MODELLING FREE-SURFACE DYNAMICS IN THE RIBBON GROWTH ON SUBSTRATE PROCESS (RGS)

P. BECKSTEIN*[1], V. GALINDO[1], G. GERBETH[1]
[1]*Institute of Fluid Dynamics, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany*
**p.beckstein@hzdr.de*

Keywords: *RGS, electromagnetics, hydrodynamics, free-surface, interface-tracking, block-coupling*

The cost efficient, high throughput production of metal- and semiconductor alloys is the foundation of many advanced technologies. With the development of the Ribbon Growth on Substrate (RGS) technology [1,2], a new crystallization technique is available that allows the controlled production of silicon wafers and advanced metal-silicide alloys. In contrast to other crystallization methods, like e.g. melt spinning or even directional solidification, the RGS process allows high volume manufacturing, better crystallization control and a high material yield due to a substrate driven process. The principle of the process is sketched in Figure 1 (left).

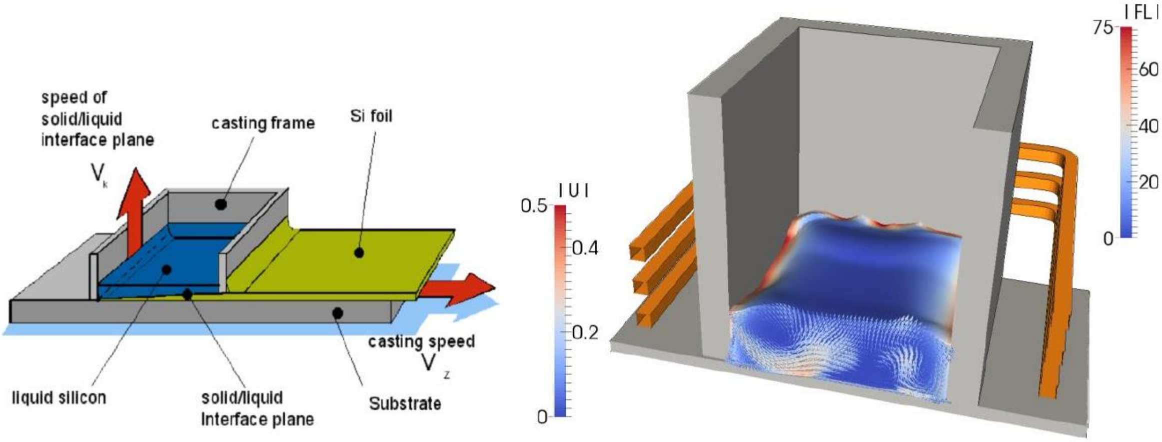

Figure 1: Scheme of the RGS process (left) and snapshot of the free-surface flow with magnetic forces (right).
The picture shows the velocity field (front, vectors, [m/s]) and the Lorentz force density (back, surface, [m/s²]).

To optimize the application of RGS further, insights from modelling the liquid metal flow are very desirable. We have already conducted extensive numerical investigations in order to study the involved AC magnetic fields [3]. For the RGS technology, these magnetic fields play an essential role in realizing inductive heating and an additional magnetic retention effect.

Latest simulation results, as shown in Figure 1 (right), demonstrate the effect of the applied AC magnetic fields on the melt flow of liquid silicon. The focus of our work is thereby devoted to the simulation of the melt surface dynamics based on a coupled multi-physical modelling approach in *OpenFOAM (foam-extend)* [4].

We present our newly developed numerical tool called *interTrackEddyCurrentFoam*, which allows us to model hydrodynamic and magnetodynamic effects and their interaction. One part of this tool is a new solver named *eddyCurrentFoam* for electromagnetic eddy-current problems [5], involving block-coupled matrices of *foam-extend*. A second part concerns an extended realization of the interface tracking method in [6] based on *interTrackFoam*. The efficient union of both tools finally relies on a multi-region backend based on several superposed moving meshes for fast and bi-directional mapping. The whole solver-concept is illustrated in Figure 2.

Studies of the time-dependent free-surface flow under the influence of magnetic forces are the key for improving the RGS process as main flow structures and possible instabilities strongly depend on the melt shape.

