WACKER SILTRONIC

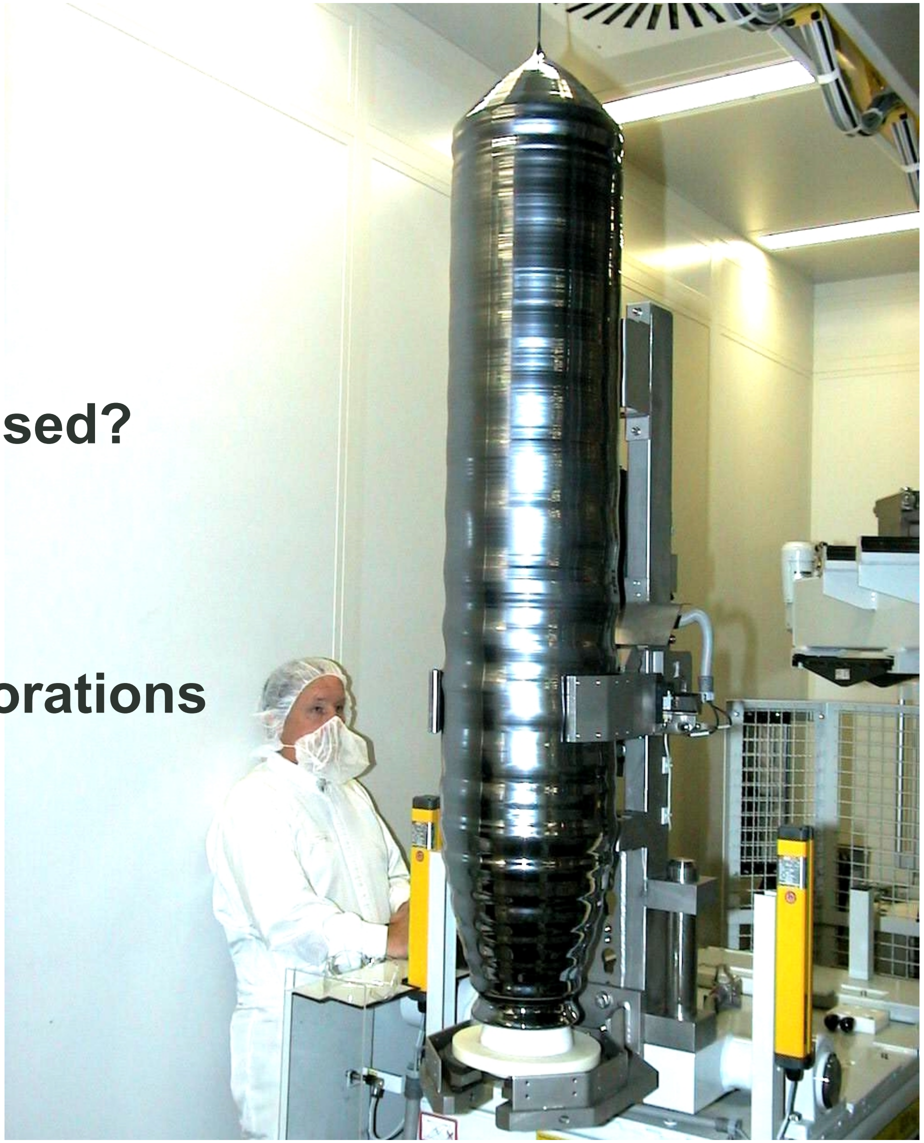
The use of magnetic fields in industrial growth of single silicon crystals

