VĚDECKÉ SPISY VYSOKÉHO UČENÍ TECHNICKÉHO V BRNĚ

Edice PhD Thesis, sv. 797

ISSN 1213-4198

thesis

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Non-Destructive Local Diagnostics of Optoelectronic Devices

VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ
FAKULTA ELEKTROTECHNIKY
A KOMUNIKAČNÍCH TECHNOLOGIÍ
ÚSTAV FYZIKY

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NON-DESTRUCTIVE LOCAL DIAGNOSTICS OF OPTOELECTRONIC DEVICES

NEDESTRUKTIVNÍ LOKÁLNÍ DIAGNOSTIKA
OPTOELEKTRONICKÝCH SOUČÁSTEK

Zkrácená verze Ph.D. Thesis

Obor:	Fyzikální elektronika a nanotechnologie
Vedoucí práce:	prof. RNDr. Pavel Tománek, CSc.
Oponenti:	doc. Ing. Ladislav Pína, DrSc.
	RNDr. Emil Pinčík, CSc.
Datum obhajoby:	19. listopadu 2015

Keywords:
Local characterization, optoelectronics, material, silicon solar cells, aluminum nitride, silicon carbide, heterostructure, thin film, scanning probe microscopy, atomic force microscopy, scanning electron microscopy, image processing, statistical analysis, fractal analysis

Klíčová slova:
Lokální charakterizace, optoelektronika, materiál, křemíkový solární článek, safír, karbid křemíku, heterostruktura, tenká vrstva, skenovací sondová mikroskopie, AFM mikroskop, SEM, zpracování obrazu, statistická analýza, fraktálová analýza

Místo uložení:
Vědecké oddělení FEKT

ISBN 978-80-214-5307-4
ISSN 1213-4198

CONTENT

1 INTRODUCTION

1.1 SUBJECT OF STUDY

The subject of the thesis is nondestructive surface characterization of optoelectronic devices, both widespread commercial devices (solar cells) and just heterostructures (at the material preparation and properties investigation stage). The thesis differs from the previous studies in optoelectronics. The subject of the study was chosen in the following way:

- First, the samples, provided by producers of solar cells were studied by SPM and SEM. Solar cells were chosen as readily available specimens for measurements since their efficiency strongly depends on the quality of the surface, and industry demands continuous improvement. This study brings additional information about state-of-the-art photovoltaic devices.
- Then, heterostructure surfaces, prepared as prospective solar cell materials, were analyzed. The prepared structures were characterized at each step of fabrication: from substrate choice and processing to structure preparation. Stable materials with promising properties and proven potential are of great interest for modern optoelectronics.

The aim is to study problems of material surface condition by a nondestructive approach; therefore attention in this work is also given to an explanation of the choice of method for surface characterization. The metrology plays a role and is considered in terms of the description of the surface.

The most important results could are obtained at the intersection of the fields of science and development. SPM and SEM are used for qualitative and quantitative description of the optoelectronic structures. The results may influence both the design of new structures and enhance performance of existing optoelectronic devices.

The theoretical and experimental importance of the work is reflected in the interest of scientists working on problems of a similar nature: the reference list of this thesis reflects only small part of an enormous amount of studies in this field.

1.2 STATE OF THE ART

Most modern low-cost solar cells have only one p-n junction. Only the photons with higher or equal energy to the bandgap of the absorber can generate current. The use of multilayer elements can improve the spectral bandwidth of absorption. A combination of different materials with a variation in bandgap obviously will provide lower losses, since such elements work with a wider portion of the solar spectrum.

High energy photons are to be absorbed at the upper layers, so it is necessary to situate the subcells made from wide bandgap material on the top and other layers with lower bandgap towards the bottom of the cell. Obviously, the top material should be stable to extreme conditions and transparent to other part of the spectrum.

Design of high efficiency solar cells is important both for earth (autonomic electric stations, alternative energy sources) and space (ships, satellites) applications. Solar cells provide a considerable fraction of the energy for space vehicles. Solar cells for space applications demand a specific design due to the harsh conditions of space exploration.

The authors of [1] summarize that nanotechnology can improve solar cell quality by providing improvements in crystalline semiconductor III–V materials, polymer materials, and carbon-based nanostructures. Efficient energy conversion depends on the thermodynamic properties of photovoltaic materials and their device structures.

Silicon is currently the most abundantly used material for solar cell production. However, developing solar energy technologies requires new kinds of structured layers. A lot of factors should be considered in order to obtain high efficiency solar cells, such as the composition of the layers and the optical behavior of light at each layers' interface. Using the proper buffer materials is important. The high resistance multi-layer AlN/AlGaN/GaN is often used for Si-based devices, since a thin AlN protective layer provides low contact resistance between silicon and subsequent films [2].

Wurtzite structure semiconductor materials are promising for a wide range of optical devices (light-emitting devices, solar cells, microsensors, photocatalysts), due to their variety in crystal size, orientation and morphology [3]. Their stability at extreme conditions has attracted global attention to aluminum nitrate for the implementation of high-efficiency nitride photovoltaic devices. AlN is applicable not only to silicon, but also to copper-indium-gallium-selenide solar cells as a barrier to improve conversion efficiency [4].

