BRNO UNIVERSITY OF TECHNOLOGY
VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ

FACULTY OF ELECTRICAL ENGINEERING AND COMMUNICATION
FAKULTA ELEKTROTECHNIKY A KOMUNIKAČNÍCH TECHNOLOGIÍ

DEPARTMENT OF PHYSICS
ÚSTAV FYZIKY

DEGRADATION OF GAAS SOLAR CELLS
DEGRADACE SOLÁRNÍCH ČLÁNKŮ NA BÁZI GAAS

SHORT VERSION OF DOCTORAL THESIS
ZKRÁCENÁ VERZE DIZERTAČNÍ PRÁCE

AUTHOR Ing. Nikola Papež
AUTOR PRÁCE

ADVISOR Mgr. Dinara Sobola, Ph.D.
VEDOUCÍ PRÁCE

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Introduction

Solar cells, which are expected to be highly efficient under challenging conditions, are much more demanding than conventional silicon photovoltaic cells. In most cases, efficiencies above 40 % are only achieved using multilayer technology for the use of a wide spectral region. The production of such cells is not technologically simple, and therefore these solar cells are used only for special purposes, such as concentrators, aerospace, military, or space use. In all the cases mentioned above, the effort to keep failures to a minimum and to reduce the occurrence of defects is crucial. Such defects can occur both during production and during use in operation. The extent of the particular defects then accelerates the degree of degradation, which continues to occur and is inevitable in the time horizon.

It is, hence, necessary for some degradation to be present before defects can be identified. A reliable method for causing degradation is accelerated ageing, i.e. a simulation of a given process, which creates inhospitable conditions for said solar cell, thanks to which the degradation manifests itself and increase and consequently causes noticeable decreases in performance.

Solar cell degradation can be analysed through countless methods. However, it is essential to understand to what extent and where the solar cell can degrade the most. Since the solar cell works on the principle of the photoelectric effect, its upper part, which is mostly exposed to wide-spectrum electromagnetic radiation, is susceptible. Surface analysis is consequently fundamental because even a slight change in the range of tens of nanometres can affect a wide range of its properties. Whether it is a different morphology, which results in a change in refractive index, or the emergence and spread of microstructural defects or even a change in elemental composition, causing different doping concentrations. These and other changes can subsequently cause a decrease in the performance of the solar cell.

GaAs-based solar cells appear to be the most suitable candidate which meets the conditions for working in a demanding environment. Their superior radiation hardness and resistance to other environmental influences make them ideal for these applications and development in the field of efficiency is continuously ongoing. The study of their degradation is thus becoming increasingly important in terms of efforts to minimise defects, which, due to the conditions in which they must operate, can expand, and rapidly reduce the life of the cell. Solar cells of this type are used mainly in concentrators where sunlight can be up to 2000 times higher or in satellites, space probes and other space devices, where much higher ionising radiation appear than in normal conditions on Earth. From the mentioned above, it is clear that these solar cells are under enormous stress due to radiation or other external conditions.

1 State of the art

The topic of solar cells is very lively and discussed. Practically from the very beginning of their use, many processing methods and new types for numerous applications have been invented. Whether they are various modifications of widely available silicon solar cells, high-performance multilayer cells of group III-V, or experimentally developed, for example, perovskite and organic solar cells. Gallium arsenide based solar cells have been commonly replacing silicon solar cells in harsh environments for many years. GaAs cells also holds the record for the overall effectiveness of solar cells in general, for several years in a row. Currently, they have almost reached the maximum theoretical efficiency, which is, according to the Shockley-Queisser limit of 33.5 %. From the latest measurements, an efficiency of 29.1 % was achieved for this type with a single-junction structure [1]. However, this efficiency can be increased by multi-layer technology, where up to six layers are already used [2]. It is not surprising that they are deployed in the most modern terrestrial and space technologies.

For that reason, many researchers seek not only to increase efficiency but also to improve durability or reduce production costs, which are mainly due to the purity of the material [3]. It has been shown that radiation damage caused by electrons and protons can be reduced by thermal annealing at 150 °C [4]. However, it is necessary to distinguish between thermal annealing and thermal stress, where the degradation of the photovoltaic (PV) cell already appears. For passively and actively uncooled GaAs cells, where the temperature of thermal stress approaches 350 °C, the opposite adverse effects appear when the efficiency decreases. This is also reflected in the different surface structure that arises during such processing stress [5]. Similarly, it also occurs with intense gamma radiation [6, 7]. It was found that the degradation of gallium arsenide solar cells compared to silicon is up to twofold, but suitable protective coatings or various covers appear to be successful protection against both thermal and ionising radiation [8].

A material of Al_2O_3 and TiO_2 has become the standard for anti-reflective and protective coating, especially for space applications, since they have a transmittance property compatible with the multi-junction solar cells wavelength range. Promising then become use of anti-reflective microlens arrays that have protective layers of these materials. They work similarly to Fresnel lens in concentrators. Thanks to this technology, a photocurrent increase by the amount of 5.9 % was achieved in 2019 [9]. Their advantage is also the low weight, which is desirable in some applications. It has recently been further reduced in the form of flexible substrates [10] and solar cells themselves, wherein an ultra-thin PV cell, photo-excited carriers have a very short distance to move to the terminals [11].

2 Aims and objectives

It is necessary to focus on the study of the surface where solar cells are most susceptible to degradation, i.e. various structural defects. It is also desirable to focus on the electrical properties of the solar cell, which loses its efficiency after degradation. The task is to perform potential induced degradation of the most common cases in which the solar cell degrades in the form of accelerated ageing. These include thermal stress at high temperatures, cooling at low temperatures and exposure to intense radiation (ionising and non-ionising). The premise is to carry out multiple measurements to verify the results and which ideally correlate with each other. Research and analysis of the following parameters are expected:

Optical properties

- Reflectance using a spectrophotometer in the UV-VIS-NIR range.