June 13, 2002 / Janis Virbulis

PERFECT SILICON SOLUTIONS

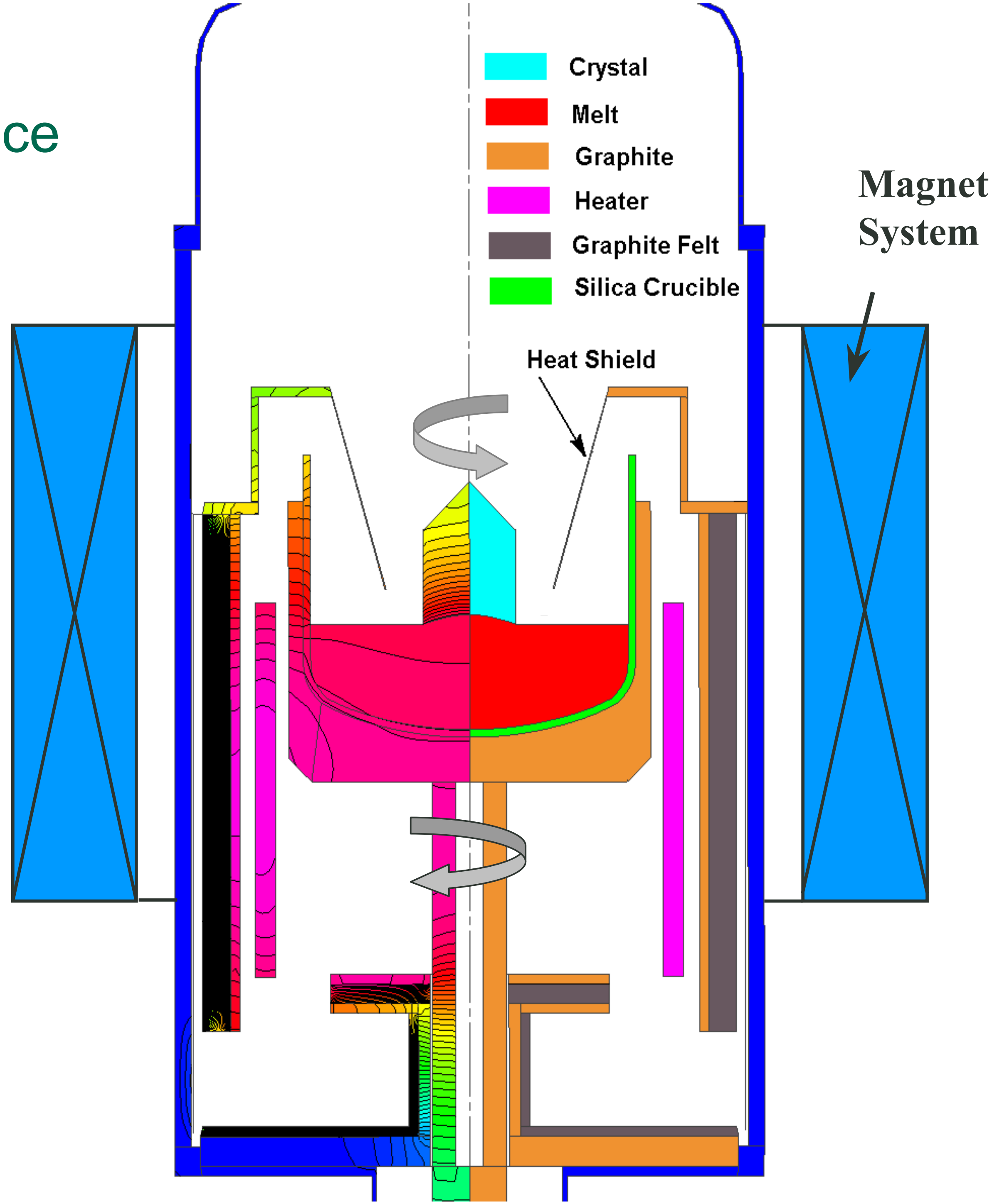
Outline

- Melt convection
- Why magnetic fields are used?
- Types of magnetic fields
- Wacker network of collaborations