The focus of reference [5] is solar selective absorbing coatings on the basis of titanium and aluminum nitride multilayer structures obtained by magnetron sputtering. According to [6] the quasi-solid-state dye-sensitized solar cell with 0.1wt% of AlN in gel polymer electrolyte exhibited high power-conversion efficiency. Reference [7] describes thin AlN buffer layers prepared on the n-type Si (111) wafers. It caused p-doping of the Si wafer by Al in-diffusion. On top of the AlN buffer is situated an n-type GaN layer. Thus, a pn-junction occurs with low lattice mismatch. The authors of reference [8] discuss thin layers of hydrogenated aluminum nitride as a combined anti-reflective coating and passivation layer in n-type cells. For photovoltaics, it could be an alternative to silicon oxide, silicon nitride and aluminum oxide.

1.3 OBJECTIVES OF DISSERTATION

The study is focused on the local micro- and nano-meter scale optical and electronic characterization of optoelectronic materials and structures, including wide-bandgap semiconductor films for optoelectronics. All contributions to this emerging field are original due to the cutting edge nature of the technology.

The development of thin films for optoelectronic devices presents challenges of both fundamental and empiric character. For instance, the problem of contacts with systems of several materials, e.g. point imperfections, and grain boundaries. All these affect diffusion of charges, segregation, recombination, and current transfer.

These problems should be investigated in combination with the parameters of complete devices, including the effects of other materials and their local characteristics. During the optoelectronics element formation, it is necessary to study the quality of each layer after every step of preparation in order to fully understand the structure, chemical composition, optical and electrical properties, and their potential influence on the completed device.

The quality of prepared structures studied here is evaluated by scanning probe microscopy and scanning electron microscopy.

Optical properties of both Al_2O_3 and AlN are well studied. Based on the literature survey mentioned previously, its exceptional properties could find applications in solar cells. But it is still a challenge to prepare AlN films with the required quality and properties. Texture of the material surface is one indicator of film quality, and will influence efficiency and reliability of the heterostructures. For this reason, the work reported here is oriented toward the description of surface morphology using modern surface characterization systems. The goal of the work is not only to reveal the basic processes of thin films morphology and control, but also to provide perspectives on new materials implementation and their possible application in optoelectronics.

The choice and preparation of the substrate for individual subcells, as well as the deposition and processing techniques used, are important steps that need to be optimized in solar cell production.

The objectives of this study include investigation of:

1. texture and morphology of solar cell surface layers,
2. new methods for morphological characterization,
3. explanations for the choice of materials used in heterostructure preparation,
4. the influence of preparation condition on thin film morphology,
5. a statistical description of morphology characterization.

2 SELECTED METHODS OF INVESTIGATION

2.1 SCANNING ELECTRON MICROSCOPY

Scanning Electron Microscopy (SEM) measurements are in the range of micro- and nano-metrology. SEM has some advantages over AFM when the height and depth of of morphological features exceeds the limited range of an AFM. There are a number of devices which need to be characterized at both milli-, micro- and nano-scale; while their components are designed in milli and micro-scale, nanoscaled morphology influences strongly their characteristics and lifetime (e.g. optoelectronic, microelectromechanical, microoptoelectromechanical devices) [9]. In some cases [11] AFM seems to be more reliable for fine profile characterization.

Beam parameters define the final resolution and depth of electron interaction with surfaces [10]. In comparison to SPM, SEM has quite a large depth of focus. SEM has become a widely used tool for imaging and manipulating nanostructures. SEM applications are expanded from nanoscience laboratories to many fields of industry where micro- and nano-scale control is essential. A focused ion beam, which is quite often combined with SEM, is also of great interest in the semiconductor and materials science fields [12]. There are many factors that must be taken into account for obtaining good images with an SEM: proper sample preparation, elimination of noise and undesired effects (spherical aberration, chromatic aberration, diffraction, astigmatism [10]), etc.

