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SURFACE CONDITION OF GAAS SOLAR CELLS

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Abstract: This study is devoted to the description of GaAs solar cells topography and choice substitution of the method for surface study. It is in the attention because the surface condition can predefine the behavior of the heterojunction and efficiency of the device in common. The impact made to description of solar cells surface by atomic force microscopy and scanning electron microscopy. The sizes and shapes of surface morphology play an essential role in behavior and properties of materials in micro and nano-scale. The right choice of microcopy technique for morphology characterization is important for obtaining valuable data.

Keywords: Solar cells, topography, microscopy, fractal analysis

INTRODUCTION

For optoelectronic device fabrication it is necessary to study every layer at heterostructure preparation. Study [1] emphasizes that the quality of surfaces and interfaces is a key problem in solar cell manufacturing process.

Hence, efforts towards increasing of surface absorption within active layers, improving light scattering at the interfaces, reducing of losses, should include more detailed study of texture [1], [2].

Based on the research of Bruzzone et al [3] the place of characterization could be described by scheme (Figure 1) which reveals each step of the device preparation. Therefore, a combination of characterization methods allows gathering more information on the subject.

Surface texturing (roughness) is often used to minimize reflection and is important for solar cells. Performance of solar cells demands improvements [5]: only the texturing reduces a reflectance of silicon solar cells from 35% to 11% [6]. Demand of texturing layers causes a lot of studies in this field, both theoretical and experimental. Light losses are huge when the optical system comprises elements with high reflective indexes. Also measured photocurrent depends on texturation, and was theoretically and experimentally proved [7].

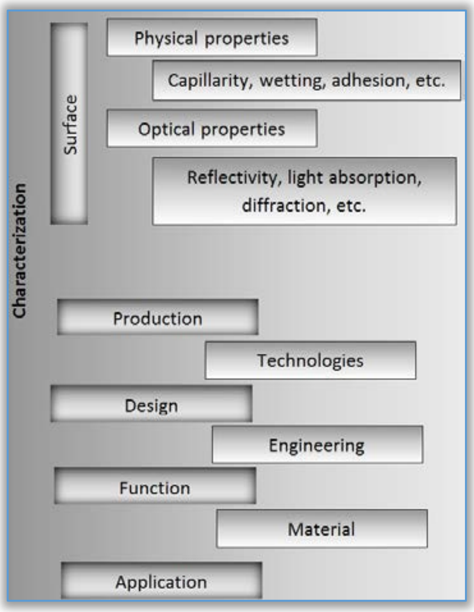

Figure 1: Presence of characterization in the surfaces-dependent devices [3]

There are a number of textural factors that influence solar cells performance: interface of different layers, grain bounders, point defects of production belong to these factors. Topography influence also the contact formation which was found and statistically described in [9] for silicon solar cells. Light trapping ability as noted in [9] could be improved by the prolonged effective path length of the scattered light and textured films could be applied to this purpose.

Textured substrate could be used in order to increase the light path within the absorber layer [11]. Surface texture has a critical influence to optical and electrical performance [11], [12]. There are a number of methods to create appropriate texturing such as: application of nanostructures, vapor–liquid–solid growth of structures, dry etching, lithography, chemical wet etching [12], variation of parameters in electrochemical films deposition [13].

Guangtao Yang et al [11] reported a deposition of solar cells on a modulated surface textures glass substrate and told that structures with smoother peaks show the highest performance due to lower amount of defects. Argon plasma-etching treatment makes smoother rough surface morphology what sometimes is necessary for high-performance solar cells [14].

The dependence of thin film solar cell performance on surface preparation and processing was studies in [15]. Even the substrate roughness for the solar cell junction preparation has a large influence on the cell properties [16].

Multi-crystalline silicon solar cells are cheaper and have good conversion efficiency [12]. But Zeman et al. [17] noted that a using of texture morphologies as diffraction grating is a good method to improve efficiency by light manipulation.