Melt convection

Schematic of CZ furnace



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Melt convection

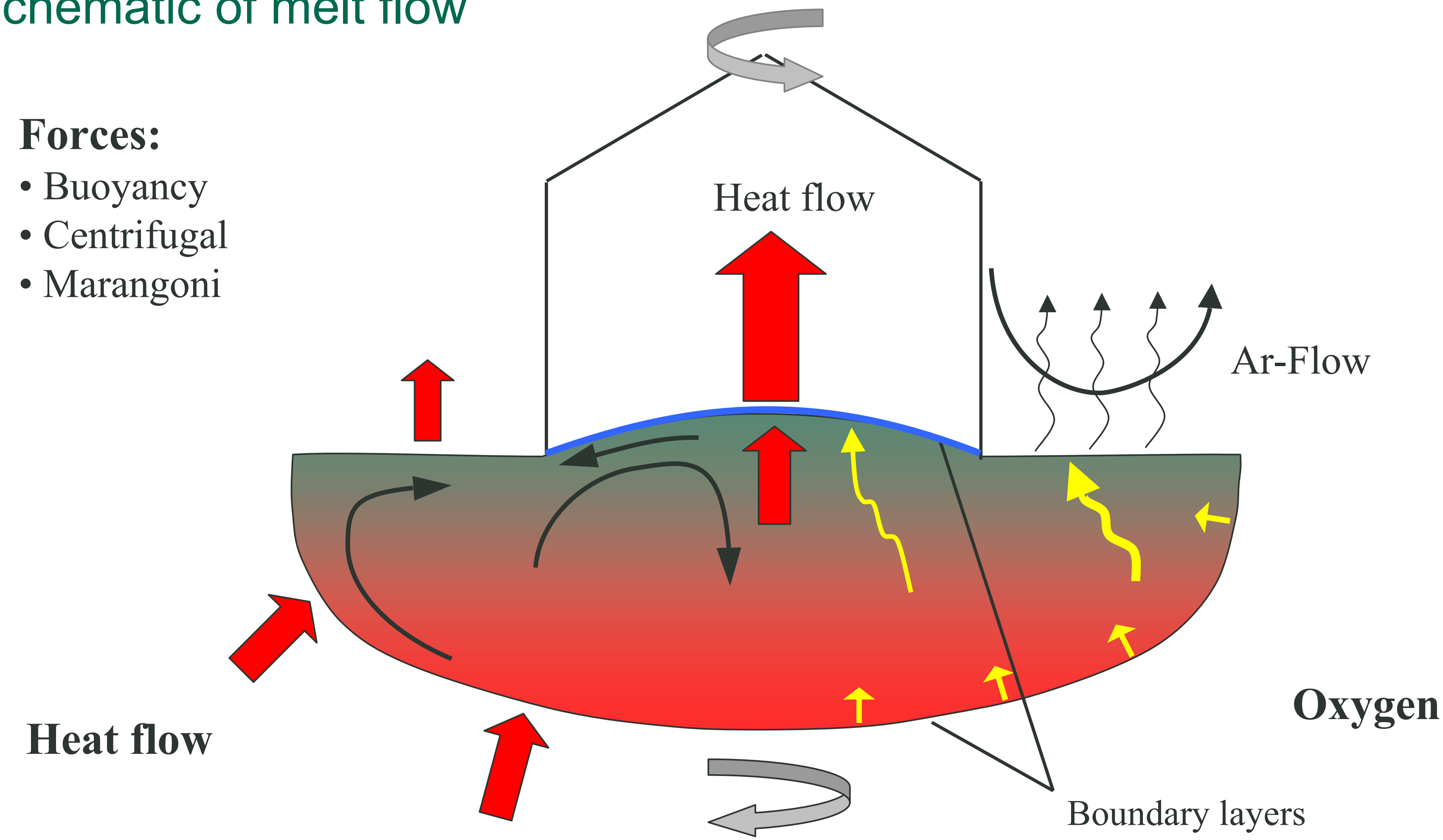
Melt convection in large CZ crucible is turbulent (Gr about 10^{10} in 32” crucible)

- **time - dependent**
- **non-symmetric**
- **large fluctuations of velocity and temperature**

Melt convection

Schematic of melt flow

Forces:
- Buoyancy
- Centrifugal
- Marangoni



Melt convection...

