A CORRELATIVE OF2i®-Raman method for nanoparticle characterization and chemical analyses in liquids

Christian NEUPER[1,2], Marko ŠIMIĆ[2,3,4], Christian HILL[2,3], Harald FITZEK[1,5]

[1] Graz Centre for Electron Microscopy (ZFE), Austria, [2] BRAVE Analytics GmbH, Austria, [3] Gottfried Schatz Research Center, Medical Physics and Biophysics, Medical University of Graz, Austria, [4] Institute of Physics, University of Graz, Austria, [5] Institute of Electron Microscopy and Nanoanalysis (FELMI), NAWI Graz, Graz University of Technology, Austria

INTRODUCTION

Process analytics and nanoparticle characterization in real-world applications are challenging tasks, particularly for complex and heterogeneous particle systems on the nano- to micrometer scale. As part of the recently launched Nano-VISION project, a novel technique is being developed to detect and identify nano- and microparticles in liquids, thereby enabling the quantification of the amount and types of particles present in a fluidic environment. The technique is based on a correlation between an optofluidic force induction method (OF2i®) and Raman spectroscopy.

In this work, we demonstrate the measurement capabilities of the OF2i® technology to analyze single particles on highly polydisperse and multimodal particle systems (left column), as well as the extension of the OF2i® system by chemical analysis through Raman spectroscopy (right column).

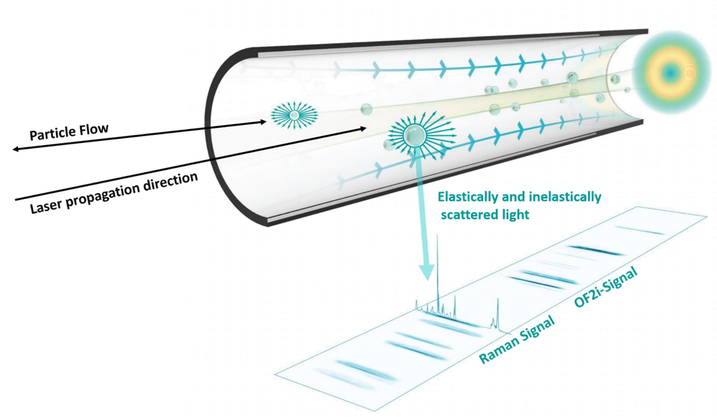

Figure 1: Schematic representation of the OF2i®-Raman technique based on [1]. The microfluidic channel of the OF2i®-Raman approach is shown above. A weakly focused laser beam can accelerate or decelerate particles in the microfluidic flow channel depending on the flow direction and momentum transfer between laser light and matter. At the bottom, the obtained signal data is shown. Each particle of the OF2i® data appears as a line due to astigmatism of the capillary. In addition to the OF2i® data, a representative Raman signal is illustrated.

OF2i® TECHNOLOGY

OF2i® is a novel counting method that combines optical and fluidic forces to characterize nanoparticles with single-particle sensitivity and high throughput, enabling real-time online nanoparticle characterization during a production process [2]. The particles are transported through a microfluidic flow channel alongside a weakly focused vortex beam, as shown in Figure 1. Single particles become optically trapped on the laser beam and experience size-dependent velocity changes due to photon momentum transfer between light and matter, from which number-based particle size, size distribution, and concentration can be determined [3]. The following two figures show measurements of NIST-Standards and industry-relevant samples.

