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Influence of materials grain structure on the performance of optoelectronic devices

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The influence of grain structure of materials on optoelectronic devices performance was examined by light beam induced current (LBIC) technique. AlGaN metal–semiconductor–metal (MSM) detectors and polycrystalline silicon solar cells were examined. In case of AlGaN MSM structures, the effective region of carrier collection of contact electrodes was estimated as hundreds of nanometers. For these structures, the regions, where measured signals were two orders of magnitude larger than the average signal, were also observed. Measurements of polycrystalline solar cells allow us to determine the recombination activity of grain boundaries. LBIC method was applied to investigate layers quality used for MSM detectors and solar cells fabrication.

Keywords: light beam induced current (LBIC), grain structure, AlGaN MSM, polycrystalline sollar cells.

1. Introduction

In recent years great progress in semiconductor devices technology has been observed. From the beginning, there was a need to develop such methods which would allow one to investigate both starting material and ready semiconductors structures. One of the most fundamental requirements for these methods was a non-destructive procedure of the measurement.

This criterion is fulfilled by light beam induced current (LBIC) method which was developed in the eighties of the previous century [1]. Many experiments proved its usability in determining of many electrical parameters of semiconductor materials, such as: diffusion length, recombination velocities and a depletion region width [2]. Small diameter of scanning light beam allows one to determine spatial distributions of these parameters and to reveal the microstructure of materials, for example grain boundaries, defects or non-uniformities in semiconductor doping.

2. LBIC technique description

LBIC is based on excitation of material by light beam with specified wavelength and intensity and on measuring the current response which was caused by this excitation.

As a result of focusing a light beam with a defined shape, the light spot with specified diameter on a tested sample is obtained. Basing on assumption of power density distribution on a sample surface and inside material, the quantity of carries generated in a time unit could be determined. All the majority carriers generated by light illuminations, which do not participate in the recombination process, contribute to the induced signal.

LBIC images of induced photocurrent distribution were obtained using an experimental set-up [3]. Two different optical systems for light beam formation were used. The first one, consisting of LED, a diaphragm with 100 μm aperture and glass objective, was used in silicon solar cells examinations. The light spot this obtained had 10 μm diameter. For the characterization of structures fabricated on aluminum gallium nitride, an optical system with a high-pressure mercury lamp, mechanical chopper, 25 μm diaphragm and quartz objective, was used. A diameter of scanning light spot was about 1.5 μm. Two computer-controlled translation stages provided the *x*-*y* scanning capability with 0.25×1.0 μm step size. The steady state current induced in the external circuit was recorded for each light beam spot position. LBIC images were obtained as the maps of values of induced photocurrent versus *x*-*y* light beam position.

3. Experiment

Polycrystalline silicon solar cells are basic parts of photovoltaic modules [4]. Figure 1 presents LBIC image of a silicon polycrystalline solar cell, scanned with 10×20 μm step using red light beam. Silicon crystallite grains were observed. Grain boundaries were visible as a lowering of a value of the induced photocurrent. LBIC measurements

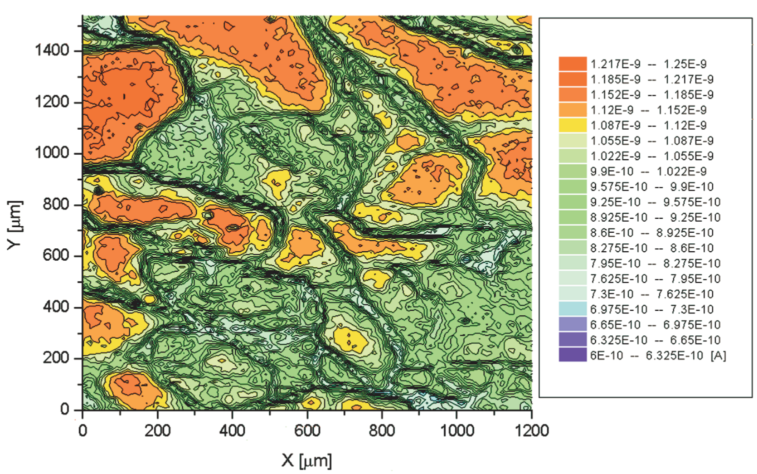

Fig. 1. Two-dimensional map of I_{LBIC} *vs.* the light beam spot position of a polycrystalline silicon solar cell (scanning resolution – 10×10 μm).

of solar cells are applied for the examination of the influence of surface passivation on electrical activity of grain boundaries. Figure 2 presents maps of induced photocurrent for a fragment of solar cells, scanned with different wavelengths of incident light beam. It was observed that for longer wavelengths the effect of carrier recombination on defects presented in boundaries became stronger.

