Solar cell surface characterization

Introduction

Solar energy is one of the most promising renewable energies. Its applications are broad, from powering small automated electronics which require low power delivery, to rural electrification that require to assemble several solar cells in solar panels to deliver larger quantities of energy. One of the newest applications of solar energy is its use on powering reverse osmosis devices in developing countries, hydrogen generation (called «solar hydrogen») and «solar cooling».

Cell efficiency depends on the silicon dopant, light density and wavelength, optical thickness and surface texture. Efficiency of current solar cells is around 20% but some texturing processes can boost it up to 50%. The manufacturing difficulty of such processes implies a higher cost, making them prohibitive. Space and solar car racing applications demand the highest efficiency solar cells.

Mono-crystalline and Poly-crystalline silicon

The greater part of solar cells are manufactured using mono-crystalline or large-grained poly-crystalline silicon.

To reduce manufacturing costs the silicon used has a lower quality than the used in the micro-electronics industry. It is called metallurgical grade silicon and has about 98% purity. The silicon light absorption efficiency is very low. There have been several attempts to increase cell efficiency, like light concentration using Fresnel lenses, solar concentrators, antireflection coatings, among others.

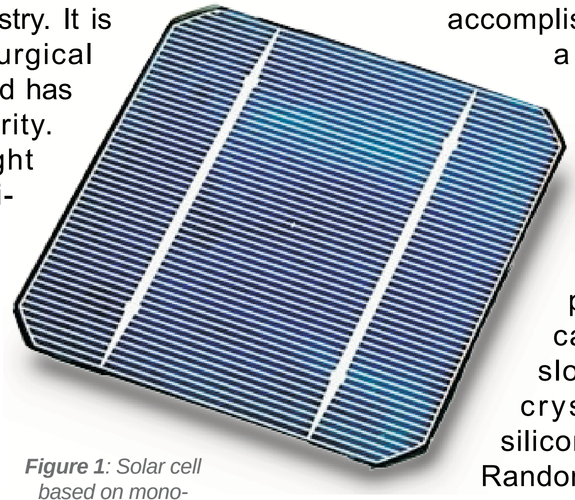
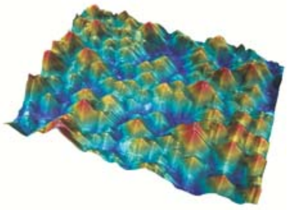
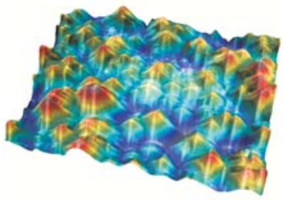


***Figure 1**: Solar cell based on mono-crystalline silicon wafer.*

The most effective way to increase light absorption is by increasing the effective optical thickness of the silicon surface. Such increase is called surface texturing and depends largely on the nature of the silicon.

Mono-crystalline silicon texturing is accomplished by a wet anisotropic etching process based on sodium hydroxide solution. The process is carried out by slowly etching crystallographic silicon plane {111}. Randomly distributed square base pyramids are obtained. The quality of the surface and the amount of pyramids depend on the temperature





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and the solution composition. The «light trapping» effect is very effective with such surface texture, increasing the amount of internal reflections, and thus the cell light absorption efficiency, from 10 to 50 times.

In contrast, multi-crystalline silicon texturing is not so effective because most of the grains have incorrect orientation. Surface texturing on this wafers have the disadvantage that different grains etch at different rates giving steps at grain boundaries, this being a problem for the subsequent process for metal screening.

Current driving on the silicon surface is accomplished by different technologies. The most typical are screen printed metal, buried contacts and metal insulators.

Surface texture characterization

Solar cell quality control is done at the end of the production chain, testing each individual cell for efficiency in a solar air mass 1.5G simulator. Sensofar offers a solution for quality control and production control for some of the key steps during the manufacturing line. The dual technology PLμ 2300 Optical Imaging Profiler offers the possibility to control silicon surface texture, roughness, pyramid statistical characterization and metal contact in few seconds.

