Science
SELCUK UNIVERSITY
ICAT'15
INTERNATIONAL CONFERENCE ON ADVANCED TECHNOLOGY & SCIENCES
ICAT'15
August 04-07, 2015
Antalya / TURKEY
PROCEEDINGS BOOK
Editors
Omer Faruk BAY
Ismail SARITAS
www.icatsconf.org

International Conference on Advanced Technology & Sciences

2th International Conference, ICAT'15
Antalya, Turkey, August 04-07, 2015

Proceedings

Omer Faruk BAY
Ismail SARITAS (Eds.)
Kemal TUTUNCU (Eds.)

International Conference on Advanced Technology & Sciences, ICAT'15
Proceedings of the 2th International Conference on Advanced Technology & Sciences
Antalya, Turkey, August 04-07, 2015

A new method of efficiency enhancement in GaAs solar cells

S. M. Manakov, K. K. Dikhanbayev

Physical and Technical Department of Al-Farabi Kazakh National University, 71 Al-Farabi avenue, Almaty, Kazakhstan, 050040

sergei.manakov@mail.ru, dkadyrjan@mail.ru

***Abstract*— An efficient antireflection coating is critical for the improvement of solar cell performance via increasing of light trapping. In this paper the results of investigation of solar cells based on GaAs with thin film of silicon nitride as antireflection coating are presented. Control samples were Schottky junction solar cells fabricated from experimental GaAs solar cells by chemical etching of antireflection coating and p-type upper emitter layer and chemical deposition Au thin film on n – type GaAs surface. Frontal surfaces both p-n junction and Schottky junction solar cells were covered by of metal-oxide nanoparticles synthesized in counter flow propane-oxygen flame on the surface of nichrome wire. Nanoparticles had the characteristic size of 50-300 nm depending on synthesis conditions and were sprayed on a solar cell surface. It is found that the metal-oxide nanoparticles have significant influence on the antireflection effect and, therefore, improve the solar cell performance. Optimum nanoparticles surface concentrations appropriated to maximal short-circuit current are determined. It is shown that the coating from metal-oxide nanoparticles increase efficiency of solar cells by to 4.7 % due to light scattering on them and increase of a number of photons absorbed in the active region of solar cell.**

***Keywords*: gallium arsenide, Schottky barrier, solar cells, metal-oxide nanoparticles, quantum efficiency.**

I. Introduction

One of the most promising materials for solar energy conversion is a gallium arsenide (GaAs). This semiconductor is characterized by a large optical absorption coefficient due to direct optical transitions in GaAs. Furthermore, high efficiency of GaAs solar cells can be achieved at significantly lower thickness in comparison with the thickness of the silicon solar cell. In principle it suffices to have a thickness of 3-4 microns GaAs in solar cells for efficiency of about at least 20%, while the thickness of the silicon solar cells cannot be less than 40-80 microns without significant reduction in their efficiency [1]. The Shockley-Queisser limitation of the efficiency of even ideal single-junction photovoltaic cells that absorb all the incoming solar radiation is restricted to 33.7% by intrinsic losses such as band edge thermalization with a band gap of 1.34 eV nearly equal GaAs band gap [2].

Increasing of GaAs solar cells temperature to +150 ... 180°C did not significantly decrease of their efficiency. At the same time, for silicon solar cells increase in temperature above 60 ... 70 ° C is almost critical and their efficiency is halved.[1] In addition, high radiation resistance of GaAs makes this material very attractive for use in space vehicles.

However, despite the aforementioned advantages of GaAs solar cells problem of increasing the efficiency is quite crucial. The efficiency increase even for some percent is very important especially in industrial production.

To ensure the decrease of optical losses using different technologies and designs including the using of a single-layer or multi-layer antireflection coating [3,4], texturing of the frontal surface [5], the formation on the surface nanowires, nanoparticles and quantum dots are used extensively [6-8].

The aim of our work is to study the possibility of increasing the efficiency of GaAs solar cells by coating its surface of metal-oxide nanoparticles synthesized in propane-oxygen flame.