Structure and composition

- Chemical states and structure using Fourier-transform infrared spectroscopy (FTIR), X-ray photoelectron spectroscopy (XPS) and Raman spectroscopy.
- Evaluation of changes in layers thickness using ellipsometry.
- Elemental analysis using energy-dispersive X-ray spectroscopy (EDS).
- Search for microstructural defects by electroluminescence.
- Analysis of the surface and its structure using atomic force microscopy (AFM).
- Elemental composition of the top layers with secondary ion mass spectrometry (SIMS).
- Examination of the surface condition, contacts and layers using scanning electron microscopy (SEM).
- Recognise contamination and surface and subsurface defects with electron beam-induced current (EBIC) method.

Electrical properties

- Dark and under illumination I-V characteristics.
- Noise characteristic by power spectral density (PSD).

3 Degradation processes

It can be said that no solar cell material is created without the defect. Defects can always be found on or in the solar cell, whether they are caused by impurities during fabrication or mechanical disorders during handling. These processes can result in increased degradation, which then results in reduced performance.

The gallium arsenide solar cells are very often exposed to extreme conditions, for which, however, they are intended. Naturally, we can also expect increased risks of damage to these cells and decreasing their effectiveness. The properties of the solid matter and its physical parameters are susceptible to many external factors such as pressure, temperature or various external fields. In most cases, if the source that caused this state disappears, the physical parameters of the matter will return to their original values. Also, similar behaviour occurs when other types of radiation affect the solid matter in the case of non-permanent changes in properties.

The temperature on Earth is lower than in Earth's space orbit in direct sunlight. However, when using concentrators, the temperature conditions are many times higher. Thus, during the constant absorption of light, the energy converted into heat can be expected to have a significant effect on the solar cells.

It is known that GaAs-based solar cells have shifted the boundary of resistance to ionising radiation to higher particle or dose fluctuations. Overall, it is proven that generally, non-crystalline semiconductors are more durable and stable in high radiation environments.

As one of the most critical tests carried out on candidates of various space devices is gamma rays which confirm their suitability for space. Several institutions commonly perform radiation hardness tests on electronic compounds for space objects and other aerospace devices. For example, by the European Space Agency in its radiation testing facilities, such as in Noordwijk – Netherlands.

Cobalt-60 (Co-60 or ^{60}Co) is a by-product of nuclear reactor processes and the most common radioactive isotope of cobalt. It is established when metal structures are exposed to neutron radiation. As the radiation source is used as the agreed standard method to simulate exposure of cosmic particles in orbit for the electronic devices. Cobalt-60 decays into a stable nickel-60 (^{60}Ni) isotope by beta particles and by two corresponding highly penetrating gamma rays as photons with energies of 1.17 MeV and 1.33 MeV.

Recently, the degradation of GaAs solar cells under continuous laser irradiation was discussed by Lei Qi et al. [12] in terms of thermal-stress distributions. In this work, degradation caused by defects formed due to redistribution of aluminium and titanium components are also observed.

4 Used specimens

As photovoltaic solar cells, GaAs-based samples were tested. This type of sample was chosen because of its high resistance to radiation and other external influences. Another reason for choosing these types of cells was their frequent use on space objects. Identically the same type of solar cells used was implemented on Iridium satellite constellation. Compared to conventional silicon PV cells, these III-V compound semiconductor units have different fabrication, coating application and substrate material. They are classified in the category of thin-film PV cells for special applications.

A simple description of the layers of the solar cell for a basic idea is shown in the model in Fig. 4.1, where the dimensions of individual layers and their material are described.

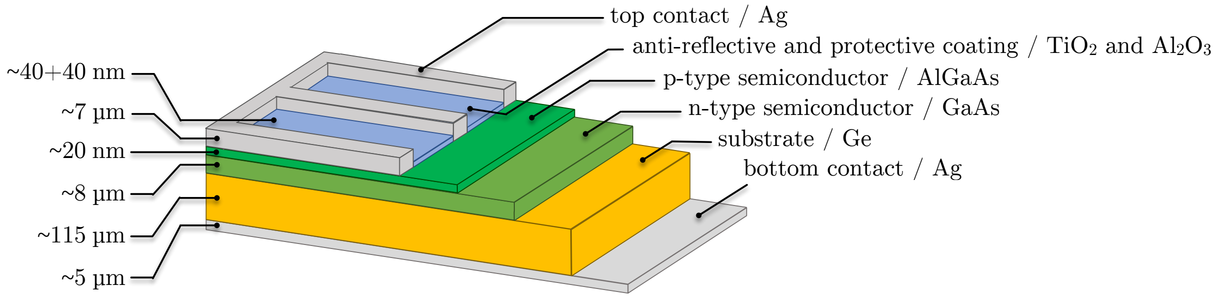


Fig. 4.1: Solar cell layer distribution, and structure. On the surface, there is the anti-reflective layer to absorb as much light as possible and the protective layer to protect against external influences. The lower layers are insulated from the air and the possibility of oxidation. A heterojunction between AlGaAs and GaAs follows this. The substrate reinforces the PV cell, and the last is a uniform layer of silver contact.

Used solar cells described in this dissertation contain a single-junction layer with silver contacts and silver backside. Thin layer of Al_2O_3 and TiO_2 about 40 nm each serves as anti-reflection coatings (ARC) as well as protection against radiation from space.

The most important part of the used solar cell in this work is the AlGaAs/GaAs interface called heterojunction. The term heterostructure refers to two different materials with two different bandgaps.

The GaAs layer thickness is about 8 µm, the rest being a substrate and a bottom contact. As a substrate is used n-type germanium (triple or more junction PV cells use p-type Ge wafer – depends on solar cells design). Germanium is used mainly due to its very high mechanical strength. This parameter is important for the use in space by virtue of the production of very thin wafers and thus a reduction in weight and material consumption. The total PV cell thickness is about 135 µm.

5 Experimental methods

High demanding conditions were performed to simulate accelerated ageing. The selected solar cells were exposed to a wide range of temperatures and radiation at which their degradation is expected.

5.1 Heating to high temperatures

Thermal processing was the relatively aggressive method, which can be simulated the difficult conditions and degradation of the samples. The temperature was set to 350 °C. The required furnace temperature rose from 23 °C during 30 min. Subsequently, it was stabilized for 240 min. After that, next 30 min program waited as soon as it dropped back to room temperature of 23 °C. During the thermal processing, the stress temperature of 350 °C was chosen as a limit value that, for the period of 240 min, the solar cells were able to withstand and continue to operate without complications.

