Scientific report

regarding project implementation between January - December 2012

Activity 1.2. Execution of numerical modeling of the fluid flow using different values of the magnetic and electric field for the 2 electrodes configuration.

The numerical model developed in activity 1.1 was used to study the melt flow for different values of the applied fields, in the case of two electrodes placed symmetrically (Figure 1).

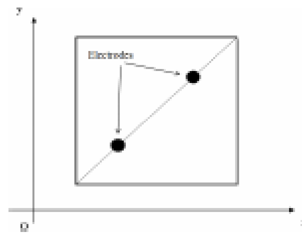
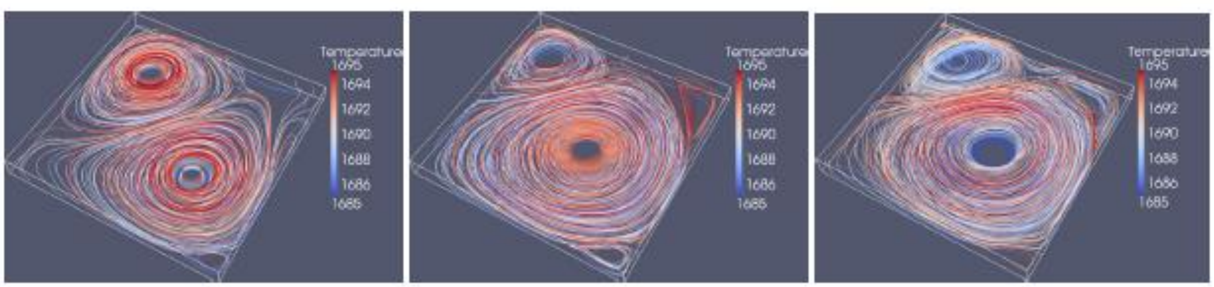


Figure 1. Electrodes layout in a horizontal section.

The most significant result shows that the intensity of the electric current is taken into account as a parameter for controlling the convection structure. Thus, it can be observed that, by increasing the intensity of the electric current, the flow structure changes from two approximately symmetrical convection cells, into a structure in which one of the cells become more significant.



(a) I = 2 A (b) I = 5 A (c) I = 10 A

Figure 2. The influence of the intensity of electric current on the melt convection.

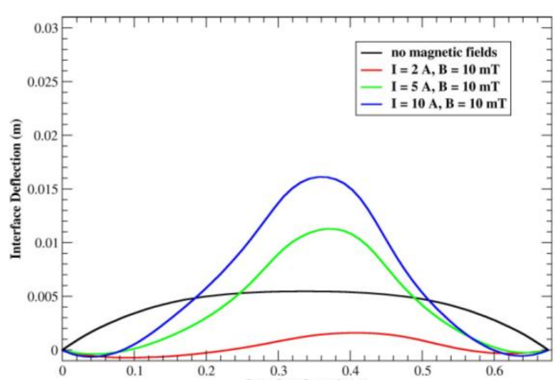
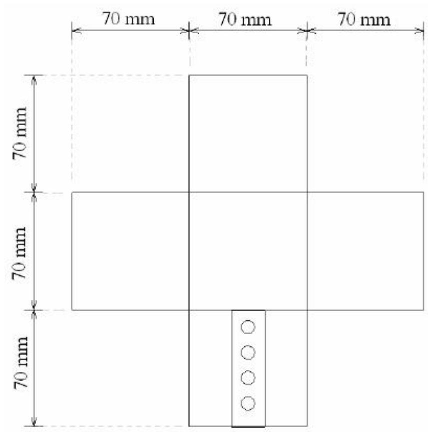


Figure 3. Influence of the intensity of electric current on the shape of the crystallization interface.

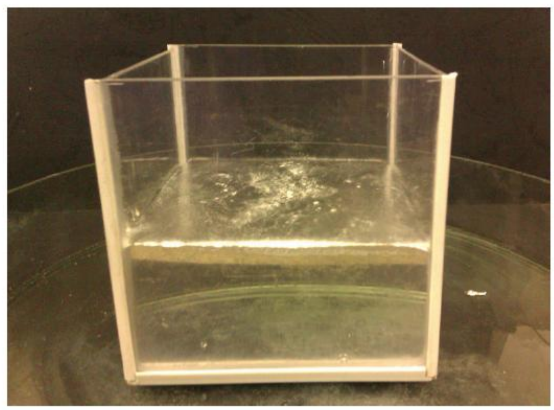
Also, one can observe that this type of flow will lead to a stopping of the heat exchange with the hot area (top zone) so that the deflection of the solidification interface will increase. This behavior is clearly observed in Figure 3.

