An Optofluidic Microplatform for Quantifying Structure–Stress–Flow Coupling in Complex Fluids under Extensional Microflow

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Microfluidic extensional flows provide a powerful route to investigate how complex fluids deform, orient, and relax under processing-relevant conditions. This is particularly relevant for colloidal and interfacial soft-matter systems, where the macroscopic flow response is governed not only by solvent viscosity, but also by flow-induced reorganization of internal microstructure, including self-assembled aggregates, semiflexible macromolecules, and anisotropic supramolecular networks[1]. In such systems, interfacial interactions, electrostatic coupling, and structural anisotropy give rise to nonlinear rheological behavior and flow-dependent optical and nanoscale structural responses that are absent in simple liquids. However, quantitatively linking these responses to the local microfluidic flow field remains a major experimental challenge[2].
Here, we present an integrated optofluidic microplatform that combines contraction–expansion microchannels with spatially resolved flow birefringence, in situ SAXS, and μPIV to probe structure–stress–flow coupling in complex fluids under well-defined extensional microflow. The platform integrates complementary optical and scattering measurements within matched microfluidic geometries, enabling direct access to birefringence maps, anisotropic SAXS patterns, and local velocity fields under identical flow conditions. In combination with μPIV-based flow reconstruction and numerical analysis, the system provides a quantitative framework to correlate local deformation rate, optical anisotropy, and nanoscale structural orientation throughout the microchannel.
The approach is especially suited to colloid and interface systems whose behavior is controlled by self-assembly and interparticle or intermolecular interactions, such as surfactant-based wormlike micelles and charged biopolymer solutions. It makes it possible to resolve where and how flow-induced alignment develops in contraction–expansion regions, how orientational order evolves under strong confinement and high deformation rates, and how local structural anisotropy couples to the underlying kinematics. More broadly, the platform establishes a versatile experimental tool for microfluidic rheology and optofluidic characterization of complex fluids, and offers a general route to investigate flow-induced orientation, stress generation, and microstructural reorganization in colloidal and interfacial soft-matter systems.

Keywords:
microfluidic rheology, extensional flow, structure–stress–flow coupling

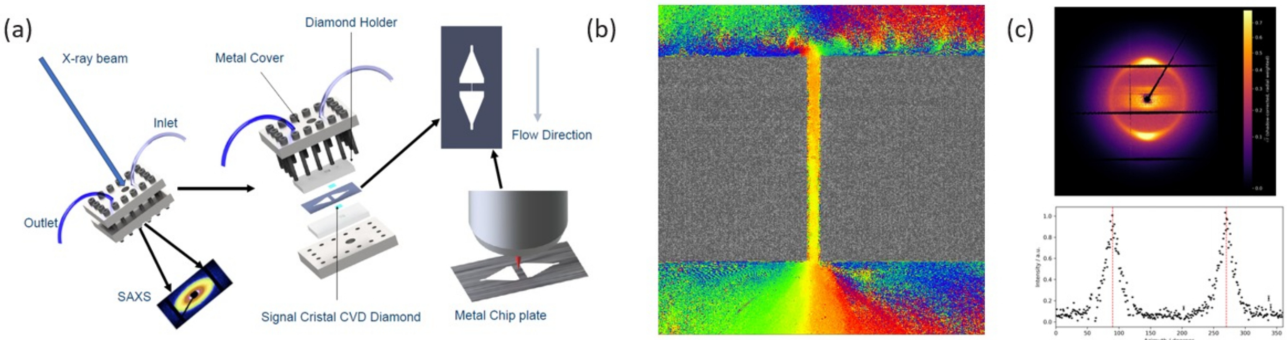

Fig. 1 Integrated microfluidic platform for birefringence and SAXS measurements under flow. (a) Microfluidic SAXS chip design. (b) Flow birefringence map. (c) Anisotropic SAXS response.

References:

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