Figure 2 shows a 3D measurement of a mono-crystalline silicon wafer after pyramidal etching. In contrast to the time, consuming Scanning Electron Microscope measurement, the wafer is placed under the PLμ 2300 and a 3D measurement is obtained in less than 10 seconds. The high local slope of the pyramid faces requires the use high numerical aperture objectives, only available in confocal technology. For such 3D measure a 150X objective with a 0.95 numerical aperture was used, reducing the field of view to few tens of microns, similar to the field of view

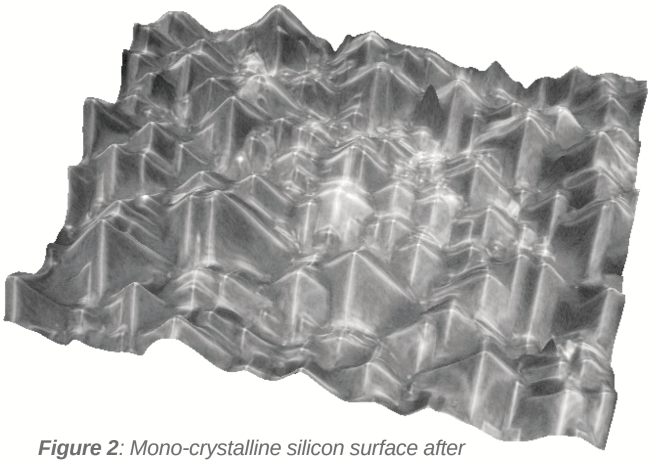

***Figure 2**: Mono-crystalline silicon surface after crystallographic {111} wet etching. The pyramidal surface texture increases «light trapping» up to 50 times, increasing the cell efficiency.*

of a SEM. The surface is scanned few microns along the focus position of the objective, collecting the confocal images plane by plane. The result is a SEM like image with infinite focus and 3D information of the heights of the pyramids.
In figure 3 a profile cut show a single one of the segmented regions.

Figure 4 shows the segmented topography and figure 5 the statistical pyramid height distribution. The histogram distribution is a key parameter that gives information about the number of pyramids, its uniformity, if there are non-textured regions and if the texturing process has created regions with different size pyramids.

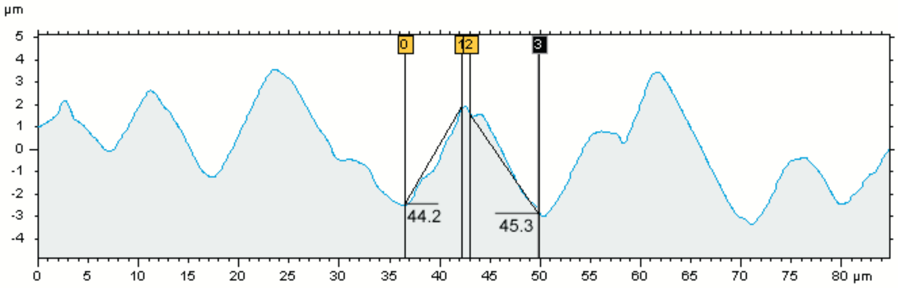

Figure 3: *Profile cut of the pyramids on a mono-crystalline silicon surface.*

pyramid characterization for height, base area and face angles. For the statistical pyramid characterization, a special watershed segmentation algorithm is used. This segmentation separates each individual pyramid by the use of the height information and calculates area, volume, average height and maximum height for each

In contrast to pyramidal mono-crystalline silicon texturing, a multi-crystalline silicon surface is much smoother. Heights and angles of each

