USING OF AFM AND KPFM IN CRYSTALLINE SILICON SOLAR CELLS PRODUCTION

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Abstract: This paper deals with the using of Atomic Force Microscopy (AFM) and Kelvin Probe Force Microscopy (KPFM) for the characterization of a silicon surface in the solar cell production. Surface properties are measured by using some interactions between the surface and the silicon-nitride tip that progressively scans the entire sample surface. Unlike the optical microscopy and the electron microscopy the AFM method allows three dimensional imaging of the solar cell texture. KPFM is used to measure electrical properties of surface using the contact potential difference.

Keywords: Atomic Force Microscopy, AFM, Kelvin Probe Force Microscopy, KPFM, Solar Cell, Texture, Back Surface Field, BSF

1. INTRODUCTION

An important part of the crystalline silicon solar cell production is surface properties characterization, e.g. texture topography, diffusion depth, and antireflection and passivation layers. An applicable tool for the surface texture mapping is the Atomic Force Microscopy (AFM). The AFM allows a surface visualisation of conductive, semi-conductive and nonconductive samples by force interaction between the surface and the silicon nitride tip which scans the whole sample. Kelvin Probe Force Microscopy (KPFM) is used for the surface electric properties imaging using contact potential difference (U_{CPD}). This method can be used for measuring thickness of various layers or determination of the layer homogeneity.

The experimental part of this work was focused on the AFM and KPFM application during study of monocrystalline (mono-Si) and multicrystalline (mc-Si) silicon solar cells properties. Experiments were carried out in the laboratories of Solartec s.r.o. The image evaluation was done by the Gwyddion and NOVA programs.

2. SURFACE TEXTURING

The first etching process in the solar cell production is saw damage removal by etching in alkaline or acidic solutions which removes a 5 -10 µm thick layer containing a lot of defects and impurities. Due to easier waste disposal alkaline etching solutions of potassium hydroxide (KOH) or sodium hydroxide (NaOH) are preferred. Acidic solutions are composed of a mixture of nitric acid (HNO_3), hydrofluoric acid (HF) and acetic acid (CH_3COOH). For saw damage removal solution composition with an isotropic etching is preferred [1].

The substrate surface after saw damage removal is polished and reflects a large amount of light. Surface texturing is performed to reduce reflection and to increase the absorption efficiency of the silicon surface for the wavelength range of visible light surface texturing is performed. When a ray incidents air-silicon interface, a part of light is absorbed and a part is reflected. It is more probable for the textured surface that the remaining part of a ray is reflected again into the silicon where its next part is absorbed again [2].

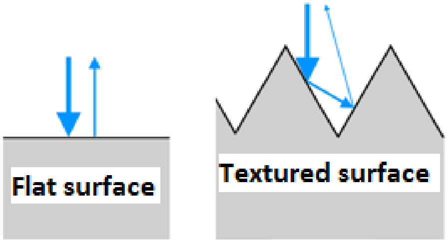


Figure 1: Effect of surface texturing

Texturing is done by etching in strong alkaline or acidic solutions. The silicon etching rate in strong alkaline solutions (NaOH or KOH) depends on the crystallographic orientation of silicon substrate. Etching is faster in [100] direction than [111] thereby a pyramidal structure for mono-Si substrate is created. The mc-Si topography depends on individual grains crystallographic orientation, the uniform texture throughout surface can be achieved only by acidic isotropic etching [1].

2.1. MEASUREMENT OF SURFACE TOPOGRAPHY

Three types of textured surfaces were measured using the AFM – samples after saw damage etching and samples with alkaline or acidic textures on mono-Si and mc-Si substrates. A summary of them is given in the tab. 1. Because both selected methods (AFM and KPFM) measure only surface properties, it was necessary to clean samples before measurement. Wafers after etching processes were broken into pieces which were fixed to pads and then thoroughly cleaned with compressed air. Uniform size of scanned area (50 × 50 µm) and scanning velocity (20 µm/s) was selected in order to compare images each other. Resolution was set up to 256 × 256.

The following figures 2 – 4 show structures of mono-Si and mc-Si substrates after etching processes. A surface reflection (see tab. 1) was determined by the visual comparison of samples. In case of mc-Si substrates surface properties were depend on crystallographic orientation of grains and that is why three scans on different grains were done. The structure regularity and for acid-etched texture presence of underetching were determined from surface images. The texture height mentioned in the tab. 1 is an average value obtained by analysis in the Gwyddion program. The average value from particular scans is presented for mc-Si substrates.

For mc-Si substrates the average value from a particular scan is presented.

