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Fractal Analysis of the 3-D surface Topography of GaAs Solar Cells

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Abstract. This article is devoted to study of Atomic Force Microscopy (AFM) images of solar cells based on gallium arsenide (GaAs). Mathematical processing of data involves obtaining additional information about topography. The analysis was carried out using AFM data for GaAs solar cells, before and after temperature treatment. The state of the surface affects the reflectivity, so the structuring of the surface is of particular interest. Optimized textures are needed to improve the optical properties of surfaces. Fractal analysis allows quantifying the condition of the morphology of the surface on the basis of AFM data.

Introduction

There are many factors affecting the performance of solar cells: the boundaries between different layers, grain boundaries and point defects arising in production processes [1, 2].

The efficiency of light capture can be improved by increasing the effective length of the scattered light path using specially textured films. Surfaces and interfaces are a key issue in the efficiency of solar cells. The texture of the surface is important for increasing surface absorption, improving light scattering at interfaces and reducing losses [3, 4]. The photocurrent also depends heavily on the texture. Topography affects the formation of contacts to solar cells.

We used commercially available solar cells for the experiment, because the most important results can be obtained at the intersection of the fields of science and development (Fig. 1).

Advanced microscopy techniques are used for qualitative and quantitative description of optoelectronic and thin films 3-D surface micromorphology [5-9]. Using modern approaches to evaluation, the results can influence both the design of new structures and the increase in the performance of existing optoelectronic devices [10-14].

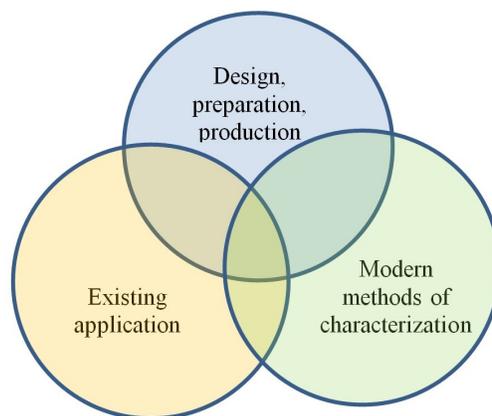


Figure 1. Interconnection of fields.

The topography of GaAs solar cells is smooth. However, AFM has sufficient resolution for studying their surface. The obtained AFM data represent an array of topographic data and provide quick access to valuable surface parameters [15].

Materials and Methods

The topography of the surface can also change during the work of the elements as a result of aging and degradation. We performed induced aging of GaAs solar cells by heating the up to 370 °C for 30 minutes and to 650 °C for 60 minutes.

Surface topography was studied before and after two annealing cycles (Fig. 2).

After first annealing process, the samples were still functional. The second heating to 650 °C demonstrates degradation of the cells and significant deterioration of electrical characteristics.

In this study, the fractal analysis was applied to the original AFM files using the box-counting method, with a linear interpolation type, which is described in detail in Ref. [16, 17].