II. Experimental

Solar cells with the GaAlAs - GaAs structure have been formed on the low-resistance n + -GaAs: Te (111) wafer, and an absorbing layer n-GaAs ($n \approx 2.10^{15}$ cm^{-3}) had a thickness about 10 μm, both an emitter layer of p - GaAs: Mg and an optical window p-GaAlAs: Mg with thickness of 0.5 μm are consistently grown on n+ - GaAs substrate by liquid phase epitaxy growth process. Back ohmic contact to n+ - GaAs substrate is made by fusing the In + 3% Te alloy at 450°C. As the metal rear contacts three-layer structure Sn/Ni/Al is used, an antireflection coating is made from silicon nitride $Si_3N_4$with a layer thickness of 70 nm. Active area of solar cell was 4.56 cm^2. Figure 1a shows cross-section of the investigated GaAs heterojunction solar cell.

As the reference specimen was used Schottky barrier (SB) Au-n-GaAs/n^+-GaAs prepared from basic structure by etching of the top layer of GaAs in solution H_2O_2: H_2SO_4: H_2O (1:1:2) to a depth of 2-3 microns. The semitransparent layer of gold on the SB Au-n-GaAs was formed by chemical deposition from an aqueous solution of $HAuCl_4$ (4g /l) + HF (100 mg /l). The thickness of the deposited layers of gold was 15-20 nm. Cross-section of Au-n-GaAs solar cell is shown in Figure 1b.

Since the surface properties of GaAs significantly affect to the characteristics of the Au-n-GaAs barrier [9] before chemical deposition of Au layers a gallium arsenide surface was treated in bromine methanolic 4% Br_2 + 95% CH_3OH etchant. Active area of solar cells with SB ranged from 10 mm^2 to 50 mm^2.

Metal-oxide nanoparticles were synthesized in counter flow propane-oxygen flame at a temperature 1100-1200^0 C. Before flame cleaning surface of the wires was acid-washed in

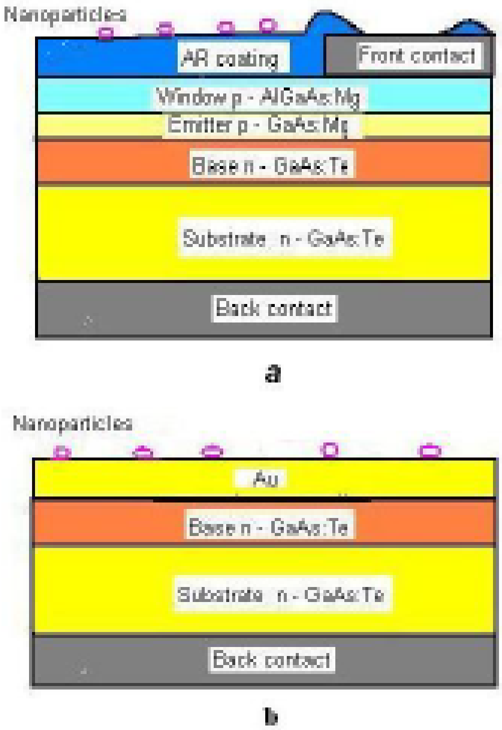

Fig. 1 Cross-section of GaAs solar cell: a) p-n heterojunction, b) Schottky barrier

25 % solution of nitric acid within 20 minutes for formation of seed metal-oxide growth. Roentgen-fluorescent analysis of nichrome wire shows the contents of metals Ni-60,27% , Fe-25,26 %, Cr-14,45 % and Ti-0,0174 %. Metal-oxide nanoparticls were produced on the surface of the nichrome wire which had the 50-300 nm characteristic sizes depending on the synthesis conditions [10]. Nanoparticles suspension in ethanol was prepared by ultrasonic treatment of nichrome wire with nanoparticles and was sprayed on the frontal surface of the solar cells. After deposition of each layer of nanoparticles the cell was placed for 15 minutes in a thermostat at a temperature of 150°C.

