HIGH THROUGHPUT MECHANICAL STRUCTURING SYSTEM FOR SOLAR CELL WAFERS

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ABSTRACT: One major obstacle for implementation of mechanical treatment in modern automated production lines was the non availability of a suitable high throughput system. Based on the experience of the University of Konstanz and solar cell manufacturers a structuring system was developed at the Fraunhofer IPT which meets the requirements for machining a brittle material such as silicon. The structuring process is carried out by grinding with profiling tools for accurate and high-speed generation of a surface topology. The machine is designed for production-line operation targeting a throughput of 1200 wafer/h.

Keywords: Texturisation - 1: multi crystalline Si - 2: Implementation - 3

INTRODUCTION

“Clean energy” is attracting more and more interest, which in turn produces cost pressure for more efficient solar panel production due to the competitive situation. Beside Al BSF formation and PECVD SiN firing through process most of high efficiency industrial type solar cells exhibit a textured front surface. Mechanical structuring is one method which has been intensively studied on laboratory level in recent years. Up to 17.2 % efficiency on screen-printed multicrystalline silicon solar cells was reached by Sharp [1], whereas 16.5 % has been obtained in a collaboration between the University of Konstanz and IMEC [2]. Using the buried contact approach for cell metallisation 16.4 % efficiency was reached by University of Konstanz [3].

For all these high efficient solar cells the structuring was done using a single V – shaped dicing blade on a conventional semiconductor dicing machine. The approach using multiple dicing blades on a special flange can not be applied for production because of the high costs of the dicing blades. To overcome this barrier a roller shaped structuring tool has been developed by the University of Konstanz. It consists of a profiled metal body coated with a diamond based abrasive layer. Using this tool on the dicing machine it was possible to fully texture a solar cell in a few seconds. The first full automatic system on the market designed for such texturing tools had a too low throughput of about 150 wafer/h which did not meet the requirements of modern production lines. Therefore based on the experience on laboratory scale at University of Konstanz a production line system was set up by Fraunhofer IPT within the frame of a European research project HIT [8].

APPLICATION

For a high throughput structuring machine with a fast handling system a large number of applications in the field of solar cell processing is possible:

- Surface structuring for efficiency enhancement of low cost multicrystalline silicon solar cells. [4]
- Surface levelling for ribbon silicon such as RGS.[5]
- Surface profiling for roller printed contacts [6].
- Surface cleaning to reuse partly processed wafers.
- Surface texturing of substrates for thin film solar cells.
- Hole formation for electrical interconnection of solar cell front and rear side (back contact emitter wrapped through cell, semitransparent POWER cell, bifacial solar cells). [7]
- Buried contact groove formation. [3]
- Parasitic edge removal as an alternative for dry plasma etching.

All these applications are tested at University of Konstanz, the fabrication of POWER solar cells has been transferred to industry.

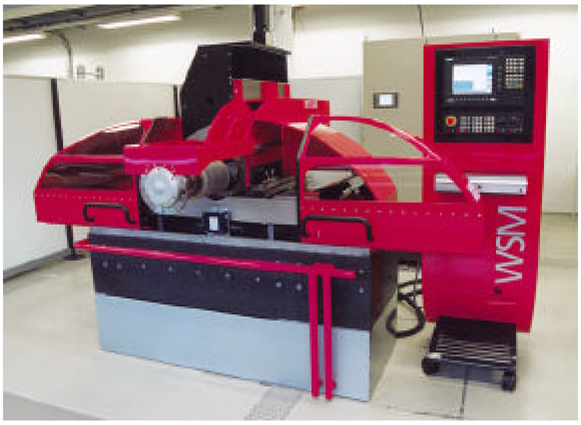

Fig 1 Wafer Structuring Machine (WSM) designed by Fraunhofer IPT

SYSTEM CONCEPT

For a system to be used in PV – industry the processing costs have to be low and throughput as well as uptime have to be high. Industrial users want to have an economic machine setup for automatically machining with high yield and high reliability. The system has to be flexible enough to optimise the process on a industrial scale. Additionally, wafer contamination has to be avoided. These requirements were taken into account in the design of the new Wafer

Structuring Machine. To reach a high throughput up to 4 wafers (12.5 x 12.5 cm²) can be placed on a square shaped chuck table and the maximum tool length is 280 mm. This gives enough flexibility to either texture four wafers with one stroke or texture two wafers and clean the two remaining positions in one step.

