Numerical and experimental investigation of the flow field in thin films during drying under impinging jets

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In the field of organic and printed electronics (e. g. polymer solar cells, OLEDs or Li-Ion batteries) there is a growing demand for thin functional layers with highly homogeneous surface topology. The thickness of some of these layers is in the range of 10 – 100 nm with an accepted mean deviation of 1 – 2 nm. If these layers are coated from the liquid phase, the coating and drying steps affect the surface quality. During the drying process, Marangoni convection might occur, leading to surface inhomogeneities. Marangoni convection forms due to surface tension gradients throughout the polymer film caused by inhomogeneous drying rates.

In this work, experimental and numerical studies have been performed to determine the flow structure in polymer solutions drying under impinging micro-jets (see Fig. 1, left). The local distribution of the heat and mass transfer coefficient causes a local variation of the drying rate. Close to the stagnation region the transfer coefficients are highest leading to a peak in drying rate (see Fig. 1, right). Depending on the surface tension of the material system mass is transported towards or away from the stagnation region.

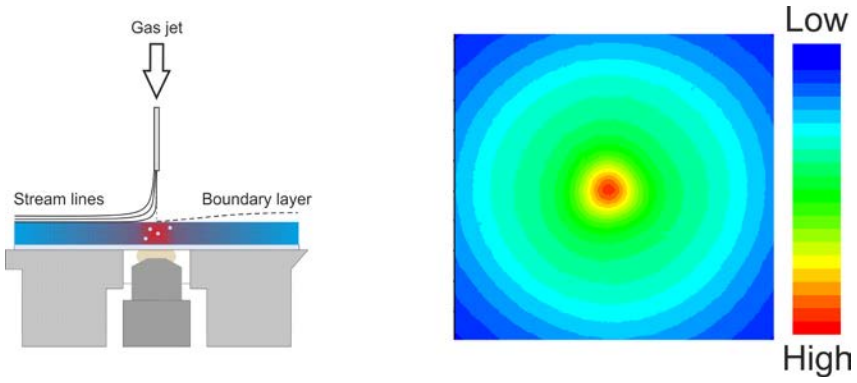

Fig. 1: Microscopic impinging jet to induce local dependency of the drying rate (left), distribution of the heat transfer coefficient under a single impinging jet (right).

The experimental investigation is based on a multifocal micro-Particle tracking velocimetry (micro-PTV) system (see Fig. 2). Using a combination of beam splitters and meniscus lenses, five different focus planes are extracted from the volume illuminated domain and projected on five sCMOS cameras. Applying a GPU enhanced version (Vogelgesang et al. (2012)) of 4D-Tracker by Wu et al. (2006) allows for a 3D-3C resolution of the occurring flow field over the film height.

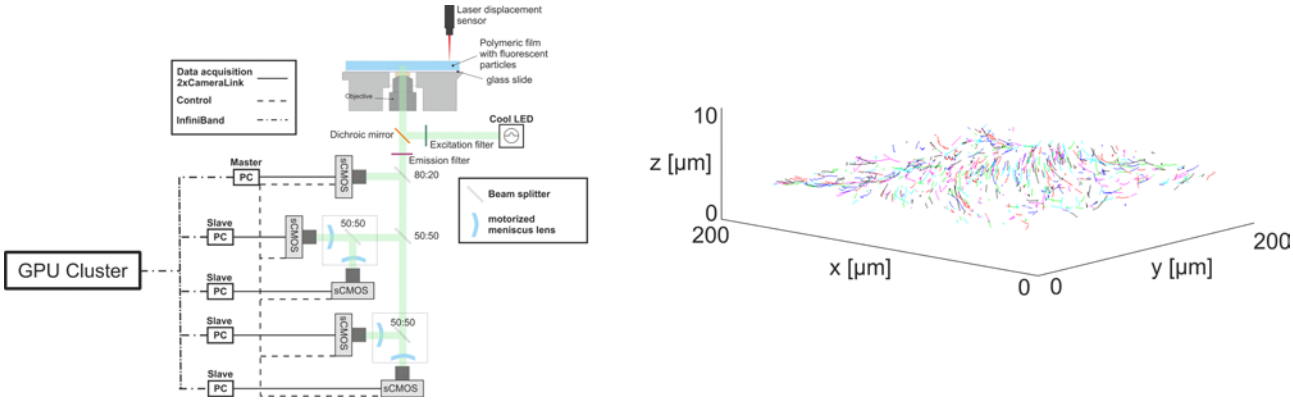

Fig. 2: Schematic of multifocal µPTV system (left), pathlines reconstructed from image sequence of a single focus plane (right).

The numerical approach is based on coupling of a solver using lubrication theory and an advection-diffusion solver to predict the phenomena. The boundary conditions in the gas phase are predicted by transient heat transfer experiments and CFD.

[1] Vogelgesang, M., Chilingaryan, S., dos Santos Rolo, T., und Kopmann, A., "UFO: A Scalable GPU-based Image Processing Framework for On-line Monitoring," Proc. High Performance Computing and Communication & 2012 IEEE 9th International Conference on Embedded Software and Systems (HPCC-ICESS), 2012 IEEE 14th International Conference on, pp. 824-829.

[2] Wu, M., Roberts, J. W., Kim, S., Koch, D. L., und DeLisa, M. P., 2006, "Collective bacterial dynamics revealed using a three-dimensional population-scale defocused particle tracking technique," Appl Environ Microb, 72(7), pp. 4987-4994.