... can be influenced by:

- Rotation of crucible
- Rotation of crystal
- Argon gas flow rate
- Argon pressure
- Hot zone (heat shield) design

It’s all !

- Heater Power is adjusted in manner
  to keep the required pulling velocity and crystal diameter

+ magnetic field(s)

Why magnetic fields are used?

- to increase the **yield**
- to fulfill the **quality** requirements

GfS Yield - Good for Structure (dislocation free part)

Reason of dislocations: stress limit exceeded at interface

Reason: - particle incorporated in crystal
- temperature fluctuation
(larger crucibles - larger fluctuations)

GfO Yield - Good for Order (part which corresponds to customer requirements)

Why magnetic fields are used?

Quality measures

Dopant distribution
- concentration (increases during the growth of crystal)
- radial variation (thickness of concentration boundary layer on interface)
- striations (temperature and flow fluctuations at the growth interface)

Oxygen distribution
- concentration (very complex behavior)
- radial distribution (flow near the crystal - no boundary layer on the interface!)
- striations (flow fluctuations in the bulk)

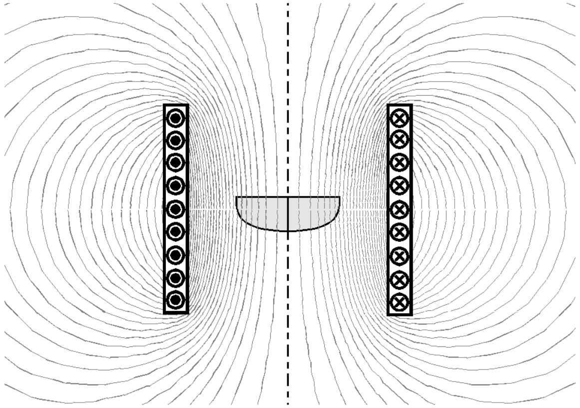
Distribution of point defect agglomerates
- type of defects (depends on temperature gradient on the interface)
- size and density (no direct dependence on melt flow)

Types of magnetic fields

Steady magnetic fields

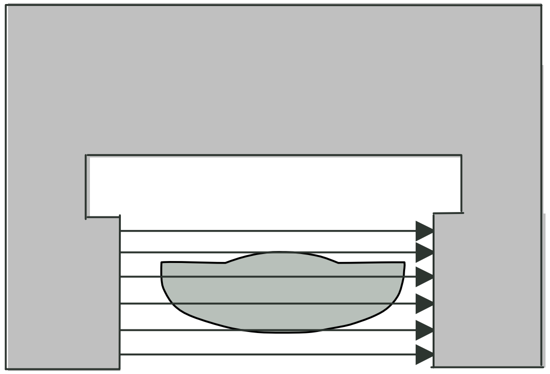
$j \sim v \times B$

Axial



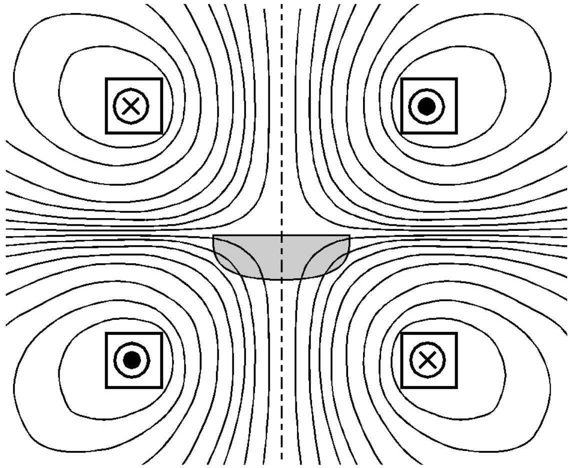
Early 70's

Transversal



Early 80's

CUSP



End of 80's

Types of magnetic fields

Advantages of steady magnetic fields

- Reduction of temperature fluctuations
- Influence of oxygen concentration (lower oxygen)