The mechanical structuring process requires a rigid machine design and good geometrical characteristics. In-process measurements reveal machining forces of up to 1.5 $N/mm_{structuring\ width}$, so the machining width of 280 mm leads to comparably high load.

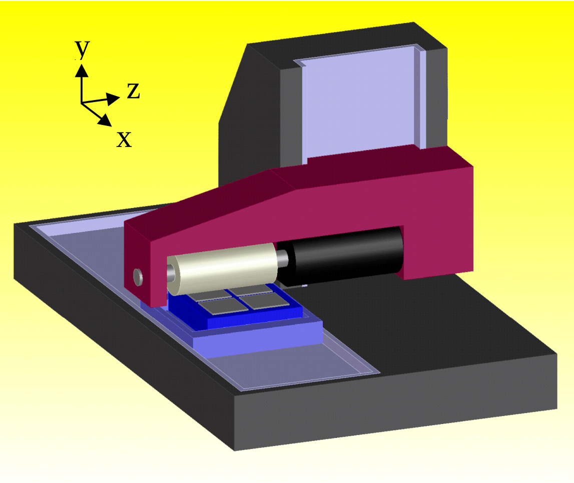

Fig 2 Arrangement of axes

Fig. 2 shows the arrangement of the axes. The machine base material is granite. There are three controlled linear axes X, Y and Z. The X-axis is the oscillating main machining axis with a travel of 900 mm. It carries the vacuum chuck which is able to hold four wafers. The Y- and Z-axis are positioning respectively shift axes with a stroke of 215 mm and 70 mm. Incremental linear scales are integrated in all linear axes.

The Y-slide carries the spindle. Due to the dimensions and the weight of the tool as well as the requirement of stiffness a counter bearing is necessary. The spindle exhibits a 33 kW built-in motor and a maximum rotation speed of 10,000 rpm. Both spindle as well as linear axes provide a high stiffness of the system. The structuring tool is clamped by an arbour which is mounted into the machine by hollow shank interfaces. To facilitate the tool change, the counter bearing cartridge can be removed and guides the tool arbour out of the machining housing. The repeatable positioning of the counter bearing part is guaranteed by spur wheels.

A handling system is not developed in the project but all requirements for an automated handling were taken into account.

PROCESS RELIABILITY

Different process monitoring systems are integrated in the system. The automatic balancing system compensates balancing caused disturbance. The balancing head is integrated into the clamping arbour. Also, the system shows an acoustic emission evaluation that detects contact between wafer and tool as well as wafer breakage. Furthermore it monitors the condition of the grinding process. The third element of the process monitoring system is the vacuum control. A broken or missing wafer leads to a vacuum loss that is indicated.

To avoid wafer breakage one has to ensure adequate fixing of the wafers on a clean chuck surface. A vacuum field cleaning is done in three steps. First rotating brushes remove wafer fragments or accumulated crusts. A water jet removes remaining small dirt particles. In the third step an air jet dries the chuck surface and prepares it for new wafer feeding. The process control system guarantees the full automatically machining of the silicon wafers.

Fig 3 WSM - machining area

The machining strategy has a large influence on the cycle time. Two strategies are suitable, that take the four wafer clamping fields of the chuck into consideration. The first strategy features two clamping fields prepared with wafers. After the wafers are machined, the vacant clamping fields are scavenged by cleaning units that are located bilateral of the machining area. The machining area is shown in fig. 3. The feeding and unloading processes take place simultaneously. This strategy realises the synchronous wafer machining and chuck preparation. Another mode considers the four wafers machined simultaneously, which makes an additional cleaning step necessary.

TOOL CONCEPT

Besides the system concept fundamental changes in tool concept were done. The tool wear is one major factor driving the processing costs, therefore the tool structure and the abrasive layer is under continuously optimisation.

