102 HighCast:
High Performance Silicon Casting and Wafering

Project duration: from 08.2015 to 03.2019
Final report submitted: 06.2019

Publishable Summary

The project has focused on research and development of advanced casting and wafering techniques for producing silicon wafers suitable for higher efficiency solar cells. Alternative casting techniques comprising “High Performance Multicrystalline Silicon” (HPmcSi) and “Mono-Casting” have been investigated and further developed.

For HPmcSi, the nucleation phase at the beginning of the solidification is controlled either by using seed material, which is not fully molten (“half melt process”), or by use of specially designed crucible interfaces with e. g. adapted silicon nitride coatings (“full melt process”). Thus, a high initial density of small grains evolving into larger grains over the ingot height is achieved. As a consequence, the internal stress during crystal growth is diminished, leading to lower dislocation densities and grain boundaries, which are less recombination-active and result in higher solar cell efficiencies. The Mono-Casting technique uses monocrystalline seed crystals at the bottom of the crucible to produce ingots with a large share of monocrystalline silicon.

Both techniques were applied at laboratory scale at Fraunhofer ISE with crucible sizes G0 and G1 using two adapted nucleation layers for the crucible bottom in combination with a full melt growth process. Silicon casting on industrial scale was carried out by Crystalox Ltd., UK. Additionally, a hybrid ingot consisting of 50 % mono-cast and 50 % HPmcSi crystallized at NTNU, Trondheim, was analysed.

At PV Crystalox Ltd., UK, progressive improvements in ingot quality, through sustained development of seeding materials and techniques, have been achieved during the period of the HighCast project. Consistently well-controlled and reproducible nucleation, the key to higher quality crystallisation, has been demonstrated. Dislocation clusters have been reduced by perhaps a factor of three to four. Commercial customers of Crystalox have also validated the encouraging progress seen throughout the project from internal assessments, reporting significant cell efficiency improvements - though absolute efficiencies were not revealed.

For cutting the ingot into wafers by steel wire sawing, the use of structured steel wires was further developed by PV Crystalox, Germany. Feed speeds could be increased. The direct costs were decreased by 13 %, the yield of silicon wafers per block length was increased by 4 % and the throughput increased by 16 %. These results can also be applied to the cutting of other hard brittle materials.

Solar cells and samples in a precursor stage were produced from selected wafers at Fraunhofer ISE at the laboratories in Gelsenkirchen and Freiburg. The development of defects after typical high temperature processes was analysed on cell level by processing heterojunction solar cells

including an amorphous Silicon layer. Since the processing temperature did not exceed 200°C, the influence of the cell processing on the material parameters to be studied could be neglected.

The project was coordinated by Karlstad University, where the specific detrimental influence of single defect types (dislocations, grain boundaries) have been studied. This was achieved by combining high resolution Light Beam Induced Current (LBIC) topography with automated optical microscope imaging to measure defect densities. On solar cells from both standard and HPmc Silicon, grain boundaries were now the dominating efficiency limiting bulk defects.

Project consortium

Coordinator and all contact details:

Full name of organisation	Karlstad University, Sweden
First and family name of coordinator:	Markus Rinio
Full address:	Karlstad University, Universitetsgatan 2, 651 88 Karlstad, Sweden
E-mail:	markus.rinio@kau.se

Participating countries and financing:

Country	**Number of organisations involved**	**Project costs in EUR**	**Public funding in EUR**
Sweden	1	389’871	389’871
Germany	3	938’471	562’529
United Kingdom	1	439’113	219’557
Total	*5*	*1’732’417*	*1’171’957*

Karlstad University-contract is in SEK, exchange rate applied 1 EUR = 9.2 SEK
Crystalox-contract is in £, exchange rate applied 1 EUR = 0.7 £

Funding agencies involved and contracts

Funding Agency	**Contract N° and Title**
Energimyndigheten	Proj. nr. 40184-1
Bundesministerium für Wirtschaft und Energie	0325894A, „High Performance Silicon Casting and Wafering (HighCast); Teilvorhaben: Entwicklung von High Performance Multicrystalline Silicon mit kontrollierter Keimbildung“
Bundesministerium für Wirtschaft und Energie	0325894B, „High Performance Silicon Casting and Wafering (HighCast); Teilvorhaben: Kostensenkung dünnerer Wafer durch Einsatz angepasster strukturierter Drähte.“
Innovate UK	620113