Activity 2.2. Designing and creating the crucible, the electrodes system and the power supply

THE CRUCIBLE. Is made out of plexiglass. It is shaped as a cube with the side dimension of 70 mm, so that it fits the C-shaped air-gap of the electromagnet with constant magnetic field. The cubic shape emulates the industrial crucible used in obtaining the multicrystalline silicon with directional solidification method. The velocimeter transducers are positioned on one of its walls. The contact between the wall and the transducers is made using ultrasonic gel. Figure 4 presents a schema of the crucible and a photo of the crucible filled with the substance used in the experiment (GaInSn). The schema in Figure 4 is only a generic configuration. Later in the experiment, other configurations will be tested.



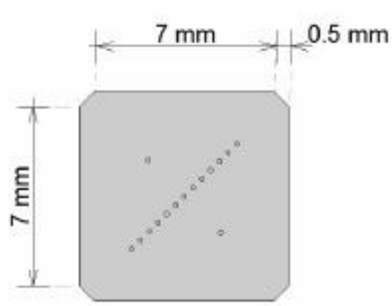
a.



b.

Figure 4. (a) Schema of the unfolded crucible; (b) Photo of the crucible filled with eutectic alloy $Ga_{0.685}In_{0.215}Sn_{0.1}$

SUBSTANCE. There were purchased two kilograms (310 cm^{-3}) of a semiconductor alloy $Ga_{0.685}In_{0.215}Sn_{0.1}$. This eutectic alloy has a solidification temperature $T_s = 10.5$°C. Due to the fact that it has physical proprieties similar to silicon at melting temperature, the experiments can be made at ambient temperature. The crucible filled with the alloy can be seen in photo 4b.



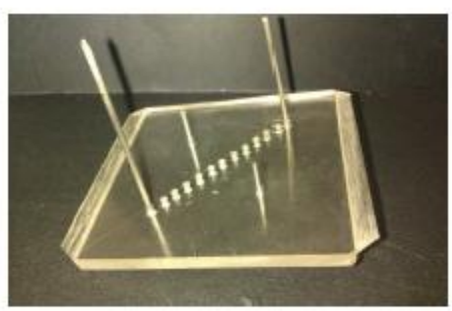


Figure 5. (a) Electrode lid schema; (b) Photo of the lid with two electrodes

ELECTRODES. The crucible is fitted with a lid which allows the insertion, in multiple configurations, of two or more electrodes in the alloy, to ensure the existence of an electric field. Because of the corrosive proprieties of the alloy, the electrodes are made from stainless steel. Figure 5 shows a schema and a photo of the lid.
POWER SOURCE. The power supply of the electrodes is provided by a LAB-EC3010 source with continuous voltage, which allows a maximum current of 10A.

2.3. The acquisition of an ultrasound Doppler velocimeter (UDV). Fitting the velocimeter sensors on the crucible exterior wall. Testing for measuring flow velocities.

The ultrasound Doppler velocimeter Doppler DOP3010 (Figure 6) was acquired with the purpose of measuring the flow velocities of multiple conductive liquids, such as the opaque semiconductor melt of GaInSn used in the experiment. During the last decades the UDV technique became an accepted method for different opaque metallic melt flow. This method is based on the echo-pulse and allows viewing of instant velocity profiles along the wave propagation path. It uses pulsating ultrasound to measure the velocity profile inside the flowing liquid.