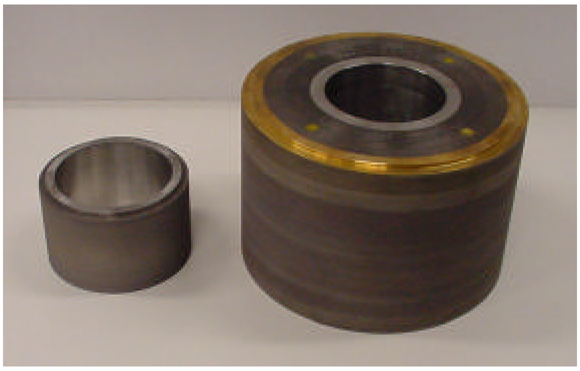

Fig 4 Ø110 mm steel tool and Ø200 mm CFRP-layer tool

The standard tool length which is currently manufactured is 130 mm. Therefore two tools with identical diameter are mounted on the flange. It is not yet sure whether a tool made out of one piece of metal (Ø 110 –140 mm) or a compound tool consisting of a light inner shell, a carbon fibre reinforced plastic (CFRP) layer and a structured outside metal bushing (Ø 200 mm) gives the optimum cost – performance ratio. Tools of both concepts are shown in fig. 4.

Regarding the abrasive layer, there are two basic concepts under investigation: Firstly a textured tool which is covered by an abrasive layer and secondly a thick abrasive layer, which is textured itself reaching a multilayer abrasive coating. The multilayer coating lasts longer than a singe layer coating, but this one is easier manufactured and a profiled tool can be recoated several times.

SOLAR CELL PROCESS

The solar cell process needs to be adapted for mechanically V - structured solar cells. Several industrial cell concepts have been optimised, here the screen printing process is described, for roller printing see [6], for the buried contact approach [3].

The defect etching time can be shortened to a half of the standard etching time. No changes needs to be made for emitter diffusion and etch isolation as even plasma etching is possible. The PECVD SiN ARC coating needs to be adapted by means of deposition time. The most significant changes need to made for the screen printing step: To reach fine line printing the contact fingers are printed on plateau regions (see Fig. 5) of the structured wafer. Therefore the wafer needs to be aligned on the same edge for texturing and printing. Alternatively the alignment system of the screen printer has to be able to detect the plateau position.

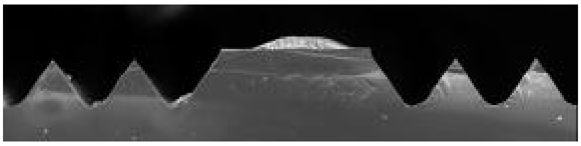

Fig 5 Finger is situated on a plateau to ensure easy screen printing.

The busbar runs perpendicular to the grooves. As the paste is shrinking during firing interruption can occur on the V –tips of the cell (see Fig. 6). Different front side pastes were investigated and a paste was chosen which enables fine line printing as well as a low shrinkage.

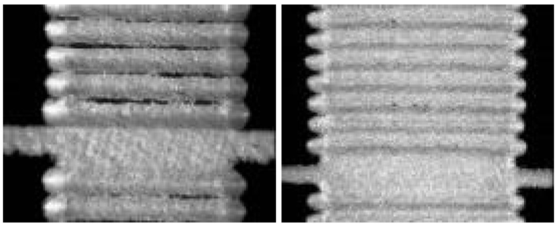

Fig 6 The busbar runs across the V – grooves. Shrinking of the paste can cause interruption on the V–tips occur. By using a suitable paste there are no interruptions.

Standard Baysix multicrystalline wafer sized 12.5 x 12.5 cm^2 were structured and processed in an industrial environment using the UKN PECVD firing through process. A standard 36 cell module was prepared reaching a maximum power of 85 Watt. The average cell data before encapsulation and in the module are given in table 1.

The fill factor drops because of the series resistance of the tabbing and cell mismatch. The used tabbing is wider than the busbar causing further shading losses.

Table 1 Average results of 50 solar cells processed in industrial environment, 36 cells in module and module itself.

	Voc [V]	Isc [A]	FF [%]	eff [%]
cells	0.602	5.314	75.9	15.5
cells in module	0.601	5.443	72.1	15.1
module	21.6	5.443	72.1	85 W_{peak}

To achieve highest efficiencies a selective emitter process was applied where the texturisation is done after the first deep diffusion. A shallow diffusion was applied for the grooved region. With this process a maximum efficiency of 16.1 % was reached.

CONCLUSION

A high throughput system for mechanical wafer treatment is now available on the market. It exhibits a powerful high precision spindle and stiff axis to provide high performance in an industrial environment. Several tool concepts are under investigation to optimise costs and tool lifetime. Mechanical structured multicrystalline silicon solar cells are processed in a industrial environment reaching an average efficiency of 15.5 %. Encapsulated in a standard 36 cell module the power is 85 $Watt_{peak}$.

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