Disadvantages of steady magnetic fields

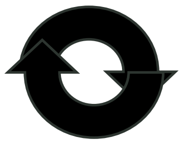
- Higher crucible temperature (corrosion)
- Lorenz force coupled to velocity, instabilities can appear
- Axial field: insufficient radial dopant and oxygen homogeneity
- Transversal field : striations due to non-symmetric flow and temperature field

Types of magnetic fields

Time-dependent magnetic fields

$j \sim \omega B$

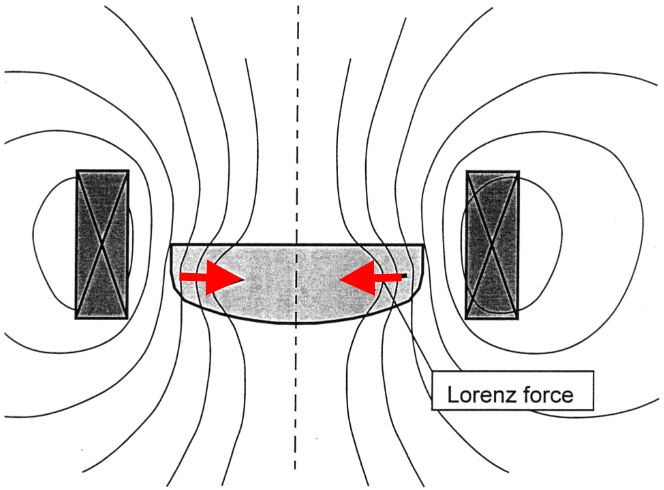
Rotating field



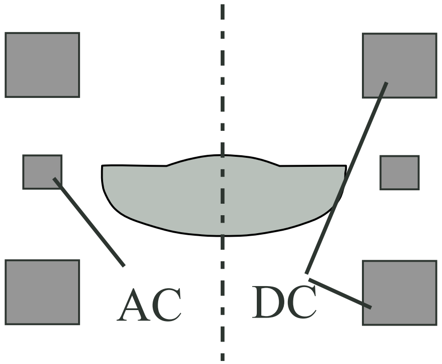
EMCZ

Influence like to time-dependent field

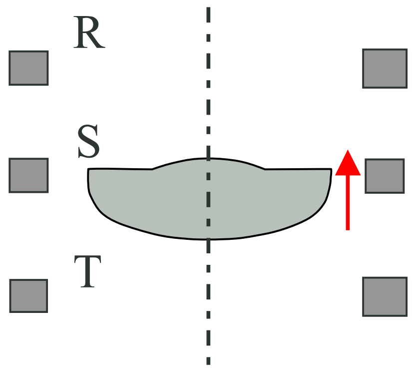
Alternating field



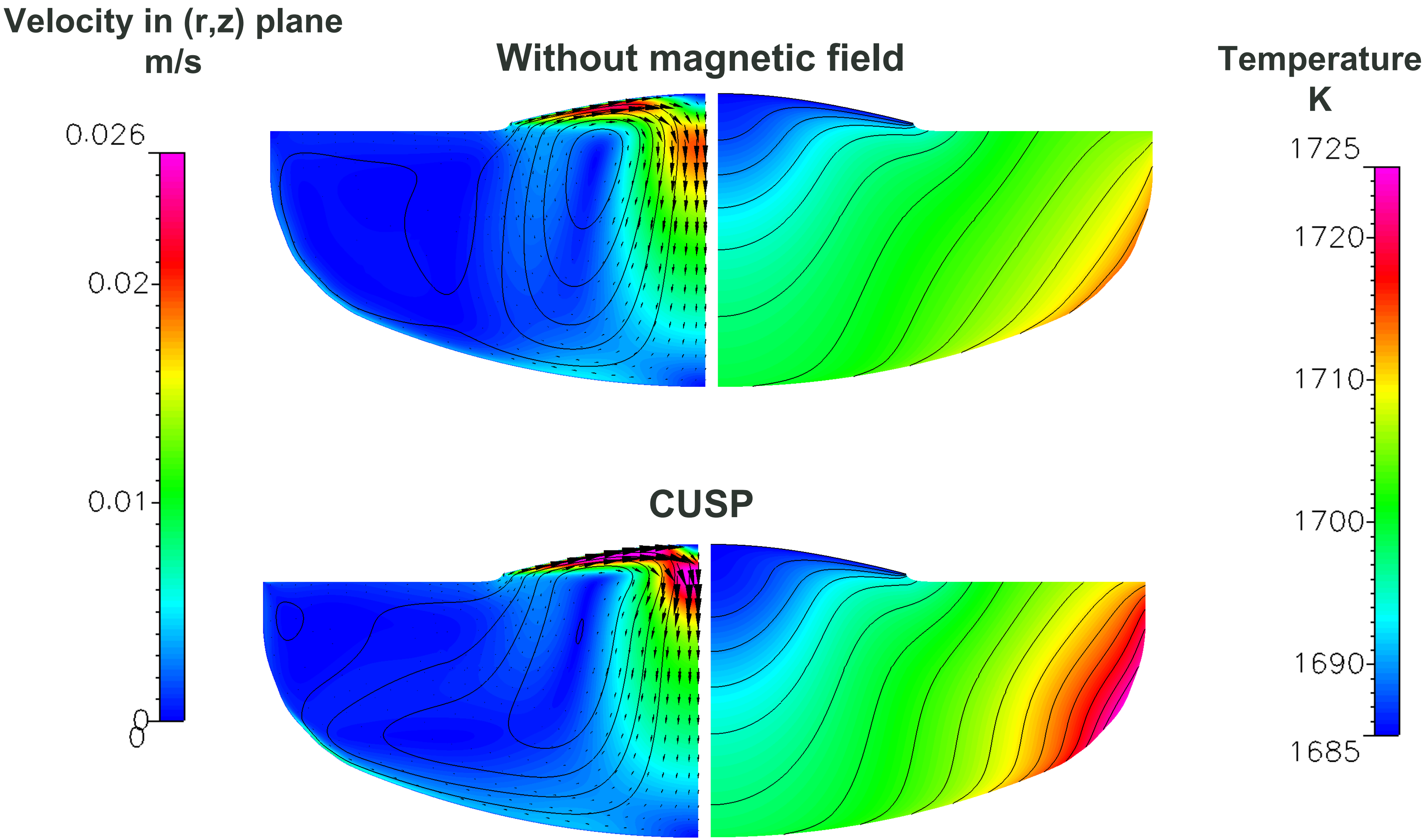
Combined field



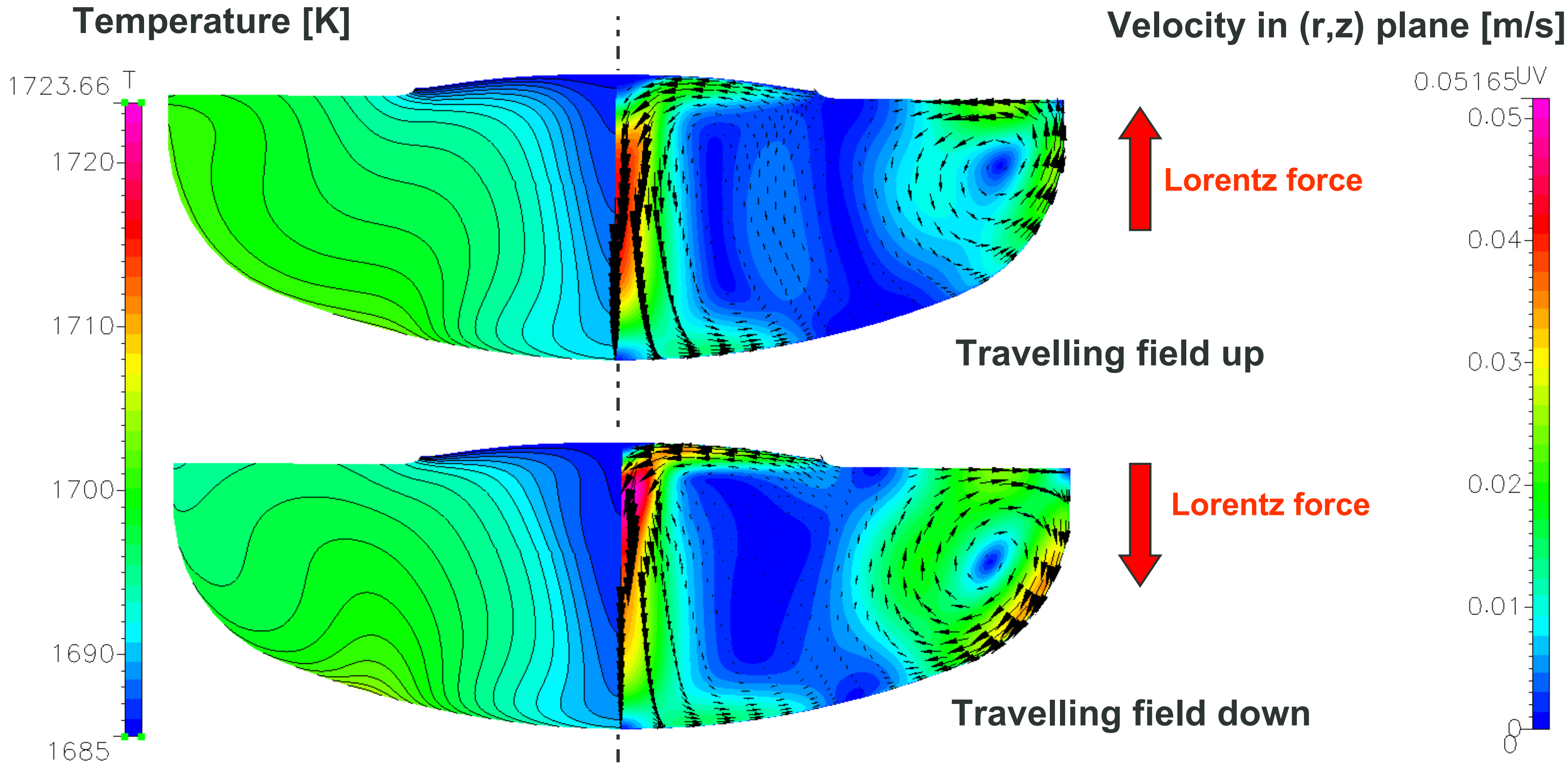
Travelling field



Effect of magnetic fields



Effect of magnetic fields



Types of magnetic fields