5.2 Cooling to low temperatures

Sample cooling was performed in a sample analysis chamber (SAC) of the XPS setup under vacuum $<6.66 \times 10^{-5}$ Pa. Thus, no undesired oxidation or condensation occurred. Dry nitrogen was used as the coolant. Cooling from 23 °C to -120 °C, and back to 23 °C for a period of 7 hours was performed. The solar cell was placed on the sample holder in good contact with the cooled molybdenum plate.

5.3 Irradiation with gamma rays

Cobalt-60 isotope with energies of 1.17 MeV and 1.33 MeV and current activity of 380 TBq was chosen as a emitter. A dose of 500 kGy was applied for irradiation of the PV cell. Within 21 days of continuous irradiation, it was simulated exposure by accelerated ageing, which typically occurs within a many years.

5.4 Irradiation with broadband light source

Supercontinuum laser (SL) with a measured spectral range of 450 nm to 2400 nm and the total average power output 188 mW without collimator was used. The samples were exposed to radiation during 67 days at a distance of 67 mm. The laser power was set to maximum 188 mW. Spot size is 5.73 mm^2 at the 200 mm^2 square samples. No cover glass to the solar cells and no bias were applied.

6 Experimental results

The experimental results below show the changes and degradation of GaAs solar cells. The chapter is divided according to selected experimental methods. For each experimental method, the observation was chosen by such an instrument, which would be the most suitable to analyse the manifested changes. Due to the nature of the short version of the dissertation, the results provide only an example of the many measurements performed for each processing method.

6.1 Mechanical stress and fabrication defects

Before the processing of any of the mentioned methods, various imperfections can already be observed on the solar cell, for example by the EBIC method. For the illustration, Fig. 6.1 and Fig. 6.2 showing the GaAs solar cell do not overlap each other, so the difference between SEM and EBIC is apparent. This pair of Fig. 6.1 and Fig. 6.2 represents the layer with PN junction and the silver contact of the solar cell. Delamination is already noticeable from Fig. 6.1, but for Fig. 6.2 the accurately damaged and delaminated parts are clearly visible. Variation of bias allows investigation of the structure. It can be observed that the distribution of carriers close to the contact is different.

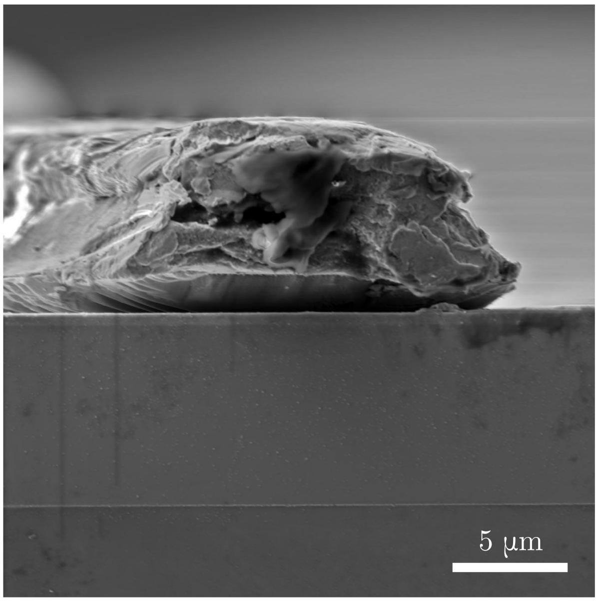


Fig. 6.1: Image of cross-section of a GaAs solar cell and its contact from SEM without applying the EBIC method.

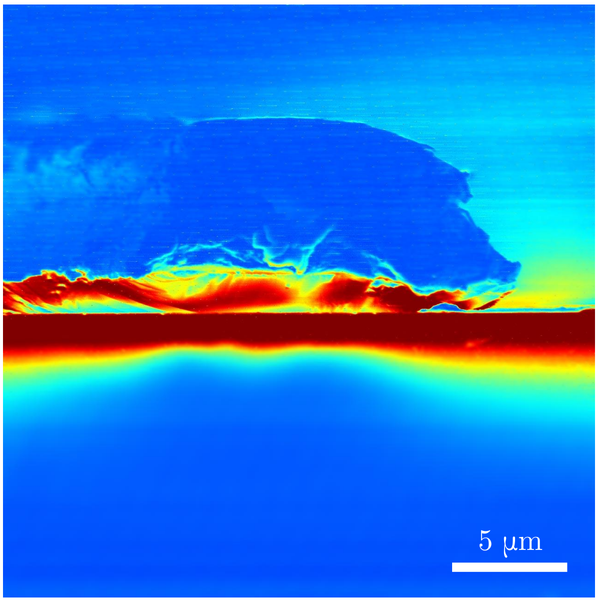


Fig. 6.2: Applied EBIC method on the solar cell shown in Fig. 6.1 without SEM image overlay. Area is the same. The exact charge distribution and PN junction can be seen.

6.2 High-temperature processing

Atomic force microscope showed with no exceptions and in all cases, the more indented surface structure of the cells after processing. Differences can be seen on the non-annealed specimen in Fig. 6.3a as compared to the annealed sample (350 °C) in Fig. 6.3b. These figures also show the structure in both the 2D and the 3D imaging. Such a structure may, in some cases, influence a better absorption and less reflection of light, thus gloss of the photovoltaic cell. Slight growth of features of an average height of 15.73 nm is observed after processing. That is the change over 8 nm compared to the non-annealed characteristics of an average height of 7.16 nm. The processing thus influences the course of degradation.