III. Results and Discussion

The experimental results of reflectance (R) as a wavelength function for a polished GaAs wafer, the surface of the solar cell with Si_3N_4 antireflection coating and the Schottky barrier are shown in Figure 2. As seen from the graph without antireflection coatings the reflectance of GaAs surface is more than 30% in the whole spectral range. Single-layer antireflection coating decreases the reflection coefficient up to 6%. Thin film of Au deposited on the surface of GaAs increases the reflectance up to 50%.

Influence of metal-oxide nanoparticles on short-circuit current density (J_{sc}) and open circuit voltage (U_{oc}) of solar cells evaluated after coating and annealing of each layer of nanoparticles. Figure 3 shows the dynamics of changes in photocurrent and voltage of heterojunction GaAs solar cells (a)

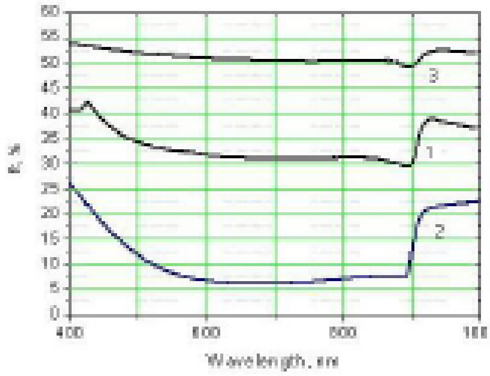

Fig. 2 Reflectance spectra for a polished GaAs (1), for the surface of the solar cell with Si_3N_4 antireflection coating (2) and for the Schottky barrier (3)

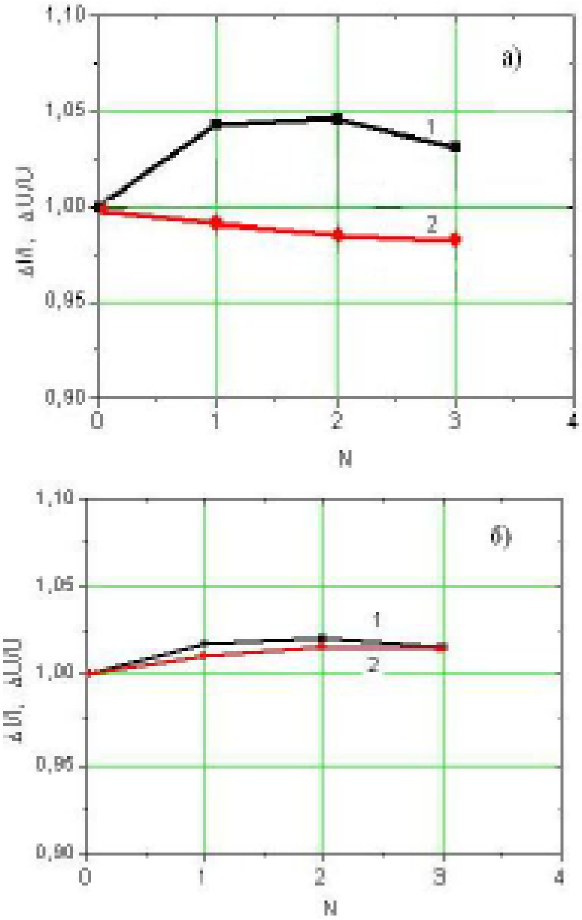

Fig. 3 Influence of a number nanoparticles layers (N) on short-circuit current (curve 1) and on open-circuit voltage (curve 2) for: a) heterojunction solar cell, b) solar cells with SB

and Schottky barrier (b) as a function of number of metal-oxide nanoparticles layers, i.e., on their surface concentration.

As it seems on Figure 3, there is an increase in photocurrent, which reaches its maximum value for two layers of nanoparticles, then the current decreases both for a hetero-junction solar cell and for a Schottky barrier. The maximal increase of photocurrent for first cell reaches 4.7%, and for Schottky barrier reaches 2.2%. Taking into account that the maximum part of incident photons entered into a heterojunction solar cell is 94%, and in solar cells with SB only 50% (Figure 2), we can conclude that the effect of increasing photocurrent connected only with the nanoparticles and its quantitative characterization is the same for the two studied types of solar cells.