Type of Substrate	Process	Reflection	Height of Texture [µm]		
			Scan 1	Scan 2	Scan 3
Monocrystalline	saw damage removal	high	1,37	-	-
Monocrystalline	alkaline texturing	low	3,38	-	-
Monocrystalline	acidic texturing	low	3,15	-	-
Multicrystalline	saw damage removal	high	1,48	2,23	2,64
Multicrystalline	alkaline texturing	high	1,82	1,91	2,96
Multicrystalline	acidic texturing	low	3,25	3,46	3,52

Table 1: Overview of samples measured by AFM

Structure after saw damage removal (see fig. 2) reflected the most of light and in the case of the textured mc-Si substrate the greatest contrast between particular grains was shown. The average height of the texture was the smallest for the mono-Si substrate. The texture height on the mc-Si substrate varied considerably according to the grain crystallographic orientation.

The light reflectance of the mono-Si substrate with the alkaline texture was considerably much lower than the alkaline textured mc-Si substrate wherein substantial differences between grains were demonstrated once again. In the image of the mono-Si substrate in the fig. 3 a) typical pyramids are shown evenly distributed over the entire surface. In the picture 2 d) there is a structure of the mc-Si grain with the lowest reflectance. The average texture height of the mono-Si substrate was much higher than mc-Si but in all cases it was higher than the average texture height after saw damage removal.

The fig. 4 shows that the crystallographic orientation of grains has not significant effect on the surface texture created by the acid etching. The reflectance of mono-Si and mc-Si substrate was low and the mc-Si texture did not show great differences between separated grains. The height of the texture was comparable in all cases. In fig. 4 b-d) is seen a presence of underetching which is undesirable because underetching is locally weakening the substrate. The substrate is then prone to breaking.

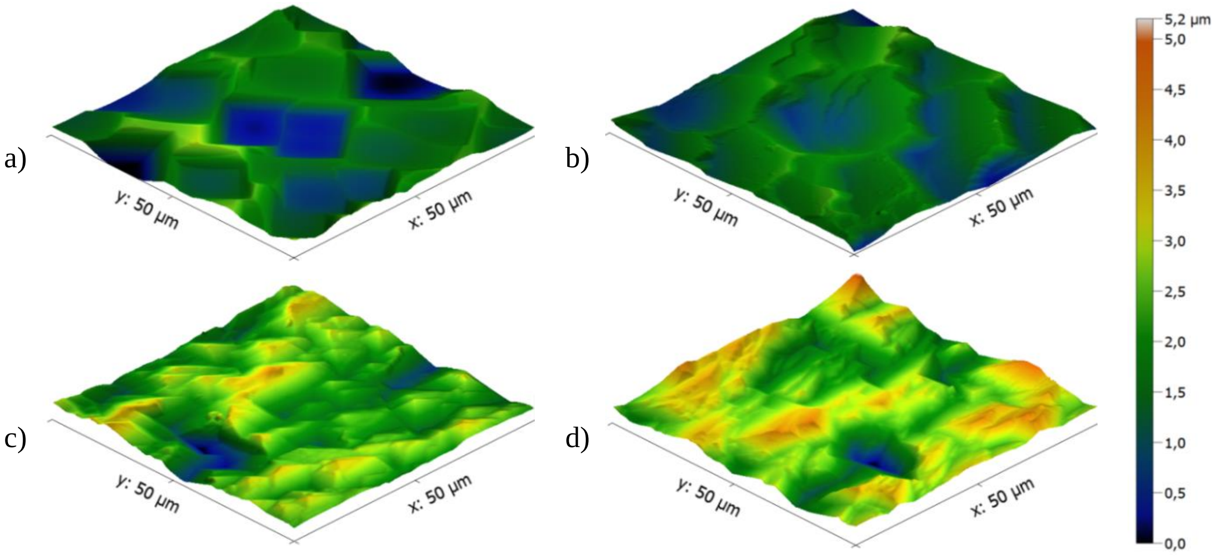


Figure 2: Surface of monocrystalline (a) and multicrystalline (b – d) silicon wafer after saw damage etching in alkaline solution.