TOPOGRAPHY CHARACTERIZATION

» Significance of topography: hydrophoby and self-cleaning

Study of textured morphology is also stimulated by interest to improve the self-cleaning and hydrophobic properties and reduce influence of weather and in the same time absorb the maximum range of spectrum [18], [19].

Investigation of surface topography is a way to improve the self-cleaning properties of surface, which is a problem for GaAs solar cells. Here we present the comparison of topography appearance of natural hydrophobic surface (feather) and artificial surface of solar cell. The first is hydrophobic and the second is hydrophilic. The behavior of the surfaces to water could be characterized by angle between the site of a water drop and the surface (Figure 2).

Environmental erosion can change optical properties of the surface therefore the cleaning is so important. Some natural structures demonstrate such outstanding integrated optical and mechanical properties of surface. Due to the structure which is responsible for that perfect light absorptivity they used as template for solar cells by Wang Zhang et al [20].

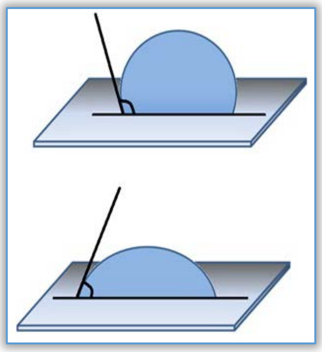

Figure 2: Top: hydrophobic surface (angle > 90°), bottom: hydrophilic surface (angle < 90°)

A variety of surface structures demonstrates hydrophobicity (Figure 3) and hence self-cleaning of the surface. Such structures are applicable in different fields due to connected with surface condition of optical quality and mechanical stability. The contact angle could be observed by eye. The surface of solar cell in figure 3 have smaller contact angle with the water drop and not as hydrophobic as natural structure.

Geometrical factors of surface morphology play a role in contact angle of the surface and liquid. The inspiration could be taken from nature. Both images of figure 3 represent optical structures but with different wettability. Such behavior depends on both material composition and structure. The structure in range of microns could be easily observed by optical microscopy. But it is necessary to use other types of microscopy such as SEM and AFM for studies with higher resolution.

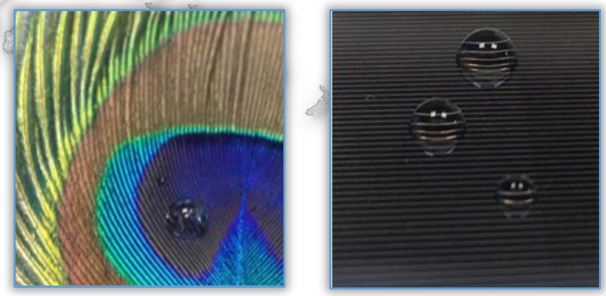

Figure 3: Left: Demonstration of hydrophobic surfaces in nature, right: GaAs solar cells with a drop of water

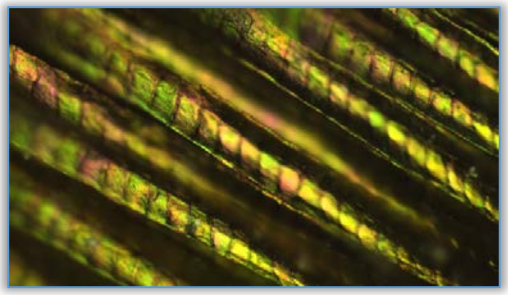

Figure 4: Optical microscopy image of the feather. Magnification: 20x.

Optical image shows that feather has a semiperiodical structure (Figure 4). The contact surface between the sample and water drop is small. It caused by the structure, and particularly by spaces full of air between the sample surface and water drop. A water drop touches the surface only in some places.

But image of the GaAs sample solar cell (even at five time large magnification) don't show presence of organized surface structuration (Figure 5). The area of contact with water drop of the GaAs solar cell surface is larger than for the feather surface. Besides difference of materials, the large difference exists between the topography of hydrophobic and hydrophilic surfaces.