The measured U_{oc} from the number of nanoparticls layers shows that these dependence different for a heterojunction solar cell, and for the solar cell with SB: for all heterojunction structures there were a slight decrease in the voltage of 1-2%, while for SB voltage changed as well as the current and for the first two layers was increased to 1.5%, and then decreased. For a heterojunction solar cell with N = 2 decrease in U_{oc} was 1.4%.

The initial increase in voltage U_{oc} and current J_{sc} with increasing number of layers N in the Schottky barrier connected with increase in the number of photons absorbed in the depletion region adjacent to a semi-transparent layer of gold. With further increase in the concentration of particles on the surface of the solar cell reflected photons from the surface increases, resulting in decrease of the current and voltage in both types of structures.

Spectral characteristics of solar cells were measured in the range 400 - 900 nm by the modulation technique. Figure 4 shows the spectra of the external quantum efficiency EQE of heterojunction structures before nanoparticles deposition (curve 1) and after deposition of two layers of metal-oxide nanoparticles (curve 2). The initial spectrum is characterized by a sharp decline in the long-wavelength region, characteristic of GaAs based solar cells, which is a direct-gap semiconductor with a band gap Eg = 1.42 eV.

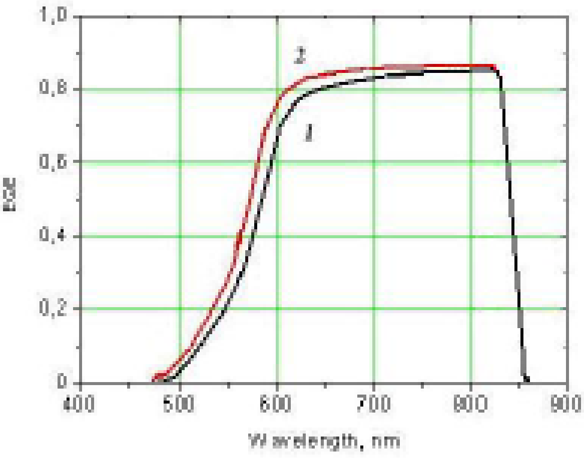

Fig. 4 External quantum efficiency spectra of GaAs solar cells before nanoparticles deposition (curve 1) and after deposition of two layers of metal-oxide nanoparticles (curve 2)

The decline in short-sensitivity connected with absorption of short-wavelength photons in the heavily doped emitter p region and the recombination of photogenerated carriers in it.

Metal-oxide particle sizes are less than the wavelength of incident light. In this case diffraction of light scattering takes place and, consequently, a more full capture of photons. The increase in the external quantum efficiency was observed over the entire range of spectral sensitivity of the solar cell (curve 2). The maximum increase of EQE was observed at short wavelengths, and monotonically varied from 6.8% at λ = 540 nm to 2.2% at λ = 800 nm.

Using an electron microscope Quanta 3D200i we investigate the shape and distribution of the nanoparticles on the surface of the solar cell. Figure 5 shows a scanning micrograph of metal-oxide nanoparticles on the surface of the solar cell.

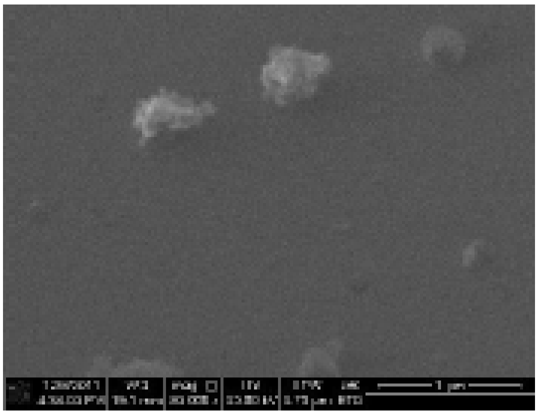

Fig.5 SEM image of metal-oxide nanoparticles on the surface of the solar cell

The surface morphology of the nanoparticles is quite complex and has a fractal structure: on the surface the particle size were about 100 nm one can observed semi-islets formation with a typical size of about 20 nm. The increase in photosensitivity due to nanoparticles in addition to scattering effect may also be due to the effect of re-radiation on the particles of metal-oxide components.