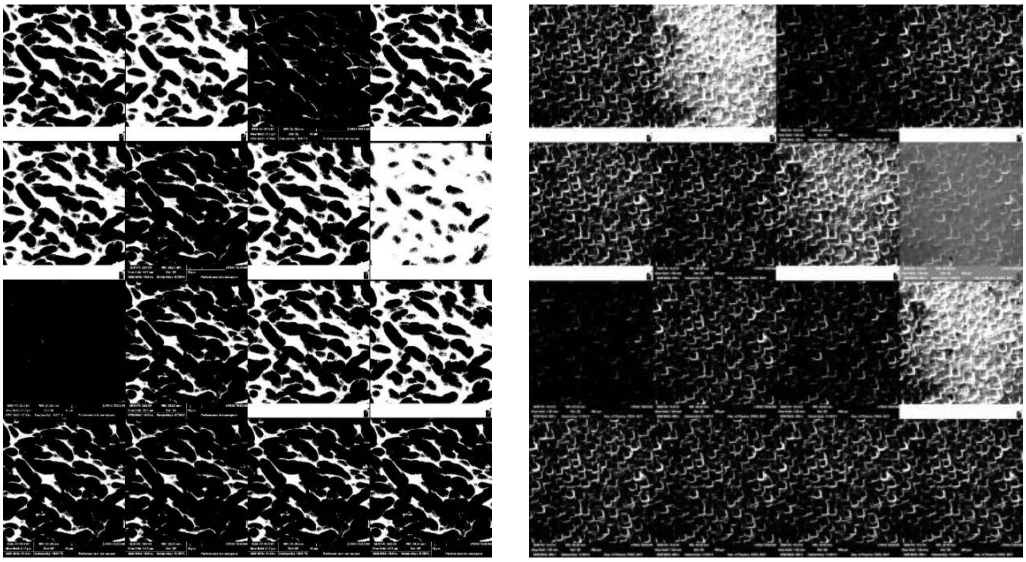
2.2 SCANNING PROBE MICROSCOPY

Scanning probe microscopy (SPM) has better resolution then traditional instruments, such as a profilometer or optical microscope [13], and can be adapted to bare and untreated surfaces without complicated sample preparations. The results reported in reference [14] demonstrate SPM as a powerful tool in III–V semiconductor device structure metrology. SPM is one of the best modern methods for studying morphology and local properties with high resolution. The method has progressed from a strange and unusual scientific tool to widespread way to study surfaces in many applications. Progress in SPM has enabled new methods in nanotechnology for structure characterization. Since AFM gives both the possibility to watch atomic structure of the surface and global information about whole surface, precise information about surface details could be extracted with high resolution. Another advantage is the sample will not be damaged by exposure to a high energy beam, as could be happen in scanning electron or ion methods. There many classes and modifications of SPM, as many scanning modes and methods have been invented. Nevertheless, there is still a large unstudied potential for the use of SPM for investigation of defects. Most importantly, AFM measurements allow evaluation of surface roughness parameters with a high degree of precision.

2.3 PROCESSING OF THE TOPOGRAPHIC IMAGES

Statistical processing of AFM images provides statistical information about topography. An analysis was carried out using our AFM data for AlN films in cooperation with Talu´s group. Fractal analysis allows to quantify morphological variance, and identify the links between the fractal dimension and the physical processes. Edges of grains influences recombination, current, and diffusion, and should be studied in combination with local characteristics. Slopes, holes, heights, valleys, scratches, and contact areas influence the light wave behavior at the near surface area. Such structures traps light waves and change the direction of their propagation. AFM and SEM images can be thresholded to get information for evaluation of discrete areas with certain levels within a given range. An example which was carried out for both a polycrystalline and monocrystalline solar cell is shown in Fig. 2.1. ImageJ software [15] was used for evaluating geometrical elements of the topography.

In the case of solar cells, statistical parameters such the volume fracture parameter give a measure of materiál properties. By these well known microscopy methods it is possible to obtain both qualitative and quantitative measures of a surface. Qualitative data include the distribution of the values at the surface and quantitative their precise values. Texture is a measure of surface roughness. 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.



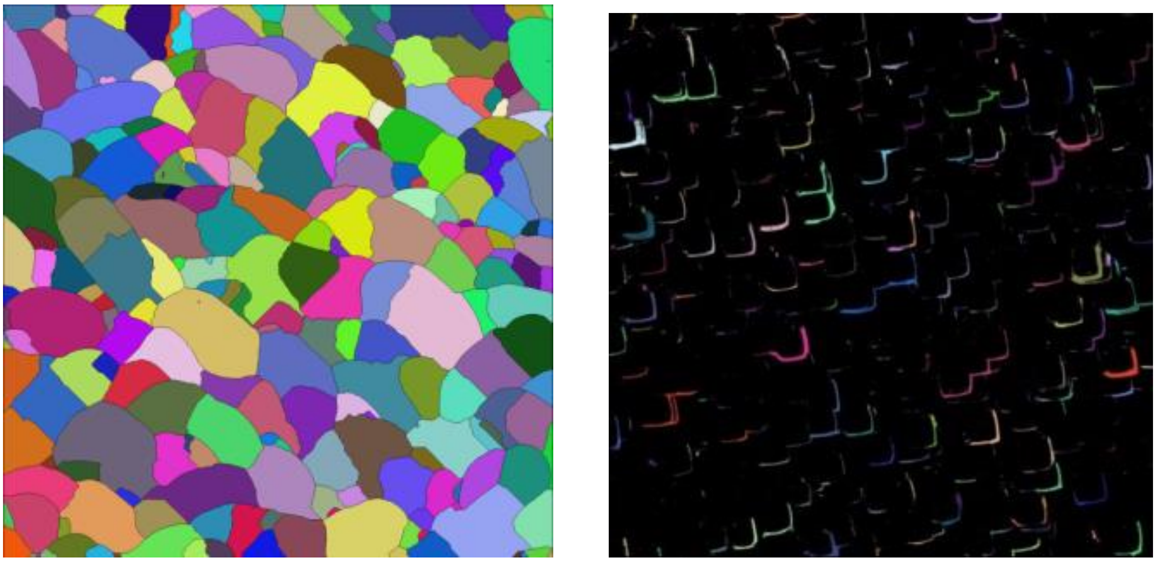
a) b)

Figure 2.1. a) Polycrystalline and b) monocrystalline image thresholding, demonstrating geometrical features of the topography.

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 overlayed features or to extremely rough morphology. A comparison of wave characteristics of light with moving water waves allows a good description of surface topography. As in the case of water waves, interference, reflection and transmission depend on the feature sizes of the sample.

The morphology of grains (roundness and sphericity) is important in textural characterization. Watershed segmentation (Fig. 2.2) was applied here to grain boundary detection in the texture of the solar cells. This helps to carry out statistical analysis and optical texture determination. A large fraction of trapped light and charges lay inside separated phases and defects in morphology.