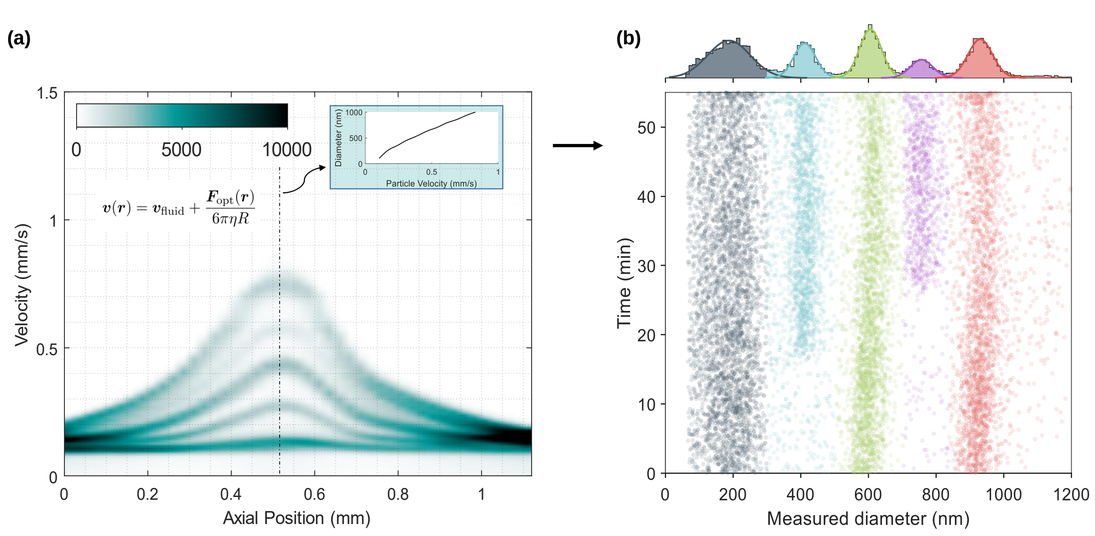

Figure 2: OF2i® measurement of a highly polydisperse mixture of PS (polystyrene) spheres (n = 1.59) with nominal diameters of 204, 401, 600, 789, and 1040 nm. Starting with a threefold mixture of 203, 600, and 1040 nm PS spheres, 401 and 789 nm particles were added to the sample at different times to demonstrate the temporal resolution capabilities of OF2i®. **(a)** Velocity distribution of the sample with inserted velocity-diameter conversion curve for the refractive index n = 1.59. **(b)** Scatter plot of the measured diameters of the PS-mixture over a large measurement time. Above, a 1D Gaussian mixture model is applied to the histogram, and the different contributions of the sample are highlighted by color [1].

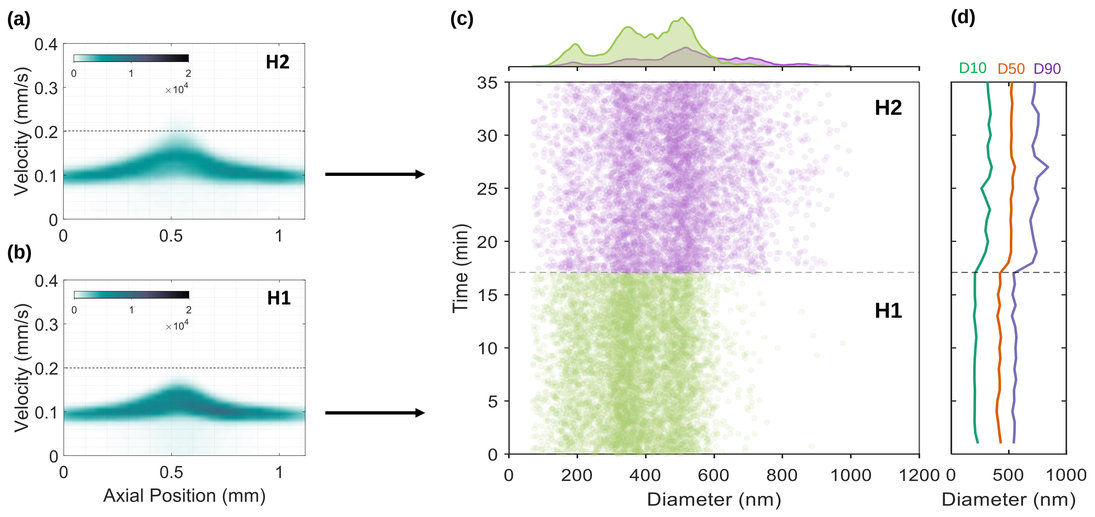

Figure 3: Continuous monitoring of an oil-in-water emulsion (n=1.46), demonstrating the applicability of OF2i® to the process dynamics of industry-relevant samples [2]. Two homogenization states of the same sample were continuously analyzed for 35 minutes. (**a)** Observed velocity distribution from the H1 homogenization state (0 to 17 min) **(b)** Velocity distribution after the change point at 17 min (H2) **(c)** Scatter plot revealing the changing size distribution at the change point from the H1 homogenization state to the second state H2. **(d)** Changing D values indicate a transition between the two phases. The D values represent the diameter below 10% (D10), 50% (D50), and 90% (D90) of the observed particle volume.