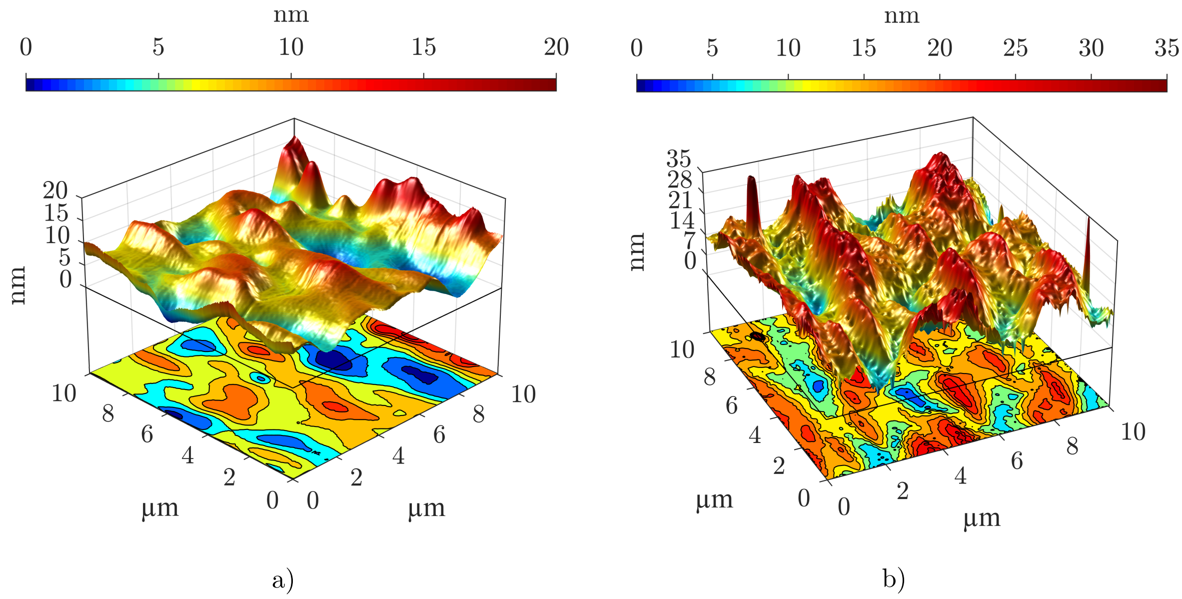


Fig. 6.3: Solar cell a) before and b) after thermal processing scanned by AFM. The picture in 2D shows the contours of the surface model in 3D for better clarity. Heights are colour-coded. At first glance, height and structural differences can be seen between figures a) and b).

6.3 Low-temperature processing

The reflectance spectrum of the solar cell after cooling (−120 °C) in Fig. 6.4 shows an almost unchanged character, mainly in the spectrum of visible (VIS) and near-infrared (NIR) region. The measurement curves clarifies a minimal change in the structure of the surface, as its reflectivity is very similar to that before cooling, morphological analysis using AFM, therefore, appears to be unnecessary. It should be noted that this result deals only with reflectivity, which does not imply that no degradation has occurred in the solar cell. Minimal degradation of the solar cell occurred only in terms of reflectivity. Complete results are in the standard version of the dissertation where the higher degradation of the sample for lower temperatures is evident due to the negative thermal coefficient, which occurs at very low temperatures and can lead to negative thermal expansion and damage to the atomic structure of the cell.

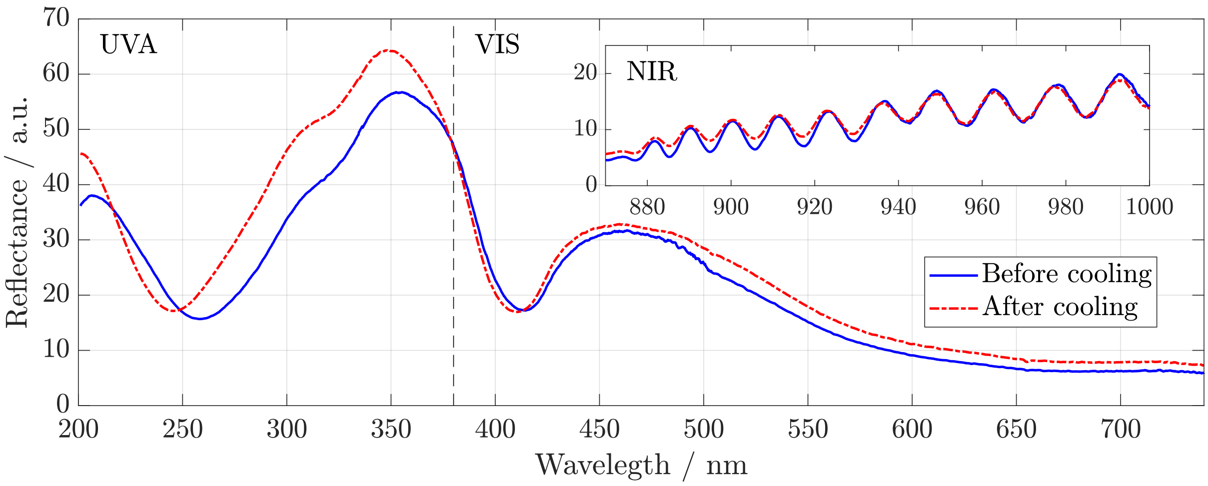


Fig. 6.4: Differences in reflectance after cooling. The excellent resistance of thin layers and surface to low temperatures is shown. The unchanged intensity and number of interference fringes in the NIR region suggest that the layers interface will not play a large role in the effect of degradation.

6.4 Ionising radiation processing

The results for gamma irradiation were the most discussed in the dissertation, and the most spectroscopic methods were used. One of them is the Raman spectroscopy depth profiling method, where several differences were noticed before and after irradiation and within different depths. The profile images in Fig. 6.5a and 6.6a show the occurrence of a particular mode at different depths from the surface, which is colour-coded according to the intensity of the mode. The coloured area is a 40 cm^{-1} wide region selected around the GaAs LO mode. It is evident in Fig. 6.6a, the distribution of this occurrence is broader, while in Fig. 6.5a, it is located more centrally. Also, a slight shift from occurrence in Fig. 6.5a has been observed against Fig. 6.6a.

If we focus on plots of three different spectra in depending on their position (A, B, and C) in the range of about 800 nm apart in the surface, we see differences from the Fig. 6.5b and 6.6b again. Moving deeper from position B to A and from position B to C in Fig. 6.5b will result in almost the same decrease in GaAs LO. However, the same movement dramatically changes the ratio between AlAs TO and AlAs LO. It can be argued that the differences in the structure below from A to B position results in the aluminium containing layer mainly.

