in applications, and flow complexity that is easily adjustable.



Measurement of the flow within a droplet by measuring the trace of a particle within it.

In our approach, the internal circulation and deformation of a droplet in an immiscible continuous phase fluid flow is measured using particle tracers and a detailed shape analysis. Flow kinematics can be easily adjusted by varying the drop size, height, and channel geometry. Deformation dynamics, detailed drop shape, interfacial tension, and internal circulation patterns and velocities are all measured in Poiseuille and transient elongational flows for clean and surfactant-containing systems. This approach allows for direct observation of Marangoni effects. Surfactant mass transfer kinetics can also be measured by placing a diffusing surfactant into the droplet and probing the droplet at different interface ages.

Non-Brownian Micro-Rheometry
We have developed a new method to analyze the motions of a gel interface under shear flow. Fluid flow near a deformable solid is ubiquitous in nature and technology. Blood flow through vessels, lubrication of cartilage in joints, microfuidic valves, and coating and printing processes are all examples of systems governed by the interaction between a flowing fluid and an elastic solid. Similar interfacial phenomena also occur in the multiphase flow of complex fluids. The rheological properties of such soft interfaces are inaccessible to conventional rheometry, creating the need for non-invasive and localized techniques.



Particle trace at a gel-fluid interface

The new method utilizes particle tracking for analyzing the motion of a soft interface under shear flow. We measure the linear response and extract the rheological properties of the gel, laying the foundation for a non-Brownian optical microrheology.

Learn More

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Publications

Moon D and Migler KB *Measurement of Dynamic Capillary Pressure and Viscosity Via the Multi-Sample Micro-Slit Rheometer* Chemical Engineering Sciences, (In Press, 2009)

Moon, D, Bur AJ and Migler KB *Multi-sample Micro-slit Rheometry* Journal Of Rheology, 52: 1131 (2008)

Hudson SD, Pathak JA and Martin JD *Diffusive and Convective Mass Transfer in Two-phase Microchannel Flow: Non-equilibrium Interfacial Tension* 15th International Congress on Rheology, 1003-1005 (2008)

Hobbie EK, Lin-Gibson S and Kumar S *Non-Brownian Microrheology of a Fluid-Gel Interface* Physical Review Letters, 100: 076001 (2008)