These figures show organization of silicon graines in the material The shape of grain borders is similar in monorcristalline solar cell (Fig. 2.2 b) and is quite various in polycrystalline sollar cell (Fig. 2.2. a)



a b

Figure 2.2. Watershed segmentation of the surface topography of a) polycrystalline and b) monocrystalline solar cells.

These processing methods are conducive to the realization of better morphology. The choice of method should be adapted to the specifics of the sample. The right choice of devices, methods and modes for a given field of science is important for measurement results.

3 EXPERIMENTAL RESULTS

3.1 TOPOGRAPHY CHARACTERIZATION

In the following experiments we have used two types of microscopy (SEM and AFM) for evaluation and measurement of substrates, thin films and solar cell surfaces micro-geometry. SEM allowed to study large areas of the solar cells with considerable surface roughness (more than 10μm) and AFM was carried out on relatively smooth areas, but is truly 3D measurement. Currently, probe methods are more applicable for studying solid materials surfaces. SPM is a 3D surface morphology technique that provides quantitative information about surfaces, and characterizes roughness of the surface, and sizes of morphological features, such as grains. Numerical evaluation of the morphology allows statistical estimates of surface roughness.

3.1.1 SEM and AFM of polycrystalline solar cells

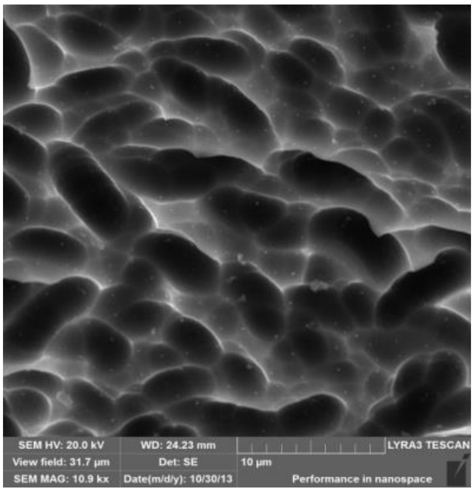
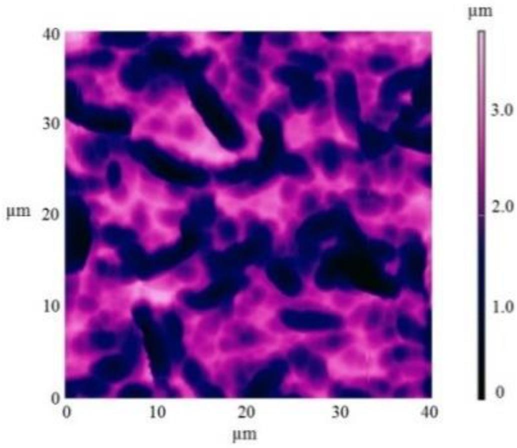
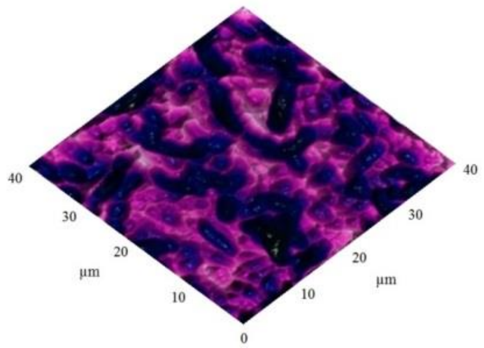


Figure 3.1. SEM of polycrystalline solar cell.

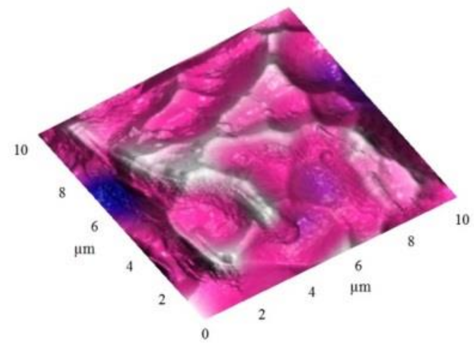
Multicrystalline solar cell performance depends on the types of grain boundaries present, as some of them reduce the cells efficiency. Deflections in surface morphology could be caused by mechanical stress between solar cell layers. This stress affects electron mobility and diffusion length, band structure, and surface passivation. Both SEM (Fig. 3.1) and AFM (Fig. 3.2) types of microscopy are suitable for characterization of polycrystalline solar cells, the elements of texture are well distinguished even without any special preparation of the sample.



a)



b)



c)