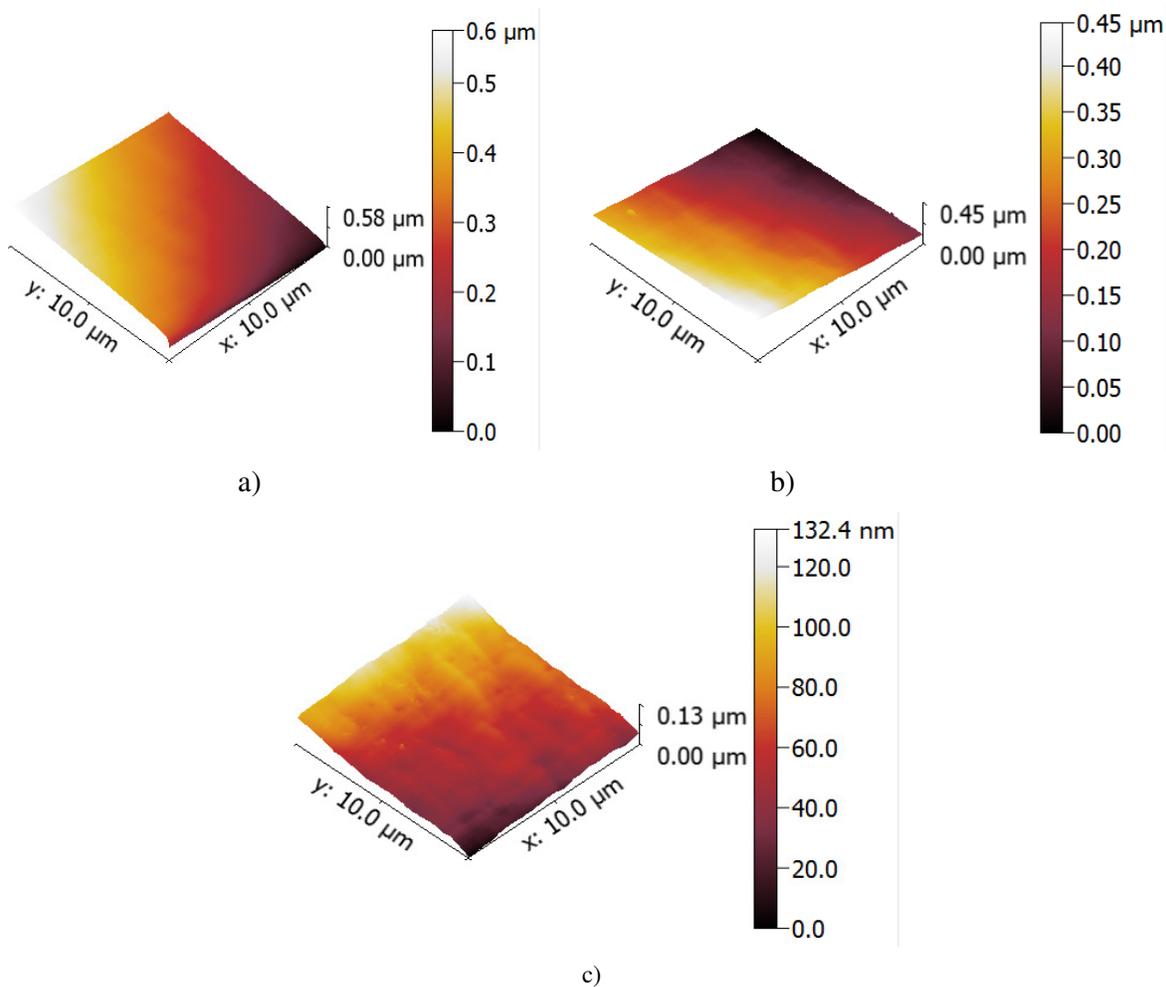


Figure 2. AFM 3D-image of GaAs solar cell:
a) without-annealing; b) 1st annealing at 370 °C; c) 2nd annealing at 650 °C.

Fractal Analysis of the 3-D Microstructure

The fractal dimensions (D) determined by the cube counting method, based on the linear interpolation type, of the GaAs surface samples are: a) without-annealing, $D = 2.02 \pm 0.01$ (Fig. 3a); b) 1st annealing at 370 °C, $D = 2.05 \pm 0.01$ (Fig. 3b); c) 2nd annealing at 650 °C, $D = 2.08 \pm 0.01$ (Fig. 3c);