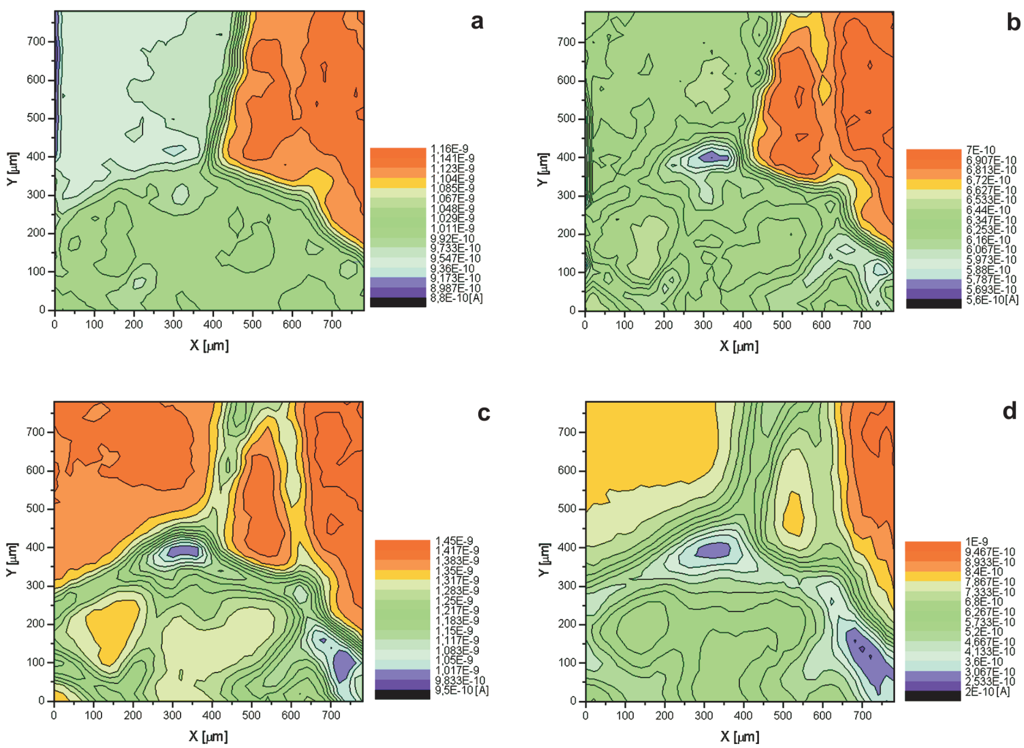

Fig. 2. Two-dimensional maps of I_{LBIC} *vs*. the light beam spot position of a polycrystalline silicon solar cell for different wavelengths of incident light beam: blue light beam (**a**), green light beam (**b**), red light beam (**c**) and IR beam (**d**).

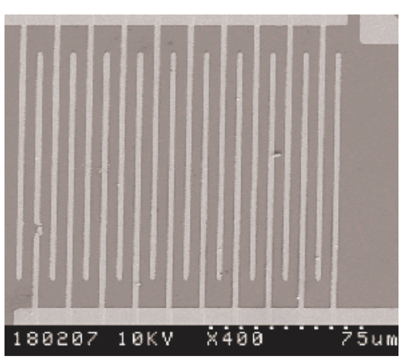

Fig. 3. SEM image of interdigitate MSM structure.

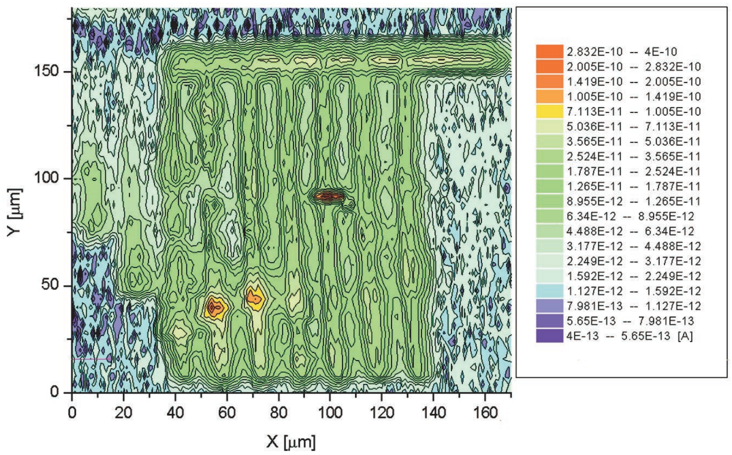

Fig. 4. Two-dimensional map of I_{LBIC} *vs*. the light beam spot position on $Al_{0.25}Ga_{0.75}N$ MSM structure (scanning resolution – 1×4 µm).

