Localized measurement of longitudinal and transverse flow velocities in colloidal suspensions using optical coherence tomography

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Introduction

Modern experiments to study mass transport phenomena in complex rheological systems such as microfluidics, polymer solutions, biofilms, blood microcirculation, and blood demand spatially and time resolved probing of concentration fields, pressure gradients, velocity profiles, wall shear stress, and diffusion coefficients.

Optical coherence tomography (OCT) is an imaging technique in which low coherence interferometry is used to produce path-length resolved complex-valued backscatter profiles of (biological) samples up to a few milliliters deep [1]. Several studies have shown the potential of OCT to measure sample dynamics, such as, longitudinal flow [2], transverse flow [3], and particle diffusion [4].

Here, we present measurements of the path-length resolved OCT signal and its autocorrelation function for the case of arbitrary oriented flow in the presence of diffusion. We show that sample morphology, flow velocities, and diffusion coefficients are determined with high temporal resolution in picoliter volumes.

Results

Figure 1 shows results from an experiment in which the flow channel was filled with a scattering solution (Intralipid 1 vol.% ) and was placed perpendicular to the imaging beam. Figure 1(a) shows the normalized magnitude of the OCT signal. The signal decays exponentially with increasing optical path length (OPL). Figure 1(b) shows the power spectral densities (PSD) calculated for the OPL shown by the blue arrow for a no-flow case and a flow case. The circles show the PSD for the no flow case and the red line the corresponding fitted model. The black dots show the PSD for the flow case and the red line the corresponding fitted model. Figure 1(c) shows the fitted path-length resolved diffusion coefficient based on the data shown in Fig. 1(b) repeated for every OPL in the channel. Figure 1(d) shows the fitted path-length resolved flow velocity. The gray parabolas show the confidence bounds of the reference velocity measurement.

As an example application for simultaneous high speed imaging of depth resolved sample morphology and quantitative flow, Fig. 2 shows contour plots of the longitudinal and transverse flow velocities through the cross-section of the channel and the corresponding OCT magnitude image. The flow velocity vector was tilted at 87.4°. The measured maximum flow velocity \( v_{\text{max}} = (v_{\text{max}} + v_{\text{sym}}) \) was 26.3 ± 1.0 mm/s at the center of the capillary is in good agreement with the reference velocity of 24.0 ± 2.3 mm/s.

Conclusion

We presented measurements of the local diffusion coefficient and the transverse and longitudinal flow velocities in a colloidal suspension determined from the path-length resolved correlation function using optical coherence tomography. Based on our model we have obtained accurate results by fitting the model to the measured data with no free/unknown parameters. Our technique yields the local velocity, the diffusion coefficient, and the sample morphology with high spatial and temporal resolution, which we demonstrated on flow in a capillary. We anticipate that the presented method will improve the quantification of complex dynamical rheological processes, such as blood flow in the microvasculature.

References