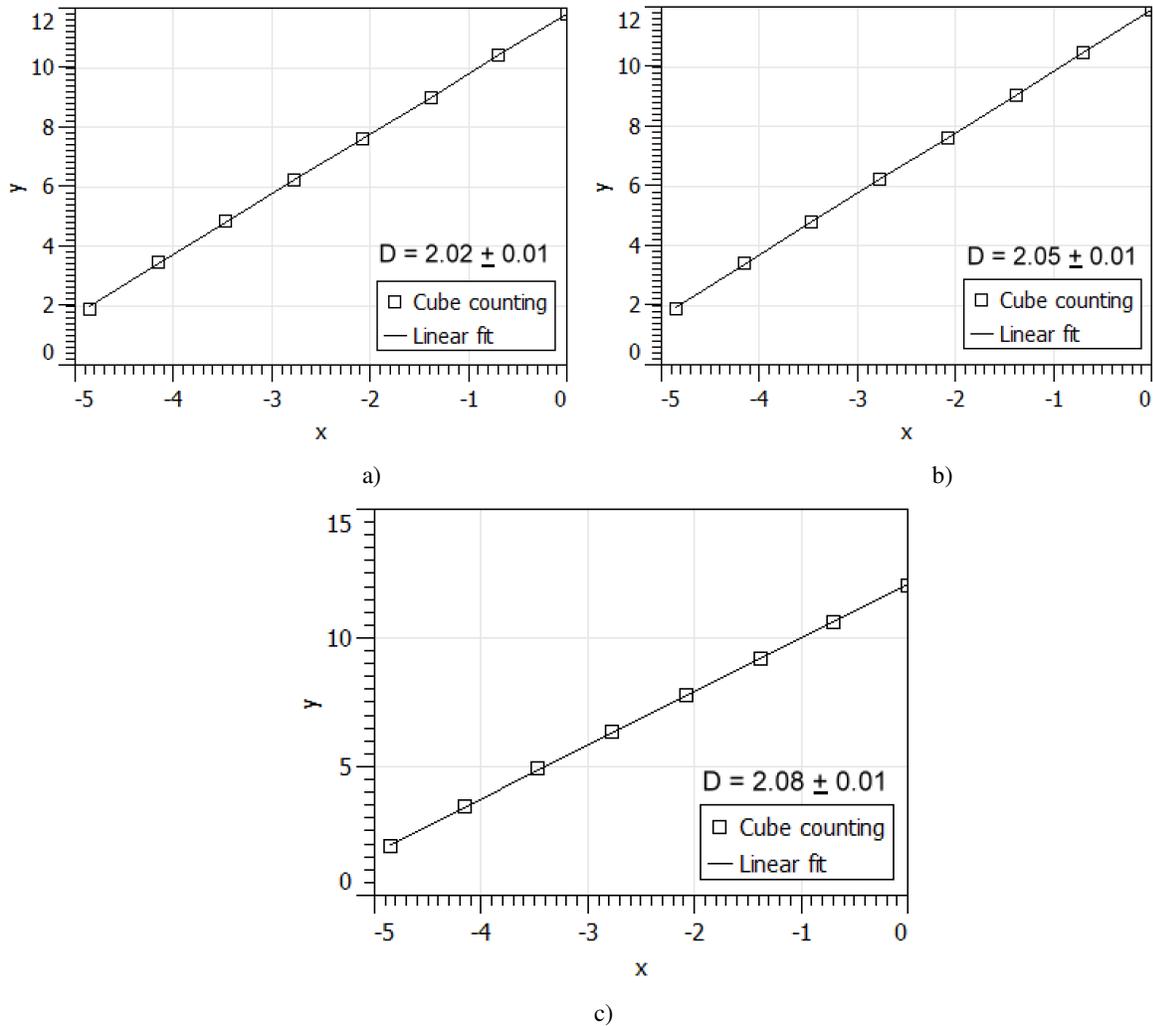


Figure 3. Fractal dimension of GaAs surface solar cell samples: a) without-annealing, $D = 2.02 \pm 0.01$; b) 1st annealing at 370 °C, $D = 2.05 \pm 0.01$; c) 2nd annealing at 650 °C, $D = 2.08 \pm 0.01$.

The basic properties of the height values distribution of the surface samples (including its variance, skewness and kurtosis), computed according the Ref. [8] is shown in Table 1, for scanning square areas of 10 μm x 10 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 10 μm x 10 μm .

The basic properties of the height values distribution of the GaAs solar cell surface samples	Values a) without-annealing	Values b) 1 st annealing at 370 °C	Values c) 2 nd annealing at 650 °C
Ra (Sa) [nm]	88.3	81.9	18.0
Rms (Sq) [nm]	108.8	96.9	22.0
Skew (Ssk) [-]	-0.125	0.0379	0.332
Kurtosis (Sku) [-]	-0.481	-0.882	-0.367
Inclination θ [°]	2.5	1.9	0.6
Inclination ϕ [°]	-51.8	18.8	-110.3

It can be observed that Ra (Sa), and Rms (Sq), are greater in samples obtained without-annealing than in samples obtained with annealing.

Summary

This work is devoted to the description of the topography of solar cells before and after the temperature treatment. The results show growth of fractal dimension with temperature of processing. This is important, because the surface state can predetermine the behavior and efficiency of the device. A detailed description of the morphology of solar cells on the basis of fractal analysis is presented quantitatively. The structure of the surface affects the characteristics of solar cells, including hydrophobic properties and self-cleaning surfaces, the transparency and reflecting properties of which are necessary for the design of solar panels.

Appendix

Statistical analysis was carried out with the software SPSS 14 for Windows (Chicago, Illinois, USA). One-way analysis of variance was applied for verification of results with Scheffé post-hoc tests. Statistically significant differences P are assumed to be 0.05 or less. The statistical parameters were expressed by Ra (average roughness), Rq (root-mean-square deviation), Ssk (skew), Sku (kurtosis), angles (θ, φ) (inclination).

In detail, these parameters have following meaning [8]:

- 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.

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