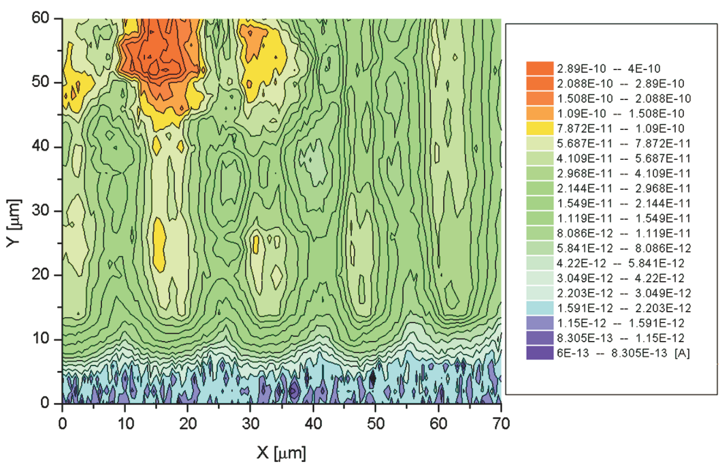

Fig. 5. Two-dimensional map of I_{LBIC} *vs*. the light beam spot position on $Al_{0.25}Ga_{0.75}N$ MSM structure (scanning resolution – 0.5×1 µm).

The other well-known materials with block structure are nitrides. For comparison purpose the interdigitate metal–semiconductor–metal (MSM) structures were examined. The MSM detector was fabricated on ~1.5 µm thick $Al_xGa_{1-x}N$ layers grown in a horizontal MOCVD reactor using trimethyl gallium (TMGa), trimethyl aluminum (TMAl) and ammonia on (0001) sapphire substrates. The GaN low temperature layers were applied as a buffer. The Al content in the layers was changed in the range of $x = 0.1$–0.4. The Pt/Au layer was applied to form a Schottky contact to AlGaN. Figure 3 presents a SEM image of interdigitate MSM structure with 2.5 µm finger width and 5 µm spacing between fingers. The samples were biased up to 30 V. Figure 4 presents the photocurrent map obtained for $Al_{0.25}Ga_{0.75}N$ MSM structure. The 170×170 µm area was scanned with 1×4 µm step. Figure 5 presents the photocurrent map obtained for the same sample (lower left 70×60 µm part of the structure) scanned with 0.5×1 µm step.

4. Results

Polycrystalline silicon is attractive material for solar cells fabrication because of its low cost of production. Large number of defects, particularly grain boundaries, is the main disadvantage of this material. LBIC technique allows one to observe that the recombination of charge carriers moving across the structure occurred primarily in grain boundaries. Energy levels induced in semiconductor by grain boundaries, localized near the center of band gap became effective recombination centers. The presence of energy levels inside band gap results in decreasing of carrier lifetime and diffusion length.

Potential barriers introduced by these defects result in carrier mobility which decrease and increase material resistivity. Obtained results were used for optimization of the solar cell construction and the passivation technology, which resulted in better efficiency of the element.

In case of AlGaN MSM, the generation of photocurrent was observed only when the nearest area of negatively polarized metallic electrodes was illuminated. Additionally, regions where the value of measured photocurrent was two orders of magnitude higher than the average signal were observed. For comparison, LBIC images of MSM detectors fabricated on aluminum gallium arsenide layer were also made. It was stated that for similar expected electric field distribution in both materials (calculated from structure dimensions, charge carriers concentration and epitaxial layer thickness), the effective region of carrier collection by metallic electrodes was narrower in case of AlGaN layer (hundreds of nanometers) as compared to single micrometers for AlGaAs layer.

It could be caused by considerably shorter carrier lifetime in AlGaN layer. Charge carriers generated in the region of large electric field in a depletion zone did not manage to pass through grain boundaries and reach the metallic contact. Also, no correlation between non-uniformity of induced photocurrent and surface morphology obtained from scanning electron microscope was observed. The occurrence of regions of a larger signal could be explained by the presence of larger crystallite grains or by local increase in the width of the depletion zone beside negative polarized electrodes.

5. Summary

LBIC measurements allowed us to examine the influence of the existence grain boundaries in semiconductor layers on the optoelectronic devices performance with submicrometer resolution. The influence of grain structure of material on charge carriers transport phenomenon in active layers of devices was determined from LBIC images for both examined samples. It was proved that for structures fabricated on AlGaN a classical design process which takes into account only electric field distribution in the layer (shape of a depletion zone) is not sufficient. Therefore unique properties of nitride epitaxial layers, such as the grain structure, must be considered.

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