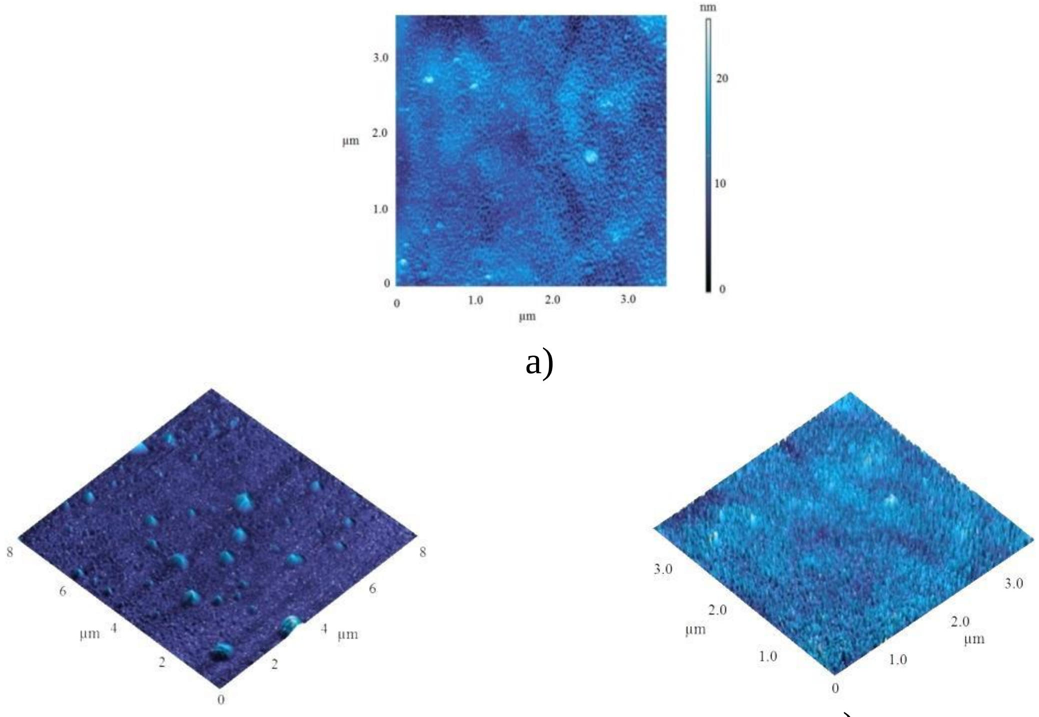
Figure 3.2. AFM of polycrystalline solar cell: a) 2D image, b) 3D image, c) 3D image of smaller area.

Figures 3.2 a-c show topography of polycristalline solar cell. The scale at figure 3.5 a shows real values of the highs and depths of the surface features. These features are presented with different magnification in figures 3.2 b and 3.2 c. They are differently oriented silicon graines, which also contain impruties and defects.

3.1.2 AFM of GaAs solar cells

The sample of GaAs cells exhibited smoother topography. For this reason the AFM, which has higher magnification, was suitable for scanning the surface (Fig. 3.3). Furthermore, in this case it was quite useful to apply semi-contact error mode for better perception of the surface features (Fig. 3.4). The measured AFM data generates an array (image) of the investigated topographic data and allows fast access to valuable data.

Figures 3.3 a-c show topography of commersionaly available solar cell on the basis of GaAs. The high of surface featrures is about 25-30 nm (Fig. 3.3 a). Figures 3.3 b, c present topography of different scan areas (8x8) um and (3.5x3.5) um and correspondingly. Decreasing of scan area allows obtaining of higher resolution and makes visible smaller features of the surface.



a)

b)

c)

Figure 3.3. AFM of GaAs solar cell: a) 2D image, b) 3D image, c) 3D image of smaller area

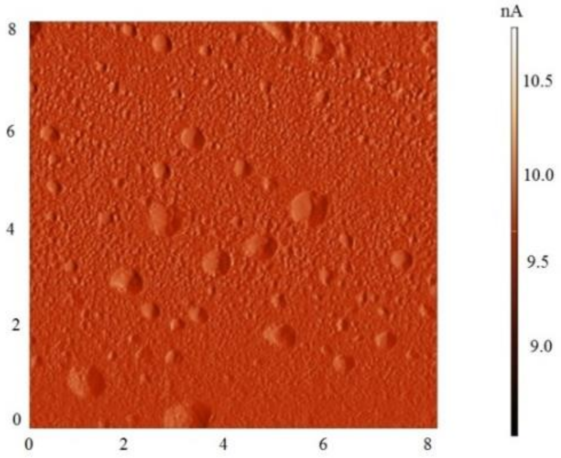


Figure 3.4. Semi-contact error mode image of GaAs solar cell

3.2 LOCAL TOPOGRAPHY OF OPTOELECTRONIC SUBSTRATES PREPARED BY DRY PLASMA ETCHING PROCESS

Generally used chemical wet etching is an isotropic etching and selective grain-boundary etching, but it seems to be inappropriate for preparation of thin film structures. Here a dry etching is a more desirable method. Dry etching means the removal of material from a rough surface by bombardment of ions resulting in a reproducible, uniform smooth surface (Fig.3.5). Simple sputtering is non-selective elimination of surface atoms due to plasma-induced non-reactive gas ions which vertically impinge on the surface of the substrate without any method to control the etch print. The anisotropy is a typical quantity of importance for dry etching.

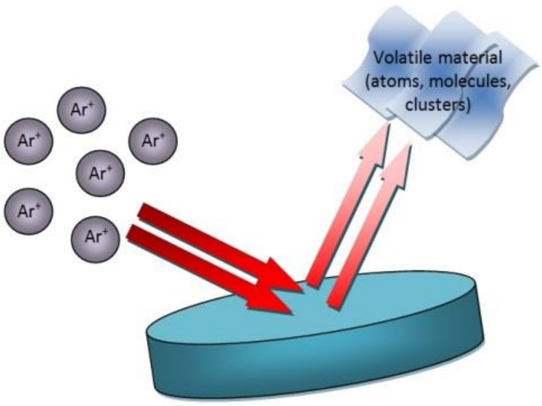


Figure 3.5. Dry plasma etching of the surface.