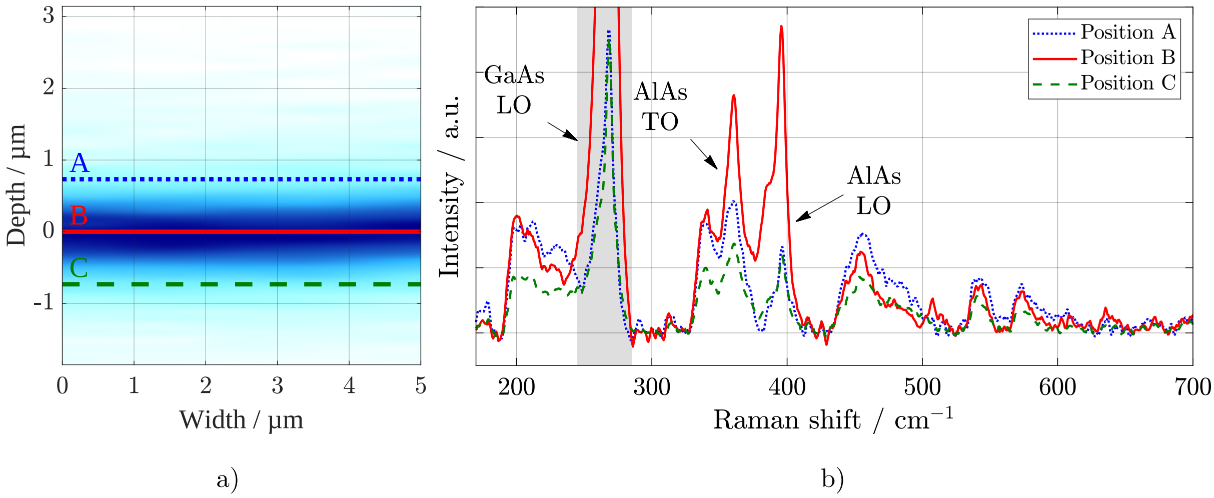


Fig. 6.5: Depth profiling of unprocessed GaAs solar cell using the Raman spectroscopy. Picture a) shows a profile map of a specific band selected and marked in plot b). This band is 40 cm^{-1} wide.

Fig. 6.6b shows a different situation. The decrease in GaAs LO mode appears between the A and C positions. Also, there is a continuous decrease in AlAs TO mode from A to C position. Nevertheless, if we focus on GaAs LO and AlAs LO in position B, peaks remain the sharpest. Also, the ratio between AlAs LO and AlAs TO is the highest in the same position [13].

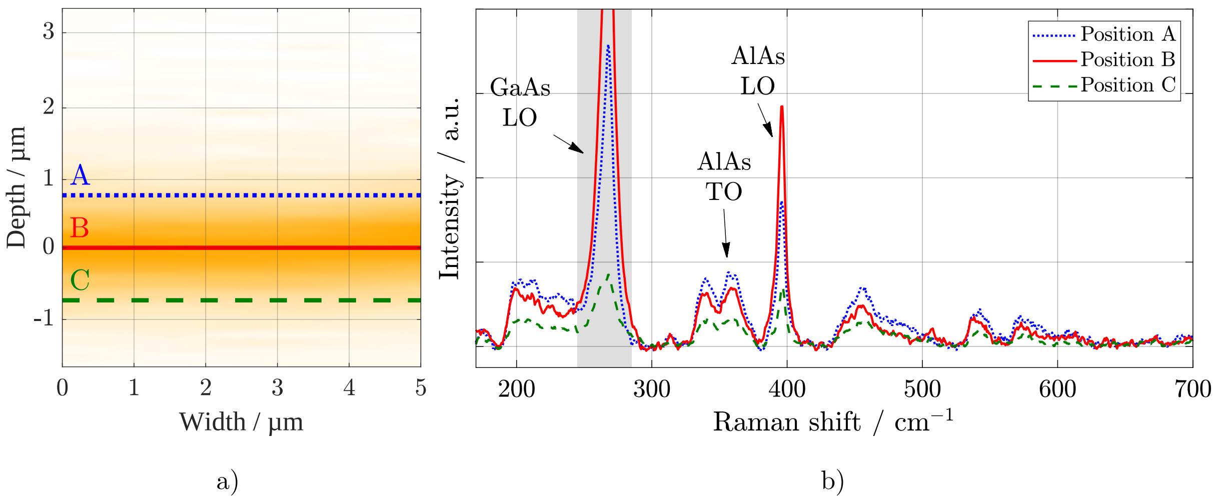


Fig. 6.6: Depth profiling of irradiated GaAs solar cell investigated by the Raman spectroscopy. Again, picture a) shows a profile map of a specific band selected and marked in plot b). The band position is the same as in Fig. 6.5b, from 245 cm^{-1} to 285 cm^{-1}.

6.5 Exposure to the supercontinuum light beam

Similar to ionizing radiation, SL irradiation results showed differences in the displacement of Al and Ti atoms. Thus, partial diffusion was observed here as well.

It is known that AlO_x is used for passivation of solar cell surfaces [14] by virtue of the excellent protective and anticorrosive properties of aluminium oxide [15]. XPS broad spectra show the presence of aluminium and oxygen peaks that belong to the coating. Al2p peaks in Fig. 6.7 were deconvoluted to Al^{3+} and Al^{x+} oxidation states. The amount of aluminium suboxides bonds [16] is lower after illumination.

Nevertheless, a slight displacement of the Al peak indicates the degradation of the film. A change of the binding energy indicates a relative loosening of the structure because the elements from the anti-reflection coating diffused into the depth. The components of O1s binding energy (Fig. 6.9) are associated with bonding with carbon and aluminium and in agreement with Al2p. Slight increase of $C-O$ bonds could be observed at C1s peak (Fig. 6.8). To minimize the specimen contamination, the exposed and unexposed areas were measured immediately after each other and without pulling out the sample from the chamber. Differences in these areas depending on the circumstances of external influences especially for oxide and carbon can therefore be ruled out.

