

Formation of flow induced structures with colloidal nano-particles in a microfluidic-jet

I. Steinke¹, C. Gutt², B. Fischer³ and G. Grübel¹

¹Deutsches Elektronen Synchrotron (DESY), Notkestr. 85, 22607 Hamburg, Germany

²Naturwissenschaftlich-Technische Fakultät, Universität Siegen, ENC C-114, 57068 Siegen, Germany

³Institut für Physikalische Chemie, Universität Hamburg, Grindelallee 117, 20146 Hamburg, Germany

The ability of modern synchrotron and XFEL light sources to produce highly intense coherent X-ray beams in the μm and sub- μm range offers the possibility to image soft condensed matter on ultrasmall length and ultrafast time scales. This ability allows to access a variety of coherent X-ray diffraction concepts e.g. X-ray Photon Correlation Spectroscopy (XPCS) and X-ray Cross Correlation Analysis (XCCA) [1, 2, 3].

The highly intense beam and the vacuum conditions in such experiments imply constraints on the sample housing, e.g. radiation damage of the samples or the walls of the sample container may affect the sample structure. One possibility to overcome this problem is a fast steady stream injection system that produces a thin liquid-jet in a vacuum.

Liquid-jets offer the possibility to study disordered samples in the fluid phase by a very fast steady streaming. In this experiment we studied the small angle X-ray scattering (SAXS) structure of colloidal nano-particles as a prototypical application of our liquid-jet setup. To form a liquid jet we used a tube with an inner diameter of $100\ \mu\text{m}$. Spherical silica particles served as test colloidal particles. This dispersion was already characterized with SAXS at beamline BW4 at DORIS III. The radius of the particles is $12.89\ \text{nm}$ at a polydispersity of $12.4\ \%$. The concentration is $19.1\ \text{vol.}\%$. A focused X-ray beam of $4\ \mu\text{m} \times 6\ \mu\text{m}$ at x-ray energy of $7\ \text{keV}$ was used. The scattered beam was detected at a sample – detector distance of $5\ \text{m}$. A Pilatus 300K detector was used.

A typical measured result taken on the liquid jet is shown in fig. 1. Due to the relative high concentration of the dispersion a structure factor was measurable. The SAXS patterns are deformed to an ellipsoidal shape at different location of the jet. The deformation direction of the patterns flips from the left to the right side of the jet. The SAXS pattern at the jet center shows a roundish shape. This effect was less pronounced at measurements taken downstream on the liquid jet.

As a further analysis we divided the form factor to extract the structure factor measured in the jet, see fig. 2. The structure factor measured at the jet center shows a homogenous roundish shape comparable to measurements on non-flowing colloidal samples. The structure factors measured at the sides of the liquid jet show a fourfold modulation of their first peak. The maximums are separated by an azimuthal angle of $\alpha = 45^\circ$ and $\alpha = 135^\circ$. Furthermore, the structure factors are deformed to an ellipsoidal shape comparable to the SAXS measurements. Due to the point that the structure factor expresses the degree of correlation between particles and the distance between particles in the liquid jet, it is assumable that clusters of colloids are formed at the sides of the liquid jet. This can be explained by shear forces at

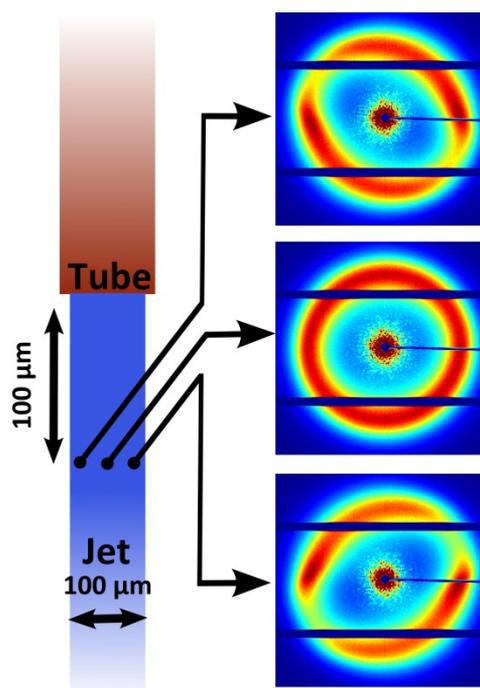


Figure 1: Overview of SAXS measurements on the liquid jet.

the liquid-tube surface in the tube. Colloidal particles can form under shear so called hydrocluster. It was published that these compounds are formed along two angles (45° and 135°), which is comparable with the separation of the structure factor modulation.

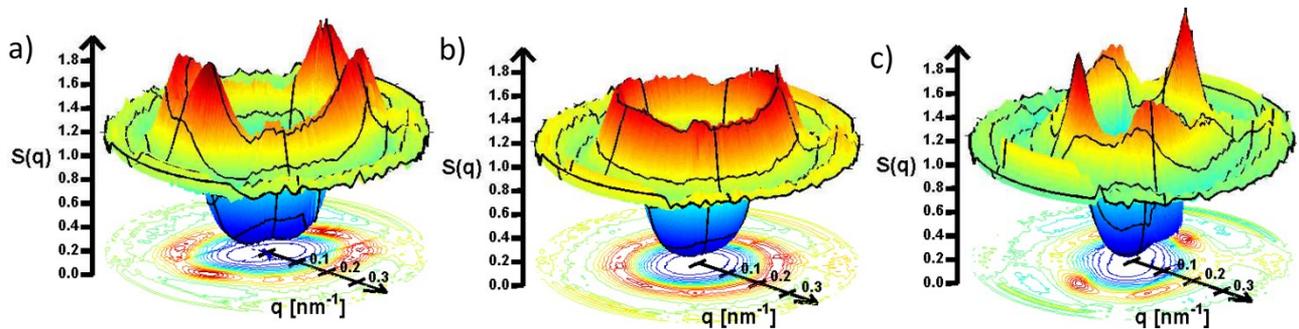


Figure 2: Structure factors extracted from the SAXS images shown in fig. 1. (a) left (b) middle (c) right.

References

- [1] N.D. Loh, M.J. Bogan, V. Elser, A. Barty, S. Boutet, S. Bajt, J. Hajdu, T. Elkeberg, F.R. Maia, J. Schulz, M.M. Seibert, B. Iwan, N. Timneanu, S. Marchesini, I. Schlichting, R.L. Schoeman, L. Lomb, M. Frank, M. Liang, and H.N. Chapman; *Phys. Rev. Lett.*, 104, 225501 (2010).
- [2] S. Förster and M. Schmidt; *Adv. Polym. Sci.* 120, 51 (1995).
- [3] P. Wochner, C. Gutt, T. Autenrieth, T. Demmer, V. Bugaev, A. Diaz Ortiz, A. Duri, G. Grübel, and H. Dosch; *Proc. Natl. Acad. Sci.* 106, 11511 (2009).
- [5] R. Pasquino, F. Snijkers, N. Grizzuti, J. Vermant, *Rheol Acta*, 49, 993 (2010).
- [6] X. Cheng et al. *Science*, 333, 1276, (2011).