A choice of etching processing depends on the nature of the material and the required characteristics of the treated surface. Chemical etching provides removal of material from all directions, while physical etching allows precise size control of the processing area. As opposed to chemical etching the physical treatment does not leave the products of the reaction at the surface. There are a number of physical etching techniques useful in semiconductor technologies.

The well etched surface should be characterized by an appropriate profile: reduction of polishing defects, impurities and defects. Nevertheless it is necessary to reckon with some surface changing under the influence of ionized atoms of noble gas. Plasma etching is applicable in the case of materials where overcoming a strong bond energy between the component atoms is necessary.

Shape, structure and size of topographic features are a significant consideration for optoelectronic semiconductor structure design. Some roughness of wafer morphologies could be observed because of damage produced by the ion bombardments with excessive energy, but it provides both more flexibility because of anisotropy of the process and better reproducibility of the results.

The quality of substrate is very important for optical heterostructure preparation. It should be smooth and clean. It has to be sufficiently electrically, thermally and mechanically stable. Composition and morphology should be suitable for the application. Defective substrates lead to heterostructure properties variation. For optoelectronic devices it may lead to local heating and further damage.

Plasma etching is possible either by physical sputtering or by etching of chemical reagents. In order to have purely physical etching argon plasma was used. The experiment was carried out at argon atmosphere at pressure $3 \div 4 \cdot 10^{-2}$ Pa for 10 min. The substrates were initially prepared by ultrasonic cleaning. The substrates of SiC and Al_2O_3 were processed by discharge rate 150 mA in the ion source and voltage varying from 3 kV up to 6 kV. Since these materials have a relatively high resistance, a radio frequency field was applied. The substrates were initially prepared by ultrasonic cleaning.

The tilt angle between etched substrate and defocused beam of argon ions is a very important parameter of investigation because it also makes differences in the process results.

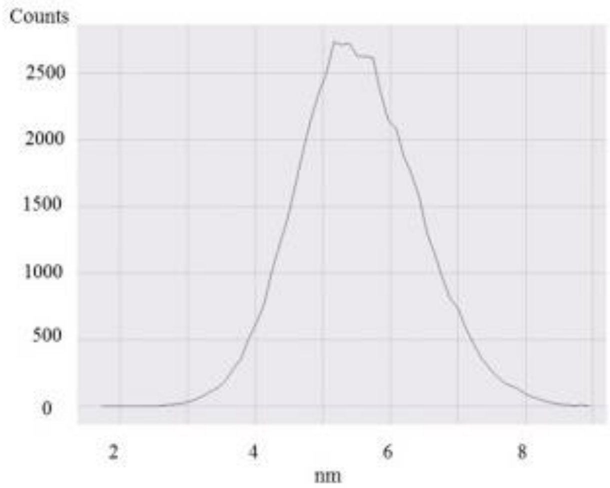
Light interference is a useful and important tool for surface characterization. The Linnik interferometer is easy to operate and allows measuring of topography imperfections (width and depth of holes, scratches, etc.) with accuracy comparable to the wavelength. In order to use this method a part of the sample was isolated from plasma by shield. As a result of interferometric measurement, it was found that the maximum of etching rate is at the 40^o tilt. For the measurement we used this quantity.

SiC wafer etched with 20° slope were used for demonstration of morphology behavior during the etching. The AFM data of a surface is a complex representation for morphology characterization. The results show the correlation length increasing with increasing potential above 3 kV. This is caused by an increasing characteristic distance, after which the correlation is lost between the topographic features.

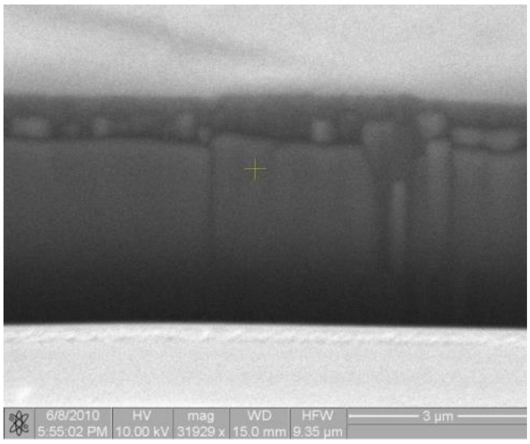
Processed substrates were studied by interferometry to define the etch depth, and by atomic force microscopy to study the topography and statistical analysis of surface roughness. The interferometry reveals the dependence of etch rate on the angle between the substrates and defocused beam of argon ions. It is also shown in select small scale images that the surface damage occurs after the substrate treatment. But the more common large area surface topography indicates a decreasing roughness. In the case of stable materials, physical etching is a good alternative to chemical etching: it provides uniformity, reproducibility and could be more suitable in comparison to wet etching.

3.3 PREPARATION OF THIN FILMS BY MAGNETRON SPUTTERING

One of the most important parameters of the deposition process is the temperature of the deposited films. Surface temperature is connected to adhesion strength, surface structure, and level of residual coating stress. By changing the deposition surface temperature, it is possible to change the structure of films and thus their mechanical and electro-physical properties. Adhesive strength increases with the temperature growth.The morphology of the deposited layers was examined by AFM and SEM.



a)



b)

c)

Figure 3.6. a) Height histogram for the AlN samples morphology obtained at 1500K and b) SEM image of the aluminum nitride layer on sapphire substrate in cross-section.