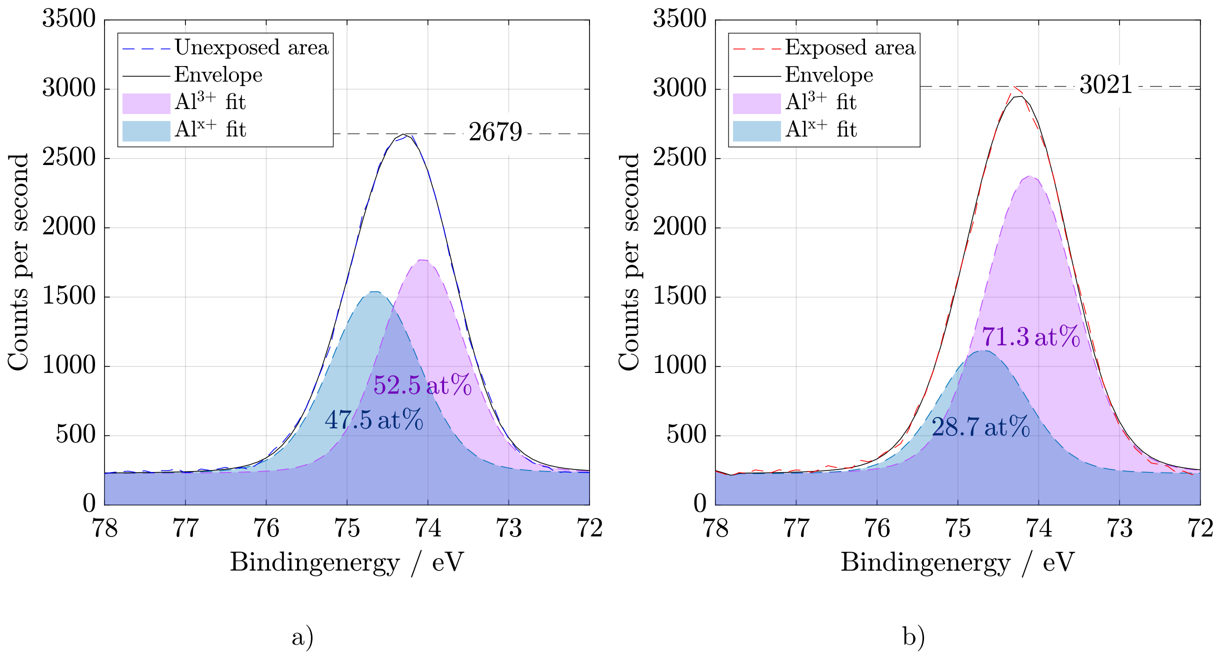
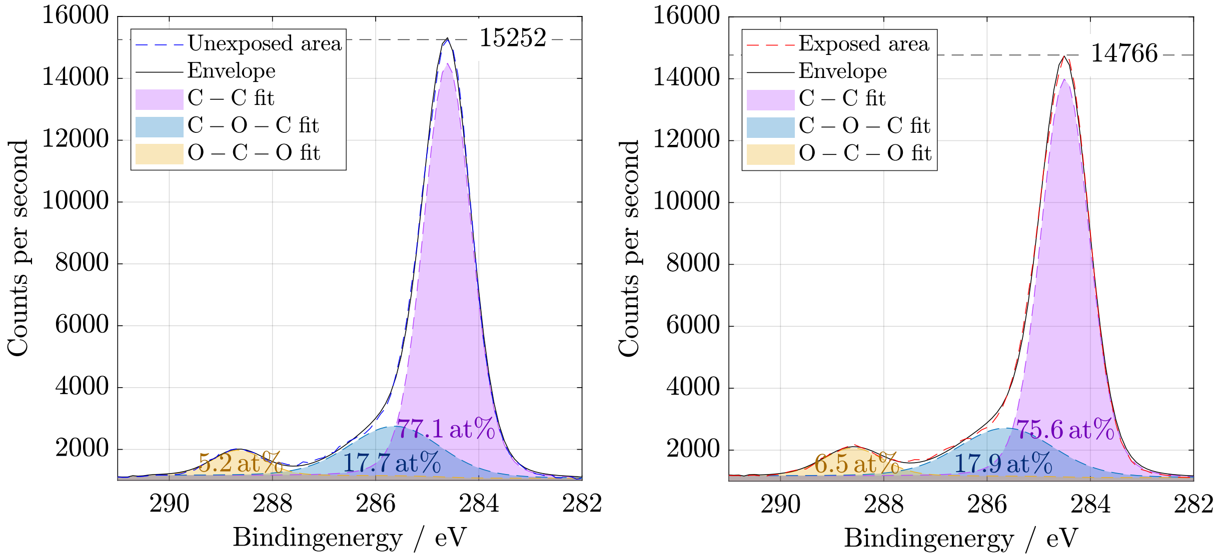
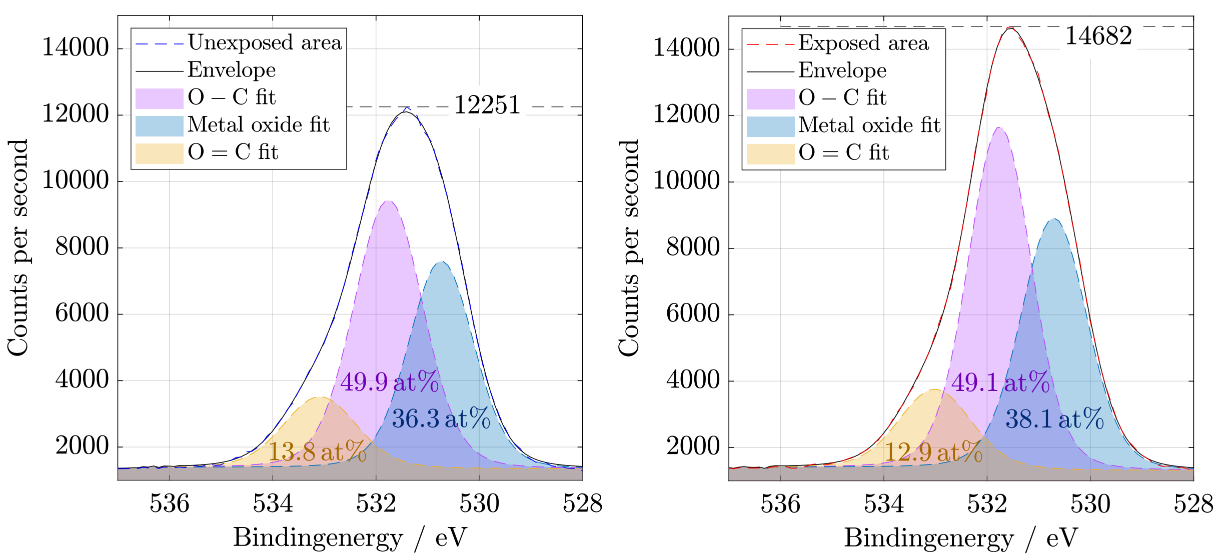


Fig. 6.7: High resolution of Al2p region from XPS measurement a) before and b) after SL irradiation.



a) b)

Fig. 6.8: High resolution of C1s region from XPS measurement a) before and b) after SL irradiation.



a) b)

Fig. 6.9: High resolution of O1s region from XPS measurement a) before and b) after SL irradiation.