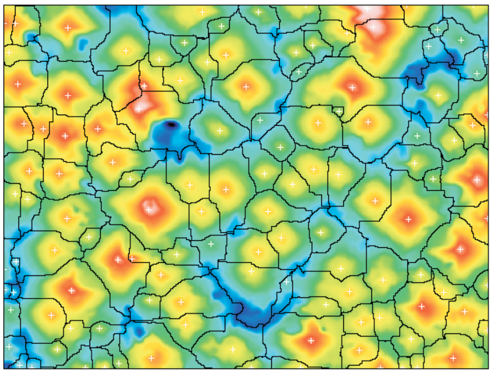

Figure 4: *Pyramid topographical segmentation using a water-shed algorithm. Each pyramid is isolated and its volume, area and height are calculated.*

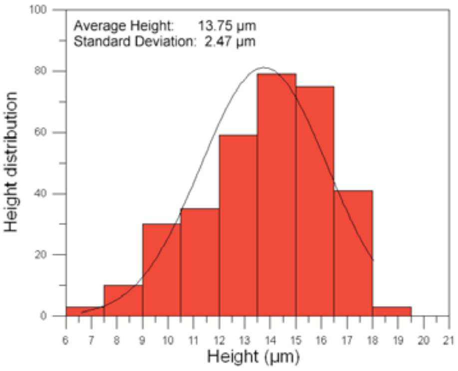

Figure 5: *Statistical height distribution of the pyramids.*

individual grain are on the sub-micron range, while size is several times bigger.

Figure 6 show the result of a 3D measurement on a mono-crystalline (left) and multi-crystalline (right) surfaces with the same field of view. Surface roughness parameters are shown for comparison. Figure 7 show a metal contact on a mono-crystalline silicon surface. The height, area and volume are retrieved from the 3D information.

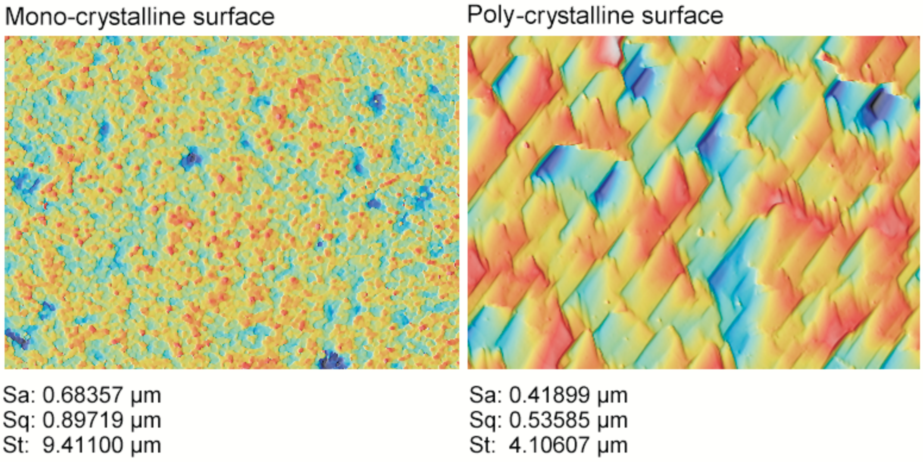

Figure 6: *Mono-crystalline (left) and multi-crystalline (right) surface texture. Surface roughness are compared for both texturing processes.*

The small and compact size of the PLµ 2300 sensorhead make it the ideal tool to be assembled in the production chain for production control.

The easy to use and programmable software allows the possibility to control statistical texturing parameters in different regions of single wafers, as well as metal contact characterization during the same scanning process.

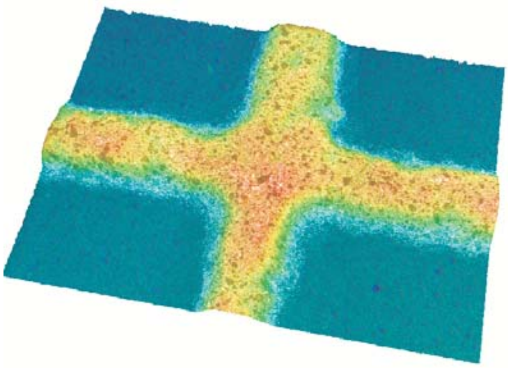

Figure 7*: Conductor made by screen printed metal.*

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