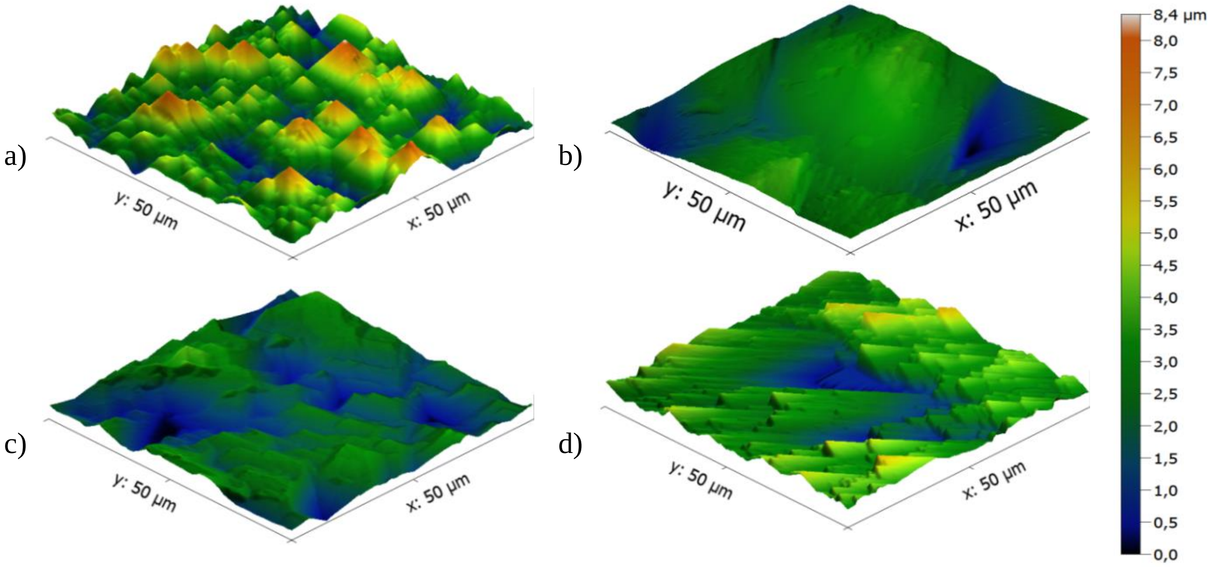


Figure 3: Surface of monocrystalline (a) and multicrystalline (b – d) silicon wafer after texturing in alkaline solution.

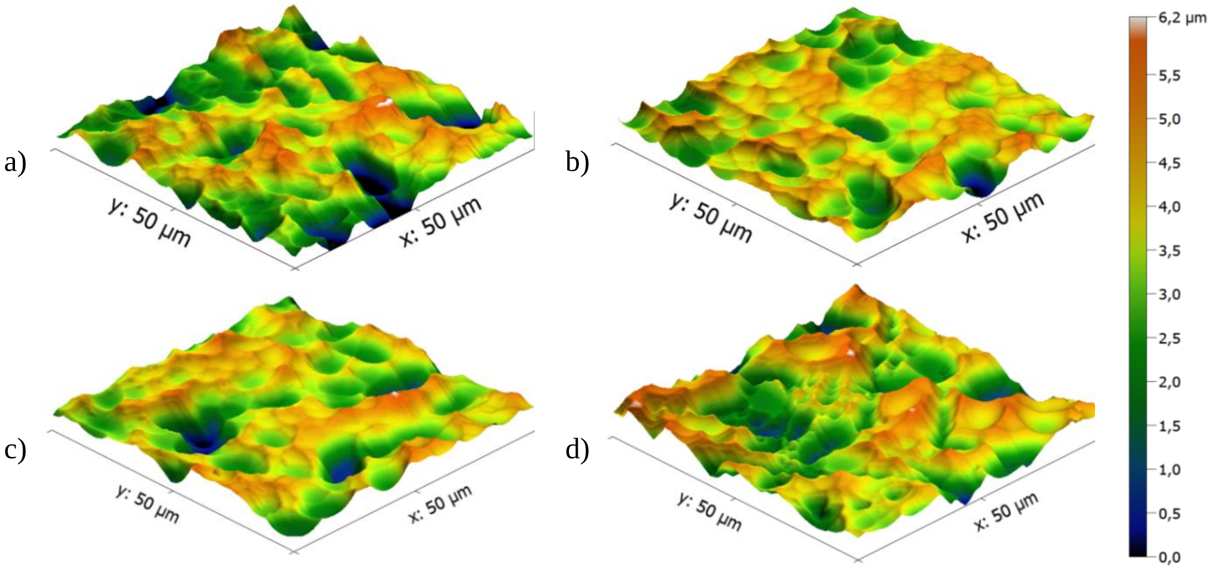


Figure 4: Surface of monocrystalline (a) and multicrystalline (b – d) silicon wafer after texturing in acidic solution.

3. BACK SURFACE FIELD

To better extraction of carriers highly doped region under contacts is formed – p^+ for holes extraction and n^+ for electrons extraction, see fig. 5 a). Due to the most common solar cells topography is n-n^+ junction sometimes called Front Surface Field (FSF) and p-p^+ junction Back Surface field. The width of the highly doped layer must be larger than the minority carriers' diffusion length. Heaver doping under contact minimises resistance between contacts and substrate and concentration of minority carriers [3].

Another option of BSF effect formation is presence of the fixed charge appropriate polarity in the passivation respectively passivation and antireflection layer. Fixed charge in the layer creates an electric field that keeps minority carriers away from contact. This prevents their recombination on the surface. Positive fixed charge in the passivation layer is suitable for the passivation n type material where minority carriers (holes) are effectively repulsed into the substrate and vice versa. This principle of BSF effect is shown in fig. 5 b) [3].

