Executive publishable summary

FoXy is a 36-monthly EC-funded R&D project which has developed refining and crystallisation processes for metallurgical SoG-Si feedstock, has optimised associated cell and module processes, and has set parameters for these types of feedstock. The FoXy partnership originally aimed at:

1. Further developing and optimising refining, purification, and crystallisation processes for metallurgical SoG-Si feedstock, as well as for recycled n-type electronic grade Si.
2. Optimising associated cell and module processes.
3. Setting input criteria for metallurgical and electronic n-type silicon to be used as raw materials for SoG-Si feedstock.
4. Transferring the technology from laboratory to industrial pilot tests.

WP 1 has developed versatile refining techniques that are able to produce SoG-Si from the direct route but also for refining/recycling of scrap material such as ingotoff-cuts and broken wafers as well as dust from the wafering process. Some of these techniques were demonstrated on industrial scale, while simultaneously groundbreaking modelling on a new approach for refining through directional solidification has taken place. WP2 aimed at purifying available contaminated feedstock and testing it by ingot growing and wafer cutting. Focus was on optimising parameters for purification and crystallisation of N-type material. To realise this aim, N-doped silicon feedstock was purchased, ingots were produced and the directional solidification process was optimised. Both degasification and multistage segregation methods were used to refine n-type silicon.

WP3 has worked on developing methods for electro-refining of metallurgical grade silicon to produce solar grade quality silicon after subsequent re-melting. Electrochemical studies showed that silicon can be anodically dissolved and cathodically deposited from molten $CaCl_2$ based electrolytes. Promising electro-refining results for some important impurity elements were obtained in recent experiments, though the contents of phosphorus and boron are still too high for solar cell applications. Rough calculations to estimate the energy consumption for electro-refining of metallurgical silicon showed that only about 3 kWh/kg Si is needed. The main challenge is to obtain the required solar grade purity.

WP 4 has supported the other WP's by characterisation of the samples and giving feedback to WP1, WP2, WP3 for optimisation of ingot growth processes, and to WP5 in order to choose the best solar cell processes according to the quality of the materials. The electrical, spectroscopic and structural characterization of the raw material from WP 1 to WP 3, and of the ingots and wafers grown in WP 1 and WP 2 has been carried out. All the ingots grown were characterized with relevant parameters (efficiency, lifetime, impurity content). In order to estimate the overall quality of the different materials, wafers and ingots were characterised in detail by different partners using different techniques, in order to obtain a complete knowledge of the material. The characterization results indicate that most of the material grown in WP1 and WP2 is suitable for solar cells. Some important properties, like lifetime and resistivity, have been measured using different techniques by more than one partner. Furthermore, specifications of SoG have been outlined. In addition, fundamental studies were carried out on the effect of compensation and dislocation mechanism generation

Workpackage 5 has worked on large area solar cells (150x150 mm^2) and achieved 16.7% on SoG-Si p-type feedstock Cz-Si cells from 10% blend; with texturisation the efficiency increased to above 17%. Furthermore, with industrial n-type process after optimisation of individual processes: 16.4% on mc-Si and 18.3% on Cz-Si was achieved. These are the highest efficiencies ever reported for a screen printing process on n-type mc- and Cz-Si material. WP6 has evaluated and tested modules made from Foxy cells, resulting in a FoXy module with comparable efficiency as the reference. Furthermore, it has assessed the recycling possibilities of FoXy modules and cells, and evaluated the life-cycle environmental impact of the processes developed. WP 7 has integrated the feedback loops and parameter discussion, to ensure the exploitation and dissemination of the results outside the project. Furthermore, it provided a starting point for discussions on a solar grade silicon standard that are now continued outside the project.