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PROJECT SUMMARY NO PS246

Innovative Equipment For The Preparation of 150mm Multicrystalline Silicon

OBJECTIVES

- To design, develop and manufacture the next generation of multicrystalline silicon growth systems to match the latest industry standard 150mm & 156mm square wafers, and to accommodate the future generation of 200mm & 210mm square wafers.
- To increase silicon production rates.
- To improve PV (photovoltaic) silicon quality during the growth process.
- To produce a higher efficiency machine through the use of the latest analytical techniques; through system design to silicon output.
- To design and develop an automated process line for the key stages in the production and handling of 150mm – 210mm square blocks cut from silicon ingots.

SUMMARY

The project has undertaken the design and development of the next generation of multicrystalline silicon ingot growth system, capable of producing ingots up to 90cm square and weighing up to 500kg.

A crystal growth system operated successfully during production trials, proving the reliability of larger-scale crucibles and furnace component designs required. The system produced high quality silicon, meeting the photovoltaic industry requirements, while dramatically improving the productivity in comparison with current 66cm production systems.

This project has also covered automation of downstream ingot processing equipment. The developed processes include block chamfering, inspection and packaging.

Previous procedures to prepare blocks for wafering have largely depended on manual handling, increasing risks of injury from

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repetitive strain and loss of product from handling damage.

The development of automated systems has resulted in a reduction in manual handling of 60% and 100% for chamfering and inspection / packing operations respectively. The accuracy and repeatability of these processes has also improved.

CONTRACTOR

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COST

The total cost of this project is £984,250, with the Department of Trade and Industry (DTI) contributing £393,700, and Crystalox the balance.

DURATION

25 months – January 2004 to February 2006.

BACKGROUND

The photovoltaic (PV) silicon industry has seen a rapid global expansion in recent years with annual growth rates in the order of 30-35%. During this time the majority of the world's solar cells have been produced using crystalline silicon either in the form of single crystal or multicrystalline material. Crystalox has played a major role in increasing the use of multicrystalline silicon through both the development of equipment for industrial production of multicrystalline silicon and also in the volume manufacture of multicrystalline silicon ingots.

In 2004 the industry standard wafer size was 125mm square, cut from a 66cm square ingot typically weighing 270kg. However, the drive to reduce cell manufacturing costs has led to the adoption of larger wafer sizes in the range 150 to 156 mm square.

The optimum ingot size for the production of twenty five 156mm square blocks requires a larger, 83cm square ingot with a corresponding increase in weight to approximately 400kg. The larger ingot size and weight together offer the potential for reduced production costs.

Crystalox has also undertaken the design and manufacture of new automated downstream ingot processing equipment, capable of handling larger-size blocks, including systems for chamfering, block measurement, final inspection and packaging. Previously, procedures to prepare blocks ready for wafering largely depended on manual handling for transfer of blocks between process stations and for most operations within each station.

THE WORK PROGRAMME

The overall project has been carried out in two distinct sub-tasks, a) the design and build of the crystal growth system and b) the design and manufacture of block processing equipment.

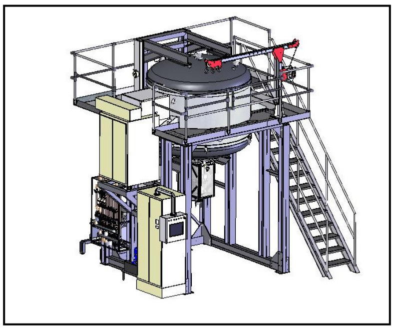

Figure 1. 90cm Crystal Growth System (courtesy of Crystalox)

Task a) Crystal Growth System
A novel crystal growth system, Figure 1, was designed to be capable of producing larger 83cm square ingots, optimised for 156mm blocks, or 90cm ingots, for the 210mm block size.

The design of the framework provides for mounting of the chamber above floor level and allows the chamber base to be lowered for easy, rapid crucible loading and unloading of the ingot from ground level. The sealed, water-cooled chamber allows evacuation and a controlled inert gas atmosphere to be maintained to minimise contamination of the silicon during melting and growth.

Furnace components are induction-heated for high efficiency and reliability.

The production process comprises of melting, crystallisation and ingot cooling stages and is fully computer-controlled, with automatic detection of critical phases. All control software has been wholly developed by Crystalox.

Task b) Block Processing Equipment
The existing manual ingot-to-block processes were broken down into separate activities and considered for automation. Three operations were identified for development under this programme:

- Block chamfering.
- Inspection.
- Packing.

All equipment was then designed to cope with the present 125mm block size through to the potential 210mm size.