Advantages of time-dependent magnetic fields

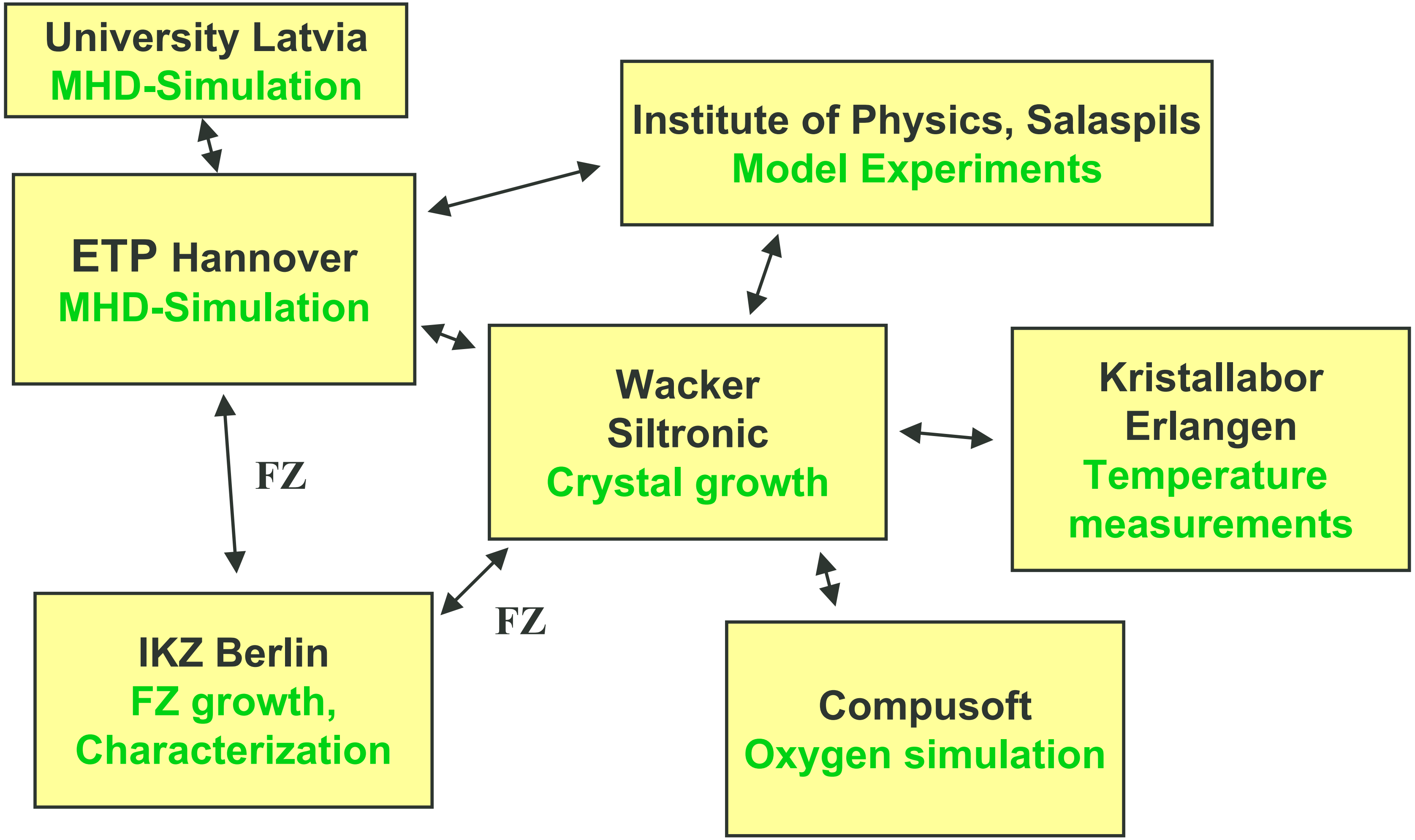
- Flow is influenced actively, totally different flow patterns possible
- Influence of oxygen concentration (higher oxygen)
- Lower crucible temperature
- At least 10 x lower field intensity as for steady fields
- Lorenz force independent on flow velocity

Disadvantages of time dependent magnetic fields

- Higher flow velocities (but more stable than buoyancy)

Wacker network of collaborations

Melt flow related collaborations



Summary

- Magnetic fields are good instrument for yield and quality improvement for 300 mm crystal growth

- Alternating, combined and travelling magnetic fields are used for 300 mm crystal growth

- Successful implementation of new magnetic fields was possible only in team with our collaborations