Electronic Techniques to Quantify Physical Properties of Nanoliter Fluid Volumes using Integrated Microfluidic-Microelectronic Structures

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We describe the development of integrated microfluidic-microelectronic devices to enable the rapid, accurate quantification of physical properties of small volumes of fluids, fluid mixtures, colloids, and suspensions using electronic techniques. We have applied such devices to develop broadband measurements of fluid dielectric properties [1] through the measurement of the complex permittivity function over the broad frequency range from ~100 kHz to 100 GHz, at variable temperatures. We show that such measurements can be sensitive to the ionic conductivity of solutions, and we have applied quantitative models to describe the charge separation effects that occur at electrode-fluid interfaces. We apply these on-chip dielectric spectroscopy techniques to characterize dielectric relaxation in a wide variety of fluid samples, including chemical mixtures, latex bead solutions, and solutions of proteins and DNA. In order to achieve improved sensitivity, we are also applying narrowband electromagnetic techniques, which are used to detect small changes in solution permittivity, and can be used to study dielectric heating effects in microfluidic structures. Together with broadband fluid dielectric measurements, we are also developing microfluidic-based measurements of electron paramagnetic resonance (EPR). Such measurements show good agreement with cavity-based EPR techniques, demonstrating the potential for integration of EPR-based techniques with other on-chip measurements for multi-parameter measurements of a single fluid using microfluidic networks. The potential for integration of different physical property measurements, including thermal properties[2], using electronic measurements combined with microfluidic networks, offers promising new approaches for rapid, high-throughput, accurate characterization of fluid physical properties over a wide range of experimental conditions.

References

[1] James C. Booth et al., “Quantitative Permittivity Measurements of Nanoliter Liquid Volumes in Microfluidic Channels to 40 GHz,” IEEE Trans. Insrumentation Meas. 59, 3279-3288 (2010).

[2] Choi, S. R. & Kim, D. “Real-time thermal characterization of 12 nl fluid samples in a microchannel,” Rev. Sci. Instrum. 79, 064901-5 (2008).