This measurement shows the occurrence of AlN film on the Al_2O_3 substrate. It means that the typical AlN growth occured. There are crystalline columnar grains of AlN there in the image of cross-section analysis image. They have flat tops and not sharp shown faceting of the surface.

The result is an experimental method for better fabrication of AlN thin films. Their surface morphologies obtained from AFM images were subjected to fractal analysis to quantitatively investigate their structural properties. In addition, the fractal nature of the AlN thin films real surface was investigated and the fractal dimensions can be used as a quantitative factor to estimate the of degree of fractality and to understand their 3D roughness. The presented results show that fractal dimensions include important surface topography information and can be used to investigate the AlN thin film surfaces. The results suggest that AlN thin film surface morphology gets textured with an increase in temperature of the Al2O3 substrate, and can be tailored to feature particular morphologies.

4 CONCLUSION

Current optoelectronic technologies demand a detailed analysis at the nanoscale level. In spite of a long history of research, surface investigations are still one of the most important fields to study. This is explained by the continuously decreasing size and scale of devices.

It is possible to note the following fields of this thesis contribution:

1. Measurements in micro- and nano-scale (survey and argumentation of SEM and AFM application in optoelecronics).

2. Solar cells study (review and description of the morphology impact to improving the quality and efficiency of solar cells).

3. Materials for optoelectronics (study and choice of process parameters for heterostructures preparation).

The important results of this study are:

1) Substantiation of the necessity of coating, buffer and active layers using wide band gap semiconductors especially in space conditions.

It transmits the wide range of the solar spectrum (above UV) and can be used as active layer for UV radiation. It explains the remaining AlN solar cell development in significant focus. My contribution in this part is the analysis of the studies concerned the topic of dissertation, definition of problems and subjections of its solution.

2) Substantiation of the applications of AFM and SEM for precision metrology.

The personal contribution is AFM and SEM measurements of the samples, processing of images and preparation of papers.

3) Comparison of SEM and AFM imaging of commercially available solar cell morphology and possibilities to provide not only average, but precise local data processing.

I asked some companies to provide me with samples of the commercial solar cells. Some of them kindly helped me and sent the samples. I performed the microscopic measurements and analysis of results to show the importance of the such kinds of complete device investigation.

4) Dependence of surface appearence on technological processes of heterostructures preparation.

The main attention is given to the topography of substrates and prepared films since it is closely connected to optical reflection, transmission, scattering. All experiments were carried out by myself (measurements) or with my direct participation (samples preparation).

5) Processing of the topography data.

My aim was to provide explanation of the fractal and statistical analysis made in collaboration with Prof. Talu and explain the connection between parameters.

The scientists which took part in this work are presented as co-authors of the articles. The results were published in articles listed in Appendix 1, also they were presented and discussed in national and international conferences. There are three citations of author in IF journals.

A large amount of references were used to prove and substitute the choice of methods and interpretation of results. The count of the studies in this field confirms the interest of scientists in the characterization and design methods for optoelectronics. In spite of the modern character of this work it has already made a lot of successful attempts in the field of preparation of prospective materials for optoelectronics, as well as in diagnostic of the optoelectronics devices.

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A1. DALLAEVA, D. S., BILALOV, B. A., GITIKCHIEV, M. A., KARDASHOVA, G. D., SAFARALIEV, G. K., TOMANEK, P., SKARVADA, P., SMITH, S., Structural properties of Al_2O_3/AlN thin film prepared by magnetron sputtering of Al in HF-activated nitrogen plasma. *Thin Solid Films*. 2012, vol. 526. p. 92-96. WOS:000313703200015. **IF 1.867**

A2. DALLAEVA, D., TALU, S., STACH, S., SKARVADA, P., TOMANEK, P., GRMELA, L. AFM imaging and fractal analysis of surface roughness of AIN epilayers on sapphire substrates. *Applied Surface Science*. 2014, vol. 312, p. 81-86, WOS: 000339998700014.

IF 2.538

A3. STACH, S., DALLAEVA, D., TALU, S., KASPAR, P., TOMÁNEK, P., GIOVANZANA, S., GRMELA, L. Morphological features in aluminum nitride epilayers prepared by magnetron sputtering. *Materials Science-Poland*. 2015, vol. 33(1), p. 175-184. ISSN: 0137- 1339. **IF 0.327**

A4. ŠKARVADA, P., TOMÁNEK, P., KOKTAVY, P.; MACKU, R., SICNER, J., VONDRA, M., DALLAEVA, D., SMITH, S., GRMELA, L., A variety of microstructural defects in crystalline silicon solar cells. *Applied Surface Science*, 2014, vol. 312, p. 50-56, WOS: 000339998700009. **IF 2.538**

7 PROFESSIONAL CV

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Languages: Native Russian, Fluent English, Middle level Czech

EDUCATION AND QUALIFICATION:

Dagestan State University, Machachkala, Russian Federation

- Bachelor “Electronics and microelectronics” (2004-2008),

Topic: Ohmic contact to silicon carbide.

- Master “Electronics and microelectronics” (2008-2010),

Topic: Study of morphology and structure of SiC and AlN layers by AFM and X-ray diffractometry.