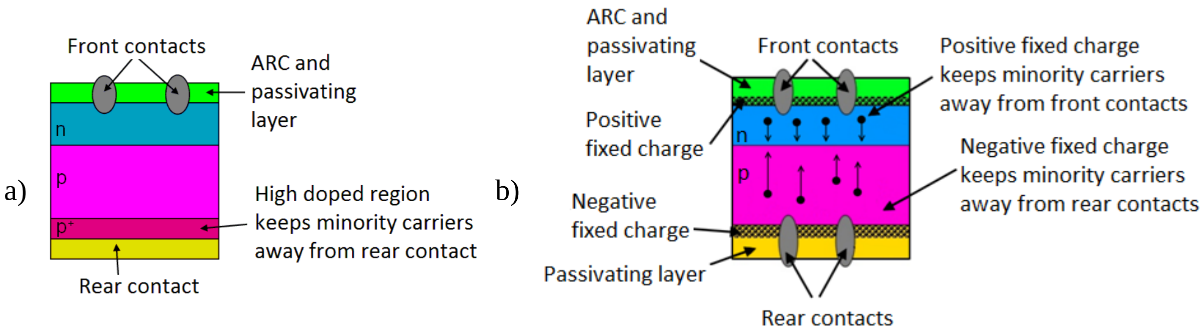


Figure 5: Schematic illustration of function of BSF and FSF effect

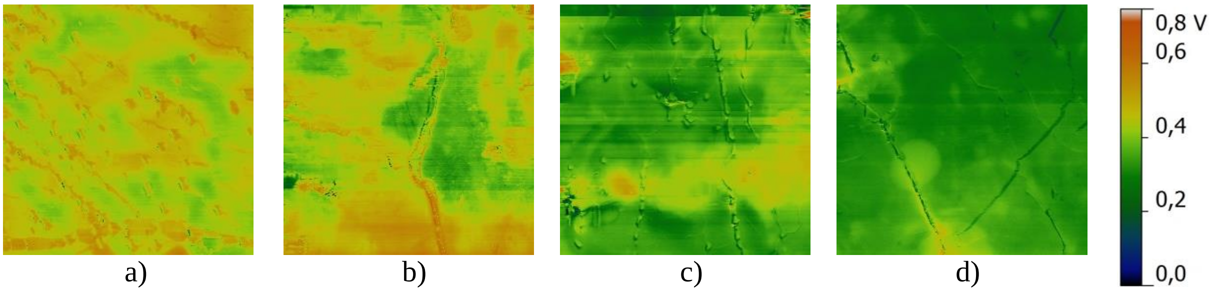
3.1. MEASUREMENT OF CONTACT POTENTIAL DIFFERENCE

The contact potential difference U_{CPD} measurement using KPFM was used for the detecting of aluminium (Al) and silicon (Si) sintered layer on the rear side of mono-Si and mc-Si substrates. Presence of this layer causes the BSF effect. For mc-Si substrate measurement three regions of different crystallography were chosen from witch the Al layer was previously etched. U_{CPD} of the Al layer, mono-Si substrate with etched aluminium layer and p type mono-Si substrate was ascertained. It is possible to expect that the U_{CPD} value of the sintered layer lay in the interval between Al and Si U_{CPD}. Because U_{CPD} measurements were affected by the surface topography the average value of U_{CPD} obtained by analysis in the Gwyddion program is shown in tab. 2.

Based on U_{CPD} images in fig. 6 and its average values shown in tab. 2 it is possible to presume that sintered layers were formed in all cases. Variances between images and theirs corresponding average values of U_{CPD} were probably caused by a different quality of layers which was affected by the grains crystallography. Topography influence is presented only by highlighted edges similarities.

Type of Layer	U_{CPD} [V]		
	Scan 1	Scan 2	Scan 3
Aluminium	0,82	-	-
Monocrystalline silicon	0,17	-	-
Sintered layer on monocrystalline substrate	0,46	-	-
Sintered layer on multicrystalline substrate	0,44	0,36	0,32

Table 2: Overview of samples measured by KPFM



a) b) c) d)

Figure 6: Contact potential difference U_{CPD} of sintered layer measured on monocrystalline (a) and multicrystalline (b – d) substrate. Size of scanned area is 50 × 50 µm.

4. CONCLUSION

This work illustrates the using of atomic force microscopy and Kelvin probe force microscopy in the silicon solar cell production. The selected size of the scanned area gives a clear idea of the surface structure. Obtained informations can be used for the configuration and the control of etching process conditions. U_{CPD} values of Al-Si sintered layer, Al layer and *p* type Si were ascertained using KPFM. From these values it can be concluded that sintered Al-Si layer was formed with a different quality which depends on the substrate crystallographic orientation.

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