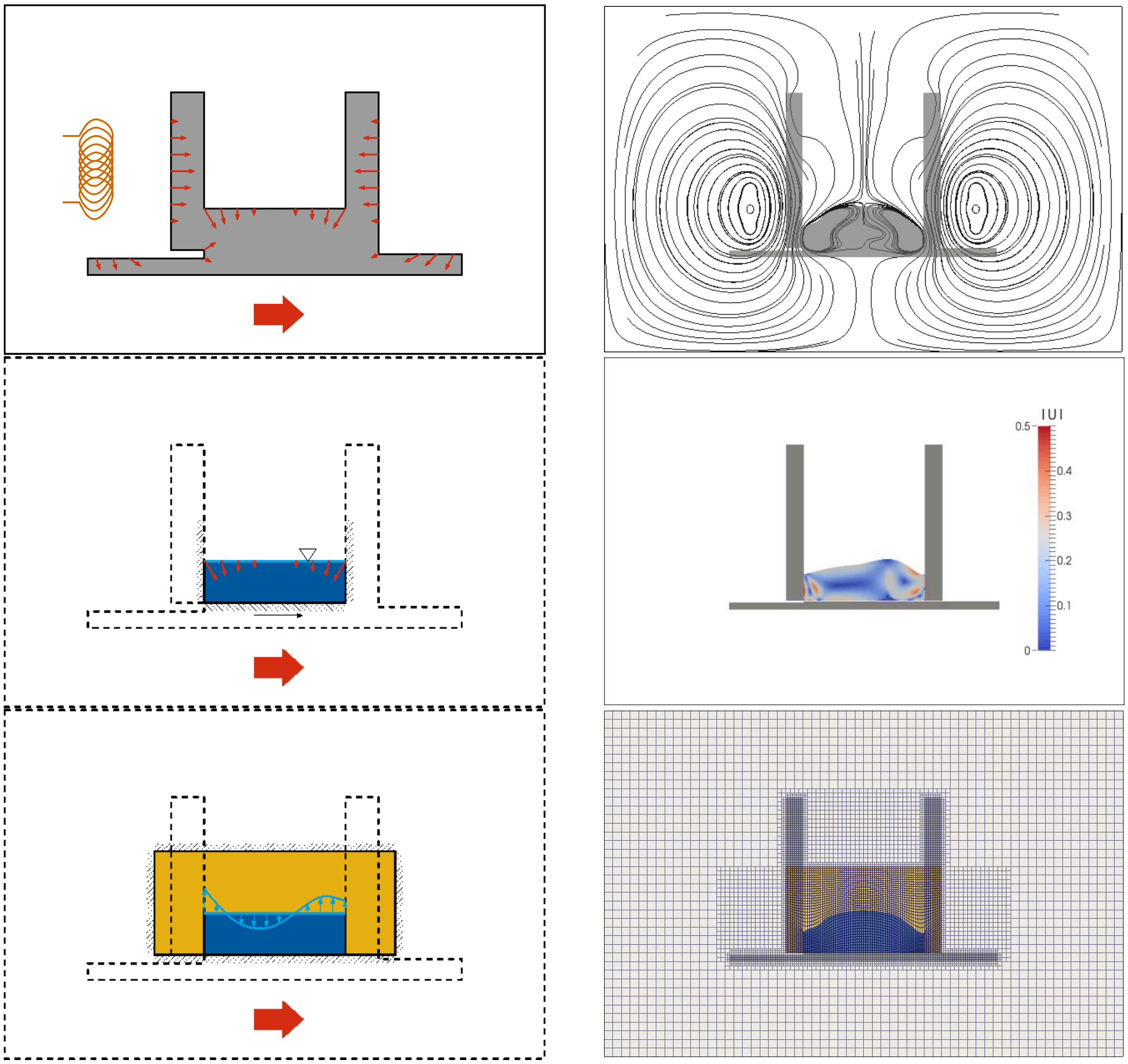

Figure 2: Solver concept of *interTrackEddyCurrentFoam*
Eddy-current problem (top) with conducting region, background region and excitation coil; Lid-driven cavity flow with free-surface and electromegnetic forces (centre); Interface-tracking precedure (bottom) on a dynamic mesh including fluid and surrounding buffer region. The red arrows indicate the casting direction of the RGS-model as given in Figure 1 (left).

References

[1] G. Hahn and A. Schönecker, "New crystalline silicon ribbon materials for photovoltaics," *Journal of Physics: Condensed Matter*, vol. 16, pp. R1615-R1648, 2004.

[2] A. Schönecker, L. J. Geerligs, and A. Müller, "Casting Technologies for Solar Silicon Wafers: Block Casting and Ribbon-Growth-on Substrate," *Solid State Phenomena*, vol. 95-96, pp. 149-158, 2004.

[3] P. Beckstein, V. Galindo, and G. Gerbeth, "Electromagnetic flow control in the Ribbon Growth on Substrate (RGS) process," *Magnetohydrodynamics*, vol. 51, pp. 385-396, 2015.

[4] P. Beckstein, V. Galindo, and G. Gerbeth, "Free-surface dynamics in the Ribbon Growth on Substrate (RGS) process," *Proceedings of the 8th International Conference on Electromagnetic Processing of Materials*, pp. 167-170, 2015.

[5] K. J. Binns, P. J. Lawrenson, and C. W. Trowbridge, *The Analytical and Numerical Solution of Electric and Magnetic Fields.*: Wiley, 1992.

[6] Z. Tukovic and H. Jasak, "A moving mesh finite volume interface tracking method for surface tension dominated interfacial fluid flow," *Computers & Fluids*, vol. 55, pp. 70-84, 2012.