CORRELATIVE OF2i® -RAMAN

In contrast to the OF2i® technology, which uses elastically scattered radiation to characterize particles, the inelastically scattered radiation (Raman scattering) can be used for chemical analysis. This correlative OF2i®-Raman method has the potential to detect particles that are too small for regular Raman microscopy (< 500 nm) due to the optical trapping of the particles and the high power of the laser (2 W), which helps to overcome the weak Raman scattering of small particles.
Here we explore the measurement capabilities of the OF2i®-Raman technique for analyzing single particles. PS spheres with a diameter of 5 µm are stably trapped in the measuring cell. From the inelastic scattering, Raman spectra can be obtained, as shown in Figure 4.

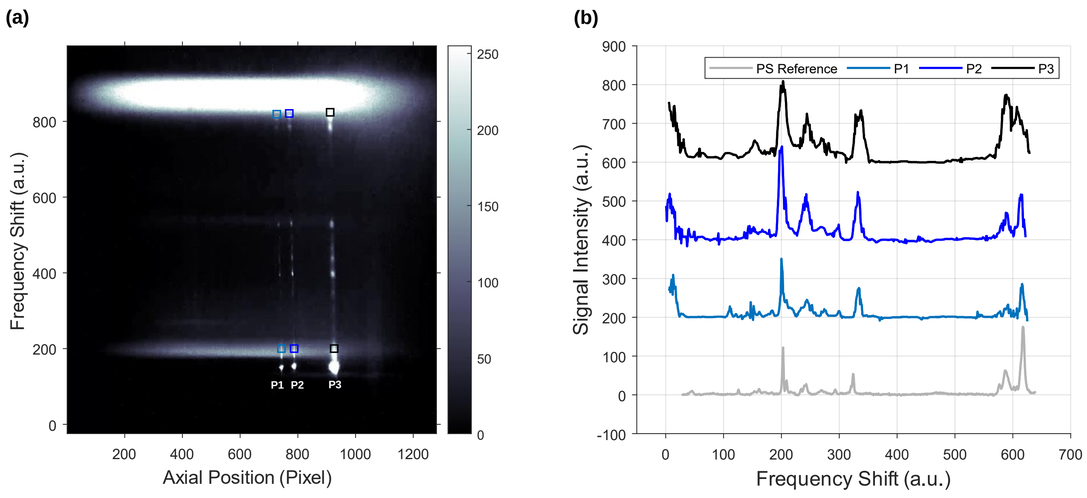

Figure 4: OF2i®-Raman measurement of 5 µm PS (polystyrene) spheres. **(a)** The image shows a stably trapped single particle at position 1 (P1) and agglomerations at positions 2 and 3 (P2 and P3). Between the inserted squares, the Raman spectra are obtained. **(b)** Spectra of a single 5 µm PS sphere (P1), particle agglomerations (P2 and P3), and a reference spectrum of bulk polystyrene measured with a regular Raman microscope.

CONCLUSION & OUTLOOK

Starting with the versatile OF2i®-technology, we were able to demonstrate that correlation with Raman spectroscopy is feasible. Furthermore, using µm-sized PS spheres, we demonstrated that Raman spectra sufficient for the identification of the particle can be readily obtained.
After accomplishing this proof of principle, our goal is to advance from the detection of microparticles down to nanoparticles. We are confident that with the optimization of both the experimental setup and data processing, this goal is achievable. The combination of OF2i® technology with Raman spectroscopy could enable a chemical analysis of micro- and nanoparticles with unmatched speed and versatility, thereby saving production time and resources, reducing out-of-spec production, and increasing efficiency.

REFERENCES

1. M. Šimić, C. Neuper, U. Hohenester, C. Hill, Optofluidic Force Induction as a Process Analytical Technology, (Submitted 2023 Anal Bioanal Chem)
2. M. Šimić, D. Auer, C. Neuper, N. Šimić, G. Prossliner, R. Prassl, C. Hill, U. Hohenester. Real-Time Nanoparticle Characterization Through Optofluidic Force Induction, Physical Review Applied 18, no. 2 (2022): 024056.
3. M. Šimić, C. Hill, U. Hohenester. Theoretical description of optofluidic force induction, Physical Review Applied 19.3 (2023): 034041.

The authors acknowledge financial support from the Austrian Research Promotion Agency (FFG) (Grant No. FFG-Bridge, 895429 – Project) and from the European Commission (Grant No. 862583 - Project NanoPAT, Grant No. 101058450 – Project MOZART)

christian.neuper@felmi-zfe.at
harald.fitzek@felmi-zfe.at
christian.hill@braveanalytics.eu
marko.simic@braveanalytics.eu
www.felmi-zfe.at

BRAVE Analytics FELMI-ZFE