Figure 5: Optical microscopy image of the GaAs surface. Magnification: 100x.

This is one of the examples why deeper study of topography is essential. A lot of properties and functional characteristics are defined by the appearance of the surface. And it is necessary to make a right choice of the microscopy technique to study the nano-topography of the samples.

Two types of microscopy, scanning electron microscopy (SEM) and atomic force microscopy (AFM) was used for evaluation of surface micro- and nano-geometry.

SEM allows studying large areas of the solar cells with considerable surface roughness (more than 10 µm) and AFM was carry out on a certain relatively smooth area but by truly 3D measurement. Actual probes methods are more comfortable for studying of solid materials surfaces.

» **Atomic force microscopy**

AFM is a 3D surface morphology technique that provides quantitative information about surface, and defines roughness of the surface, sizes of features [21].

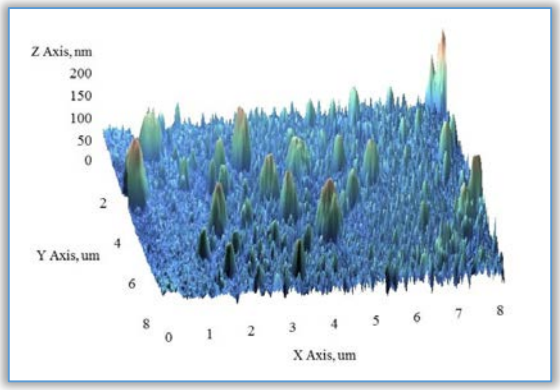

Figure 6: AFM 3D-image of GaAs solar cell

Numerical characterization of the morphology allows estimating the roughness. Even own software (we use Nova, NTMDT) provides a lot of possibilities of data processing. Being quite limited in range of heights, AFM allows precise measurements of surface nano-asperities in XYZ coordinates. The sizes of islands could be found by cross-section (Figure 7).

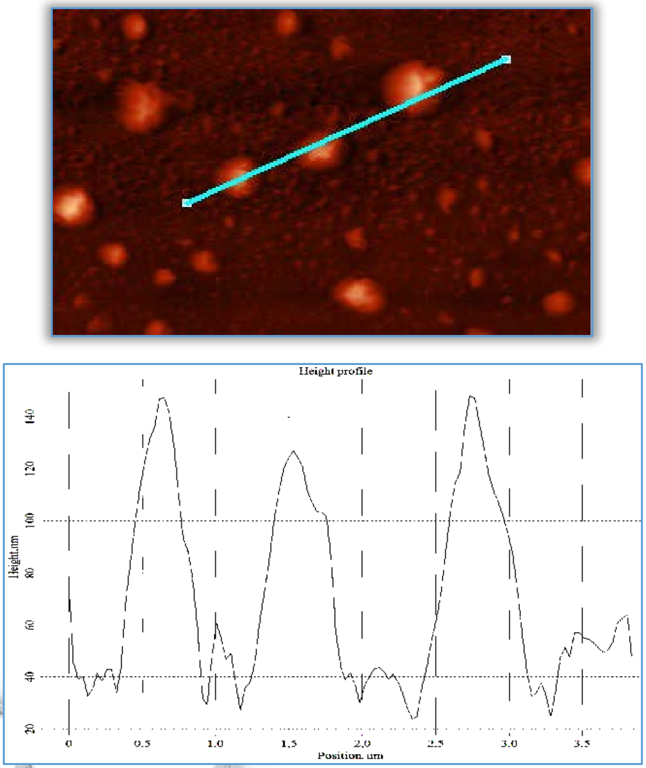

Figure 7: AFM image (left) and its: cross-section (right)

So, AFM gives quantitative data about the whole topography (Figure 7) and its local features (Figure 8). Qualitative data include the distribution of the values at the surface and quantitative their precise values.