Conclusion

A comprehensive measurement of degradation of GaAs photovoltaic cells has been performed. Surface morphology, material, electrical and optical properties were studied. All evaluation methods were selected to complement each other. Each measurement provides different information and varies in used method.

Prior to the use of the methods by which GaAs solar cells were stressed, surface and cross-section inspections and the occurrence of subsurface cracks and point defects were performed using the EBIC method. In contrast to silicon cells, GaAs PV cells are very resistant to surface cracks, which were present in substantial quantities in silicon cells. It was seen from the cross-section of the GaAs sample that electrically active impurities could be introduced into the thin layers during production and thus affect their function.

The results from thermal processing confirm the excellent stability of the material structure regarding such high temperatures. In particular, the ratio of the elements from EDS remained almost unaltered after processing and their weight differences varied within a percentage of units. Slight oxidation of contacts has been observed, but it can be assumed when using the cell only on Earth's terrestrial use. However, the roughness of the surface and the number of structural features, which were examined using the atomic force microscope, increased slightly. The thermal radiation of the cell in the case of reverse-bias has changed and increased. The high temperature resulted in the restructuring of defects, which were also observed from the dark characteristics. Fluctuations from PSD increased, and power performance from light curves decreased, which is a consequence of not only surface but also internal elementary processes. The solar cell remained functional even though the thermal stress was relatively at the high level of 350 °C for over 4 hours. However, with more prolonged annealing, an increasing incidence of defects and a consequent decrease in performance can be expected. A sudden change results under reverse bias after increasing the processing temperature of the solar cell to the limit of its functionality (420 °C). This change is in the form of an immediate electric breakdown.

In contrast to the thermal stress of 350 °C, the successful cooling to −120 °C with nitrogen and subsequent XPS analysis was performed, which also took place during cooling, as opposed to heating where measurements were achieved only before and after processing without XPS measurement. The optical properties of the solar cell after cooling were considered to be excellent and, due to the almost unchanged reflectivity, it was not necessary to measure the surface morphology using AFM. Raman spectroscopy also indicated a relatively high quality unchanged elemental composition. However, the degradation of the sample probably occurred, by reason of negative thermal expansion and internal processes. The decrease in performance was confirmed by I-V and P-V characteristics. The main surface modification at cooling is connected with C – O bond. Partial degradation of Al – O bond is associated with dissociatively adsorbed oxygen [17]. Decreasing of dangling oxygen bonds can be connected with $C-O$ local surface defects [18].

The most comprehensive part of the work from the standpoint of analysis can be considered intense irradiation of samples with the gamma emitter with a dose of 500 kGy. In exception to the EDS method and infrared camera observation, all analytical measurements and tools were used. Most of these methods used mutually confirmed differences in anti-reflection and protective layers, their diffusion and also the decrease in PV cell performance.

In results of irradiation by the continuous laser, summarized dependences of electrical properties on exposure duration show a slight increase in efficiency at 42th day of the experiment. The SL energy caused displacement defects by virtue of migration of Ti and Al atoms. A good agreement between functional (electrical), optical and structural properties was observed. The XPS spectra show the degradation of the protective AlO_x layer as well. Raman spectroscopy allows us to suggest that As sites are related to defects formation. Diffusion of Al and Ti caused the changing of interference fringes studied by reflectometry. The fact of element displacement, as well as the anisotropic character, were shown by SIMS. The current-voltage and power characteristics studied during SL illumination shows that electron traps that appear as the result irradiation can relax over time, and the bond between electrons and the lattice of the material becomes weaker. The traps originate from the displacement of an atom when the kinetic energy of radiation is sufficient, and Frankel pair can appear [19]. The minor carriers are responsible for the electrical behaviour of solar cell under illumination. Generation of electron-hole pair can be affected by defects of the material structure. Defects at the depletion region caused increasing of recombination current and indicated degradation of PN junction. The decreasing in the concentration of charge carriers can be associated with the capture of charge carriers on the resulting defects. Low effective lifetime of carriers can also be connected with defects caused by the migration of Al and Ti atoms. Electrical characteristics demonstrate non-linear character of degradation. It was most probably by cause of the fact that including of Al caused the appearance of deep donor level centres (DX centres). Diffusion of titanium creates additional charge separation in the film. The phase transformation of the $Ti-O$ superlattice from the anatase phase to rutile may occur at the interface, which contributes to a change in the efficiency [20]. In this case, Ti atoms are partially released from the structure, which is confirmed by SIMS.

The results of this work provide opportunities for new studies not only in the field of solar cells but also in semiconductors and thin films, which have been shown to diffuse into the surface during various stress tests. The work is also a valuable source of information for the advanced production of PV cells specializing in space applications because GaAs solar cells directly designed for satellites were used here as well.

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Curriculum Vitae

Nikola Papež

Pronouns: he/his
Nikola.Papez@vutbr.cz
+420 54114 6020

Education

2016—Present	**Degree:**	Doctoral in Physical Electronics and Nanotechnology
	Where:	Brno University of Technology Faculty of Electrical Engineering and Communication
2019—2020	**Degree:**	Lifelong Learning in Specialized study of Technical Expertise
	Where:	Brno University of Technology Institute of Forensic Engineering
2014—2016	**Degree:**	Master's in Communications and Informatics
	Where:	Brno University of Technology Faculty of Electrical Engineering and Communication
2010—2014	**Degree:**	Bachelor's in Teleinformatics
	Where:	Brno University of Technology Faculty of Electrical Engineering and Communication

Teaching & Working

2016–Present **Position:** Learning Assistant
Where: Department of Physics, Brno University of Technology

I am working as an undergraduate teaching assistant in Physics 1 and Physics 2 courses from the spring of my freshman year until my senior year. I teach labs, computer exercises, lead diploma thesis students as a supervisor, create exams and sometimes present extra credit problems for the classes.