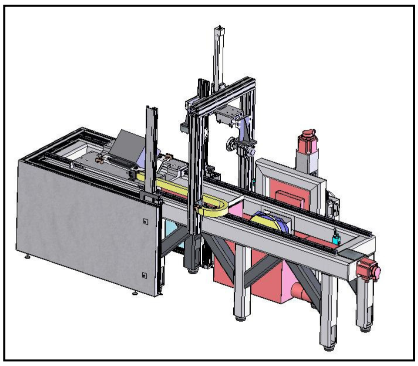

Figure 2. Chamfering Machine (courtesy of Crystalox)

Block Chamfering
The chamfering process adds a narrow chamfer to the four longitudinal edges of the block to prevent chipping of sharp edges during subsequent handling. The action of the chamfering machine, shown in Figure 2 has been split into three operations; block loading / unloading, block rotation and grinding of the chamfers. A high-speed carriage

carries the block from the loading position to a position above the diamond grinding wheel. The wheel is mounted on a high-precision ball screw which provides fine control over chamfer size. After the block has been translated over the grinding wheel and the first chamfer produced the block is lifted from the carriage and rotated to present the next edge for chamfering. This process is repeated three times until all four edges have been chamfered when the block is returned to the unload position. After each chamfer has been ground it is immediately measured and compared to the specification. If the chamfer is outside specification the operator is alerted.

Inspection

At the end of the block production process every block undergoes measurement and quality checks before being passed for wafering. There are five individual operations which are necessary: -

- Block length measurement.
- Block width and height measurement.
- Electrical resistivity measurement.
- Labelling/identification.
- Visual Inspection for defects.

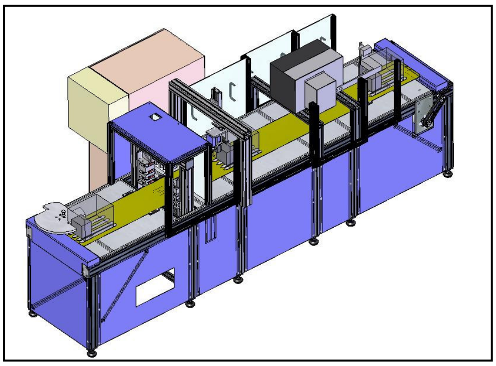

Figure 3. Inspection Machine (courtesy of Crystalox)

An integrated inspection machine has been developed and is shown in Figure 3. The system utilizes a through feed belt which sequentially transfers a block from a loading position through three operational stations and on to an unloading position. The three stations carry out, in turn, block length and geometry measurement, resistivity measurement and labelling.

The first station uses non-contact lasers to carry out both length and geometry measurement. The lasers were specially selected to operate reliably with the difficult surface silicon presents.

At the second station the electrical resistivity of the block is measured at both ends by means of an inductively-coupled probe. A touch-sense system allows the contact force to be precisely controlled and repeated.

Labelling is carried out at the third station which prints and barcodes a label with all the required identification and measured data and then attaches the label to one face of the block.

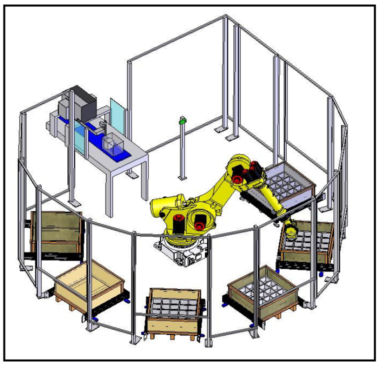

Figure 4. Packing Cell (courtesy of Crystalox)

Packing
At the unload position a robot with a custom-designed handling tool picks up the silicon block, see Figure 4. The robot presents each face of the block to a high resolution camera system which is programmed to identify cracks. Blocks that pass all the inspection criteria are packed by the robot directly into a shipping crate for transfer to the wafering facility. If any block fails final inspection it is placed into a separate crate from where it can be retrieved for manual inspection and any necessary re-work.

CONCLUSIONS

- The project has successfully developed the larger crystal growth system and automated block process line as set out in the initial proposal.
- The new crystal growth system proved that high quality 90cm and 83cm square ingots could be grown successfully, within an acceptable cycle time.
- The block processing task has produced two operational systems which demonstrate that key parts of the manual processing of blocks have been successfully automated.
- The automated processes did not achieve the full performance in all areas specified at the outset. However, overall performance was considered successful and further software and mechanical developments can be expected to address these issues.

POTENTIAL FOR FUTURE DEVELOPMENT

Initial trials on the silicon crystal growth system have been very encouraging but further developmental work under pilot production conditions is desirable to improve the system's operation and efficiency. This work will include:

- Development of the crystallisation programme to further reduce cycle time and improve productivity.
- Development of the pyrometer system to allow accurate temperature control of the furnace.
- Optimisation of furnace insulation to reduce power consumption.

The block processing machines have been considered successful at this stage but there are several areas that require further work to enhance performance:

- Improvement of laser measurement accuracy and repeatability.
- Reduction of cycle times for the block chamfering and automated packing systems.
- Further development of the defect detection camera system for recognition of fine cracks.

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