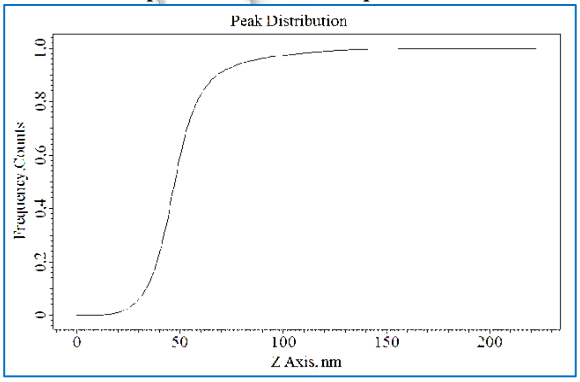

Figure 8: Distribution of peaks for the topography in figure 6

Figure 8 show that the topography has the large amount of peaks in the range from 50 to 200 nm. The surface is relatively smooth. The features are smaller than visible light wavelength.

Watershed segmentation is helpful when it is necessary to divide and to count the texture features. This is a really interesting method when surface elements are barely recognized, for example in the case where image quality is lacking.

This method receives its' name because of lines which divide topography elements. They look like the channels where water trickles down from the peaks of features.

But this method is not suitable for overlaid features or to extremely rough morphology. This method could be applied for both AFM and SEM images. Distribution of the islands by diameter after watershed segmentation is shown in figure 9.

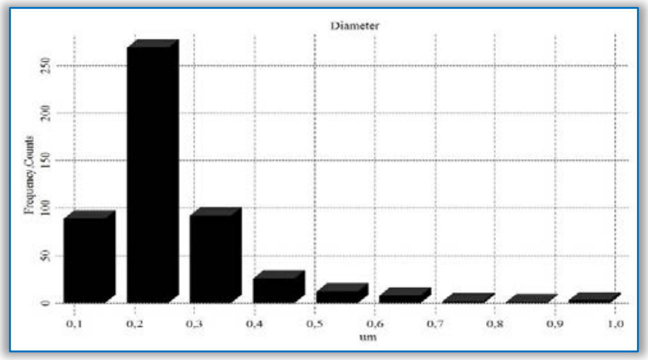

Figure 9: Distribution of the island amount by the diameter

The shape and size of topography features indicate the quality of the preparation process and defines further properties of the ready devices.

» **Scanning electron microscopy**

Because of AFM limitation, SEM is suitable for contact study (Figure 10). SEM imaging provides good quality information about contact quality, including sizes, presence of defects, cracks, etc. [21].

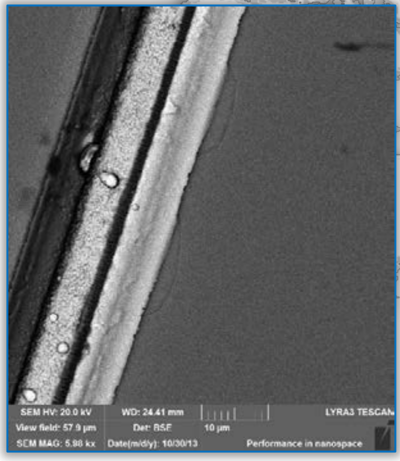

Figure 10: Metallic contacts to GaAs solar cell

Shadow effect due to metal contacts takes a part at solar cell performance and limits semiconductor absorption. The quality of energy conversion strongly depends on the total and local fractions. Metal contact design is still one of the methods for improving the cell efficiency. Optimization (choice of geometry) of both front and back solar cell contact design can help to achieve beneficial properties: maximize the current collection; minimize the series resistance due, etc.

» **Fractal analysis of the 3-D texture**

A fractal 3-D engineering surface exhibits topographical features that are independent of the measurement scale and is characterized by a spatial scale-invariance (statistical self-similarity, which takes place only in the restricted range of the spatial scales) [21-23].