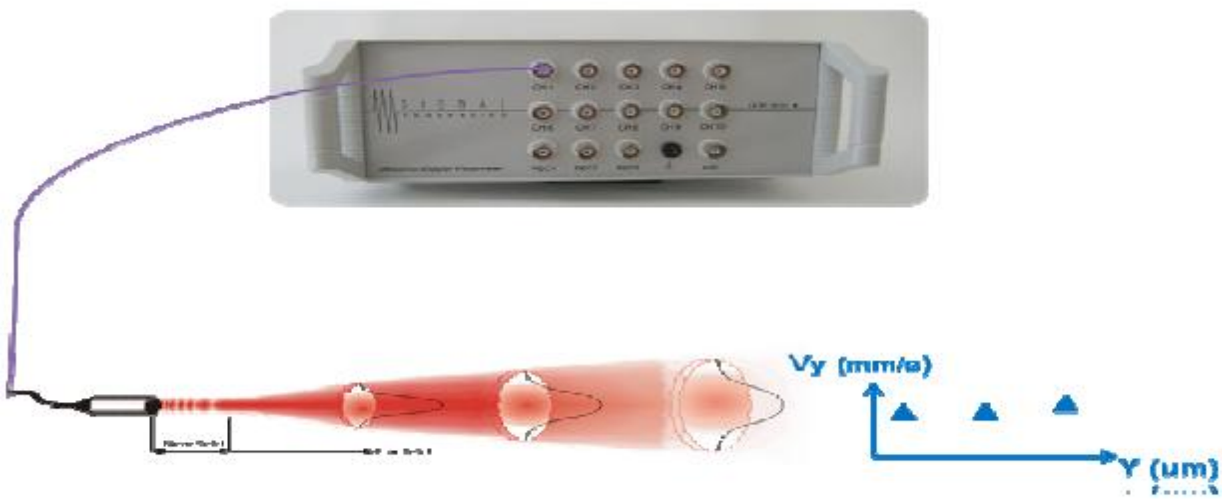


Figure 6. Measuring volumes of the velocity projection along the ultrasound pulse emitted by the transducer

The velocimeter calculates and displays in real time, the data profile based on analyzing a specified large number of measuring volumes concentric placed along the ultrasound wave emitted and received by a transducer.

By using multiple channels (transducers), the velocimeter provides spatial information regarding the velocity field. The measuring time is a few milliseconds, sequential for multiple channels. The velocimeter has its own software. The data transfer is made using an USB interface.

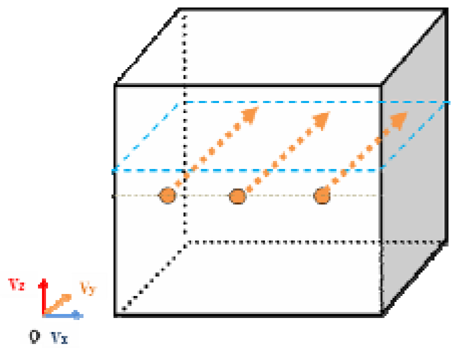


Figure 7. Transducers positions on the crucible

The UDV sensors were positioned perpendicular on the crucible's exterior wall (Figure 7), the conducting liquid being place inside the electromagnetic field. In order to measure the velocity, these sensors were placed in three different positions (left, middle, right) along a horizontal line. During the first tests the conductor liquid used was an electrolytic solution of 10% NaOH dissolved in distilled water. The solution level in the crucible is marked by the blue dotted line.

The perpendicular on XOZ transducers measure the Vy component of flow velocity. The orange squares (dots) represent the measuring volume in which the velocity Vy is determined.

First results

In Figure 8 there are illustrated long exposure photos of the flow structure obtained by placing the crucible with the conductive fluid (10% NaOH electrolyte solution) inside the electromagnetic field. Left and right along the diagonal one can observe the two electrodes positioned symmetrically. The flow structure is visible due to tracing particles (beech sawdust) introduced in liquid. Two large convection loops can be seen rotating in opposite sides around the two electrodes.

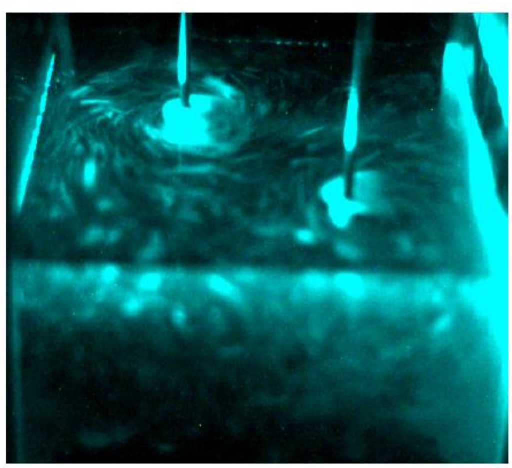


Figure 8. Flow structured experimentally observed for a 10% NaOH electrolyte solution

For the three position represented in Figure 7 (left, middle, right) of the transducers three velocity profiles along the Oy axis (depth) were recorded.

