Ultrasound Imaging in Hot Melts with Time Reversal Virtual Arrays

Richard Nauber, Christian Kupsch, Arne Klaß, Lars Büttner, Jürgen Czarske
Laboratory for Measurement and Sensor System Technique, TU Dresden, Dresden, Germany

Background, Motivation and Objective

The high availability of computational resources has spurred the recent transition from fixed-purpose devices to software-defined ultrasound platforms. This paradigm shift enables new signal processing approaches that can vastly improve the measurement performance. We demonstrate examples, where advanced signal processing can overcome the challenges posed by technical and industrial processes for ultrasound imaging, such as harsh environments and small geometries. Non-invasive online monitoring is crucial for targeted optimization of technical processes like a redox flow battery and improving of the resource efficiency of industrial processes, such as silicon crystal growth for the photovoltaics industry, continuous steel casting and plastics extrusion.

Statement of Contribution/Methods

We experimentally demonstrate in-situ process imaging using a generic ultrasound research platform, the phased array Doppler velocimeter (PAUDV).

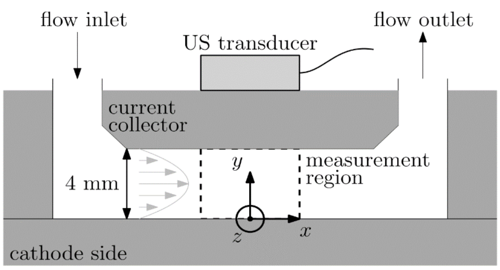
To reveal the flow in a 4 mm gap of an operational zinc-air flow battery, a sub-millimeter imaging resolution is required. The working fluid, a suspension of zinc particles in an aqueous gel, is highly scattering and a sufficient penetration of ultrasound can only be achieved at low frequencies (≈ 6 MHz), thus limiting the spatial resolution. We propose a signal-processing pipeline using harmonic imaging, coherence weighted beamforming and ultrasound localization microscopy for super-resolution vector flow mapping of particle-laden flows in small channels.

For in-situ process imaging of hot melts, we propose to use a multimode waveguide (MMWG) in combination with time reversal virtual array (TRVA) method. A MMWG can carry the information of a complete, two-dimensional image, yet it is scrambled due to the complex sound propagation. TRVA exploits the time invariance of the wave equation in linear media to focus on a set of pre-calibrated points on the far (distal) end of the waveguide with a phased array transducer at the near (proximal) end. These points are combined to form a virtual array, which allows transmit and receive beamforming into the measurement volume.

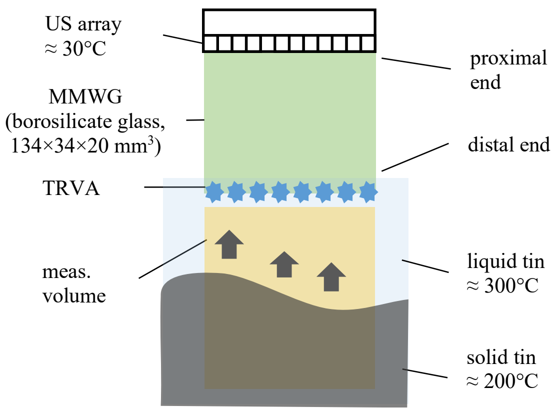
Results/Discussion

We captured the flow of a suspension electrode, consisting of 8 vol-% zinc particles in an aqueous gel, in the narrow channel of an operating flow battery using localization microscopy with a lateral resolution of 0.2 mm, which is a factor 5 better than the diffraction limit. In-situ flow mapping suggest a complex, non-Newtonian rheology and provides the basis for direct process optimization.

For a solidification process of liquid tin at temperatures (≈ 300 °C), well above the destruction limit of the transducers, we could achieve in-situ imaging of the solid-liquid interface using TRVA. This methodology opens a window into measuring and understanding a variety of processes involving hot, opaque liquids in harsh environments and therefore a new class of applications in the industrial field.



Flow imaging of the particle-laden, non-Newtonian fluid in an operational zinc-air flow battery.



In-situ ultrasound imaging of the solidification progress of tin through a MMWG with a TRVA.