The fractal dimension D (a non-integer value within the range $2 \leq D \leq 3$) is a quantitative parameter to globally estimate the 3-D fractal surface complexity [14, 24-28].

In this study, the fractal analysis was applied to the original AFM files using the cube counting method (derived directly from a definition of box-counting fractal dimension) with a linear interpolation type (the interpolated value in a point is calculated from the three vertices of the Delaunay triangulation triangle containing the point), which is described in detail in Ref. [29, 30].

The basic properties of the height values distribution of the surface samples (including its variance, skewness and kurtosis), computed according the Ref. [29] is shown in Table 1, for scanning square areas of 120 μm x 120 μm.

Table 1. The basic properties of the height values distribution (including its variance, skewness and kurtosis) of the surface samples, for scanning square areas of 120 μm x 120 μm.

The basic properties of the height values distribution of the GaAs surface samples	Values
Ra (Sa) [nm]	8.17
Rms (Sq) [nm]	12.12
Skew (Ssk) [-]	4.95
Kurtosis (Sku) [-]	104
Inclination θ [°]	0.0
Inclination φ [°]	-170

The fractal dimensions (D) with coefficients of correlation (R^2) determined by the cube counting method, based on the linear interpolation type, of the GaAs surface samples is $D = 2.15 \pm 0.01$.

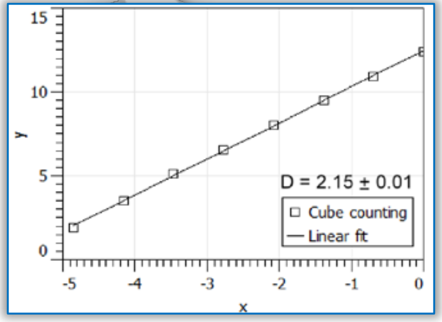

Figure 11: Fractal dimension of GaAs surface solar cell samples

For all analyzed cases (Table 1), the coefficients of correlation (R^2) associated with fractal dimensions D were greater than 0.9955 representing a good linear correlation. An (R^2) of 1.0 indicates that the regression line perfectly fits the data.

CONCLUSIONS

Both SEM and AFM types of microscopy are suitable for characterization of the solar cells. The elements of texture are well distinguished even without any special preparation of measured samples. These methods allow estimating the surface condition and amount of surface features, which can be caused by mechanical stress between layers of the solar cells. This affects electron mobility and diffusion length, band structure, surface passivation. It is possible to measure both quality and quantity data of surface by these well-known microscopy methods. Texture shows the measure of surface roughness. There are also numbers of data processing techniques for roughness estimation. And every method gives its own unique information about the surface.

Our results suggest that AFM, the statistical surface roughness parameters and fractal analysis may provide additional insight for characterization of the solar cells.

All these parameters can be included in a mathematical model to compute micro/nanotopography of the surfaces (surface texture) in describing surface contact and wear both theoretically and experimentally and could become essential in designing of new GaAs solar cells.

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Appendix

The basic properties of the height values distribution, including its variance, skewness and kurtosis, computed according the Ref. [29] is defined as follows:

- RMS value of the height irregularities: this quantity is computed from data variance.
- Ra value of the height irregularities: this quantity is similar to RMS value with the only difference in exponent (power) within the data variance sum. As for the RMS this exponent is q = 2, the Ra value is computed with exponent q = 1 and absolute values of the data (zero mean).
- Height distribution skewness: computed from 3rd central moment of data values.
- Height distribution kurtosis: computed from 4th central moment of data values.
- Mean inclination of facets in area: computed by averaging normalized facet direction vectors.
- Variation, which is calculated as the integral of the absolute value of the local gradient.

Declaration of interest: The authors claim to have no financial interest, either directly or indirectly, in the products or information listed in the article. The authors alone are responsible for the content and writing of the paper.

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