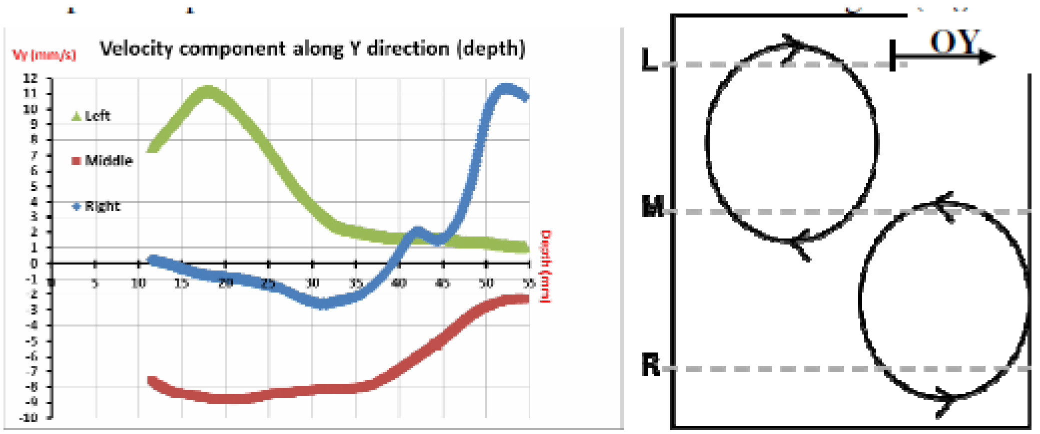


Figure 9. Velocity profiles along Oy axis comparing the three transducers positions in Figure 7 (left, middle, right) (left side of the figure) with the flow structure (right side of the figure).

The maximum recorded velocities are around 10 mm/s, the liquid having some dead areas (unmixed) where the velocities tend towards zero as seen in the visual observations (as can be also seen from Figure 8). For the left profile (represented in green in Figure 9) one can observe how the initial particle velocities along the Oy axis are higher, then go down to zero, due to the existence of a convection loop around the electrode closest to the transducer, which causes a strong flow along de Oy direction, close to the transducer. Because the flow direction is from the transducer (Oy direction) the velocities have positive values.

In the case of the right profile (represented in blue in Figure 9). it can be observed that initially the particle velocities have low values, reaching negative values in the middle (the flow is influenced by the middle zone that has an opposite direction) and then the values increase to high positive values because of a convection loop oriented from the transducer around the electrode placed farthest from the transducer.

The middle profile (represented in red) has negative values corresponding to a flow towards the transducer due to both convection loops. The fact that the velocities are higher for the closest loop can be explained by the existence of an initial particle velocity caused by the rear loop when entering the front convection loop, where they are accelerated.

In conclusion, the profiles of the variation of the velocity projection in depth (Oy axis) are in good agreement with the observed convection loop structures, which proves a high qualitative and semi-quantitative functioning of the UDV measuring method.

Dissemination:

Articles:

1. Novel method for melt flow control in unidirectional solidification of multi-crystalline silicon, D. Vizman, C. Tanasie, J. Crystal Growth, first revision

Conferences:

1. Novel method for melt floe control in unidirectional solidification of multi-crystalline silicon, D. Vizman, C. Tanasie, R. Negrila, 4th European Conference on Crystal Growth, Glasgow, 2012, poster
2. A new type of electromagnteic stirring in directional solidification of mc-Si, D. Vizman, C. Tanasie, R. Negrila, 6th International Workshop on Crystalline Silicon Solar Cells, Aix les Bains, France, 2012, poster
3. Numerical study of melt convection in directional solidification method of multicrystalline silicon, D. Vizman, A. Popescu, ROCAM 2012, Brasov, Romania, invited
4. Numerical modeling and experiment of a melt in an electromagnetic field, R. Negrila, D. Vizman, ROCAM 2012, Brasov, Romania, invited
5. Numerical studies on a type of electromagnetic stirring in directional solidification method of multicrystalline silicon, D. Vizman, C. Tanasie, R. Negrila, 7th International Workshop on modeling in crystal growth, Taipei, 2012, oral
6. Melt stirring based on a combination of electrical current and magnetic fields, R. Negrila, A. Popescu, M. Paulescu, D. Vizman, TIM12 conference, Timisoara, 2012, oral

Others:

1. A patent is being prepared.

Project manager,
Prof. Dr. Daniel Vizman