As a researcher, I write publications, review papers in impacted journals, give lectures at invited events, and attend international conferences.

Presentations & Conferences

2020	**Conference:**	Student EEICT
	Where:	Czech Republic, Brno
	Presentation:	Structural analysis of GaAs-based PV cells after ionizing irradiation
2019	**Conference:**	Student EEICT
	Where:	Czech Republic, Brno
	Presentation:	Advanced structural analysis of silicon solar cells
2019	**Conference:**	8th International Conference on Materials Structure Micromechanics of Fracture
	Where:	Czech Republic, Brno
	Presentation:	Microstructural investigation of defects in photovoltaic cells by the electron beam-induced current method
2019	**Conference:**	4th International Conference on Applied Surface Science
	Where:	Italy, Pisa
	Presentation:	Performance analysis of GaAs based solar cells under gamma irradiation
2019	**Conference:**	Progress in Applied Surface, Interface and Thin Film Science – Renewable Energy News VI
	Where:	Italy, Florence
	Presentation:	Effect of gamma radiation on properties and performance of GaAs based solar cells
2018	**Conference:**	Saint-Petersburg OPEN
	Where:	Russia, Saint Petersburg
	Presentation:	Surface morphology after reactive ion etching of silicon and germanium arsenide based solar cells
2018	**Conference:**	Student EEICT
	Where:	Czech Republic, Brno
	Presentation:	Morphological structure of solar cells based on silicon and gallium arsenide after ion etching
2018	**Conference:**	Solid State Surfaces and Interfaces
	Where:	Slovakia, Smolenice
	Presentation:	Characterization of nanoblisters on HOPG surface

2017 **Conference:** Photonics Prague 2017
Where: Czech Republic, Prague
Presentation: Thermal stability of gallium arsenide solar cells

2017 **Conference:** Student EEICT
Where: Czech Republic, Brno
Presentation: Characteristics of gallium arsenide solar cells at high temperature

2017 **Conference:** Progress in Applied Surface, Interface and Thin Film Science – Renewable Energy News V
Where: Italy, Florence
Presentation: Degradation analysis of GaAs solar cells at thermal stress

Author's publications[1]

2020 PAPEŽ, Nikola. Structural analysis of GaAs-based PV cells after ionizing irradiation. In: *Proceedings of the 26th Conference STUDENT EEICT 2020*. Brno, 2020, pp. 203–208. ISSN 978-80-214-5735-5

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- • SOBOLA, Dinara et al. Complementary SEM-AFM of swelling Bi-Fe-O film on HOPG substrate. *Materials*. 2020, vol. 13, no. 10. ISSN 19961944. Available from DOI: `10.3390/ma13102402`

DALLAEV, Rashid et al. Investigation of structure of AlN thin films using Fourier-transform infrared spectroscopy. *Procedia Structural Integrity*. 2019, vol. 23, pp. 601–606. ISSN 24523216. Available from DOI: `10.1016/j.prostr.2020.01.152`

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- • PAPEŽ, Nikola et al. Performance analysis of GaAs based solar cells under gamma irradiation. *Applied Surface Science*. 2020, vol. 510. ISSN 01694332. Available from DOI: `10.1016/j.apsusc.2020.145329`

[1] Significant publications in impacted journals are marked with a red bullet •.

- PAPEŽ, Nikola et al. Effect of gamma radiation on properties and performance of GaAs based solar cells. *Applied Surface Science*. 2020, vol. 527. ISSN 01694332. Available from DOI: `10.1016/j.apsusc.2020.146766`

2019 PAPEŽ, Nikola. Advanced structural analysis of silicon solar cells. In: *Proceedings of the 25th Conference STUDENT EEICT 2019*. Brno, 2019, pp. 723–727. ISSN 978-80-214-5735-5

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- PAPEŽ, Nikola et al. Degradation analysis of GaAs solar cells at thermal stress. *Applied Surface Science*. 2018, vol. 461, pp. 212–220. ISSN 01694332. Available from DOI: `10.1016/j.apsusc.2018.05.093`

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ABSTRACT

Gallium arsenide based solar cells are among the most powerful types of solar cells available. Their main advantage is excellent resistance to thermal and ionising radiation, and therefore they are used primarily in demanding conditions. This dissertation describes the state of GaAs photovoltaic cells exposed to thermal stress, high cooling, gamma radiation and broad-spectrum laser irradiation. The samples were examined before, after and during these processes using several analytical and characterisation methods. The measurements were focused on the characterisation of the surface, optical and electrical properties. Limits and new behaviour of this type of photovoltaic cells have been discovered, which are also affected by thin protective and anti-reflective layers.

KEYWORDS

degradation, gallium arsenide, solar cells, gamma irradiation, thermal processing, cooling, supercontinuum laser

ABSTRAKT

Solární články na bázi arsenidu gallia patří mezi nejvýkonější typ dostupných solárních článků vůbec. Jejich výhodou je výborná odolnost vůči tepelnému a ionizujícímu záření, a proto se využívají zejména v náročných podmínkách. Tato disertační práce popisuje stav GaAs fotovoltaických článku vystavených vůči tepelnému namáhání, vysokému ochlazování, gama záření a ozáření širokospektrálním laserem. Vzorky byly zkoumány před, po a i během těchto procesů pomocí několika analytických a charakterizačních metod. Měření bylo zaměřeno na charakterizaci povrchu, optických a elektrických vlastností. Byly objeveny limity a nové chování tohoto typu článků, které jsou ovlivněny i tenkými ochrannými a antireflexními vrstvami.

KLÍČOVÁ SLOVA

degradace, arsenid gallia, solární články, gama ozařování, teplotní namáhání, ochlazování, superkontinuální laser

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