Dagestan State University, Machachkala, Russian Federation

- Postgraduate study (2010-2014 unfinished)

Brno University of Technology, Brno, Czech Republic

- Doctoral study (2011-2015)

Field: Physical Electronics and Nanotechnology.
Topic: Local investigation of optoelectronic devices.

EMPLOYMENT HISTORY:

- Dagestan State University (www.dsu.ru) laboratory assistant (2009-2011)
- Dagestan State Technical University (www.dstu.ru) - Research center “Nanotechnology and microelectronics” (engineer, research assistant for 3 years). (2008-2011)
- Brno University of Technology, Brno, Czech Republic (from 2012 till now).
    - European Centre of Excellence CEITEC CZ.1.05/1.1.00/02.0068 (form 2014 till now)
    - Sensor, Information and Communication Systems SIX CZ.1.05/2.1.00/03.0072 (form 2013 till now)
    - Visegrad fund scholarship (2014-2015)
- FEI, Brno, Czech Republic (from 2014 till now) intern (application engineer).

PROFESSIONAL PRACTICE, INTERSHIPS, SOLVED SCIENTIFIC PROJECTS:

Skills: AFM, SNOM measurements, thin films preparation

Participation at Research grants of Federal task program in Czech Republic:

1. Centrum senzorických, informačních a komunikačních systémů - Sensor, Information and Communication Systems SIX **CZ.1.05/2.1.00/03.0072**
2. MŠMT ČR – KONTAKT LH11060 – Studium lokálních elektronických a optických charakteristik solárních článků (2011-2014).

8 ABSTRACT

To obtain novel materials for emerging optoelectronic devices, deeper insight into their structure is required. To achieve this, the development and application of new diagnostic methods is necessary.

To contribute to these goals, this dissertation thesis is concerned with local diagnostics, including non-destructive mechanical, electrical and optical techniques for examining the surface of optoelectronic devices and materials. These techniques allows us to understand and improve the overall efficiency and reliability of optoelectronic device structures, which are generally degraded by defects, absorption, internal reflection and other losses.

The main effort of the dissertation work is focused on the study of degradation phenomena, which are most often caused by both global and local heating, resulting in increased diffusion of ions and vacancies in the materials of interest.

From a variety of optoelectronic devices, we have chosen two representative devices: a) solar cells - a large p-n junction device, and b) thin films - substrates for micro optoelectronic devices.

In both cases we provide their detailed surface characterization. For the solar cells, scanning probe microscopy was chosen as the principal tool for non-destructive characterization of surface properties. This method is described, and both positive and negative aspects of the methods used are explained on the basis of literature review and our own experiments. An opinion on the use of probe microscopy applications to study solar cells is given.

For the thin films, two interesting, from the stability point of view, materials were chosen as candidates for heterostructure preparation: sapphire and silicon carbide. The obtained data and image analysis showed a correlation between surface parameters and growth conditions for the heterostructures studied for optoelectronic applications.

The thesis substantiates using these prospective materials to improve optoelectronic device performance, stability and reliability.

ABSTRAKT

Chceme-li využít nové materiály pro nová optoelektronická zařízení, potřebujeme hlouběji nahlédnout do jejich struktury. K tomu, abychom toho dosáhli, je však nutný vývoj a aplikace přesnějších diagnostických metod. Předložená disertační práce, jako můj příspěvek k částečnému dosažení tohoto cíle, se zabývá metodami lokální diagnostiky povrchu optoelektronických zařízení a jejich materiálů, většinou za využití nedestruktivních mechanických, elektrických a optických technik. Tyto techniky umožňují jednak pochopit podstatu a jednak zlepšit celkovou účinnost a spolehlivost optoelektronických struktur, které jsou obecně degradovány přítomností malých defektů, na nichž dochází k absorpci světla, vnitřnímu odrazu a dalším ztrátovým mechanismům. Hlavní úsilí disertační práce je zaměřeno na studium degradačních jevů, které jsou nejčastěji způsobeny celkovým i lokálním ohřevem, což vede ke zvýšené difúze iontů a vakancí v daných materiálech. Z množství optoelektronických zařízení, jsem zvolila dva reprezentaty:

a) křemíkové solární články – součástky s velkým pn přechodem a

b) tenké vrstvy – substráty pro mikro optoelektronická zařízení.

V obou případech jsem provedla jejich detailní povrchovou charakterizaci. U solárních článků jsem použila sondovou mikroskopii jako hlavní nástroj pro nedestruktivní charakterizaci povrchových vlastností. Tyto metody jsou v práci popsány, a jejich pozitivní i negativní aspekty jsou vysvětleny na základě rešerše literatury a našich vlastních experimentů. Je také uvedeno stanovisko k použití sondy mikroskopických aplikací pro studium solárních článků. V případě tenkých vrstev jsem zvolila dva, z hlediska stability, zajímavé materiály, které jsou vhodnými kandidáty pro přípravu heterostruktury: safír a karbid křemíku. Ze získaných dat a analýzy obrazu jsem našla korelaci mezi povrchovými parametry a podmínkami růstu heterostruktur studovaných pro optoelektronické aplikace. Práce zdůvodňuje používání těchto perspektivních materiálů pro zlepšení účinnosti, stability a spolehlivosti optoelektronických zařízení.