The current-voltage characteristics of the GaAs heterojunction solar cells under light intensity of 100 mW/cm^2 and its main parameters are presented in Figure 6. After nanoparticles deposition there is observed a slight increase of fill factor (FF) from 0.75 to 0.76. It is due to the increase in concentration of carriers on the absorbing layer of the solar cell and a decrease in the series resistance.

Measurements have shown that the use of nanoparticles leads to an increase in the efficiency of the solar cells from η = 14.8% to η = 15.5%, i.e. by 4.7%, despite a slight decrease in the open-circuit voltage. It should be noted that the tested solar cells before particles deposition characterized by dispersion of short-circuit current in the range of 10-12% and the open-circuit voltage in the range of 2-3 percent. Enhancement in efficiency of the different elements after deposition of nanoparticles is varied in the range 3-8%.

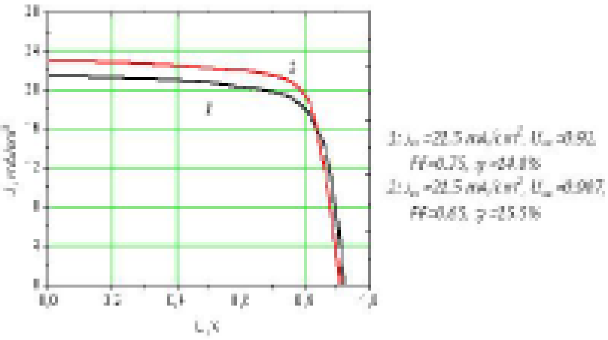

Fig. 6 The current-voltage characteristics of GaAs solar cells before nanoparticles deposition (curve 1) and after deposition of two layers of metal-oxide nanoparticles (curve 2)

The test sample is characterized by the average values of the parameters.

IV. Conclusions

In this paper the influence of metal-oxide nanoparticles on efficiency of GaAs based solar cells was investigated. When applied two layers of particles there was observed the maximum increase in the short-circuit current and cells efficiency. The investigations demonstrated that a coating of metal-oxide nanoparticles significantly increases the efficiency of solar cells by 4.7% due to light scattering on them and larger fraction of photons absorbed in the active region of a solar cell.

Acknowledgement

The authors express immense thanks to staff and management of National Nanotechnology Open Laboratory of Kazakhstan for assistance in the measurements. This work was supported by the Ministry of Education and Science Republic of Kazakhstan (contract no. 1569/GF3).

References

[1] I.M. Dharmadasa, *Advanced in Thin-Film Solar Cells*, Singapore: Pan Stanford Publishing Pte. Ltd., 2012.

[2] W. Shockley, H.J. Queisser, "Detailed Balance Limit of Efficiency of p–n Junction Solar Cells". *J. Appl. Phys.* vol. 32, 510-518, 1961.

[3] W.H. Southwell, "Gradient-index Antireflection Coatings". *Opt. Lett.*, vol. 8, 584-591, 1983.

[4] N. Shibata, "Plasma-chemical vapor-deposited silicon oxide/silicon oxynitride double-layer antireflective coating for solar cells". *Jpn. J. Appl. Phys.*, vol. 30, 997-1004, 1991.

[5] Y.A. Chang, Z.Y. Li, H.C. Kuo, T.C. Lu, S.F. Yang, L.W. Lai, L.H. Lai, S.C. Wang, "Efficiency improvement of single-junction InGaP solar cells fabricated by a novel micro-hole array surface texture process". *Semicond. Sc. and Technol. Semicond.*, vol. 24, 342-349, 2009.

[6] T. Stelzner, M. Pietsch, G. Andra, F. Falk, E. Ose , S. Christiansen, "Silicon nanowire-based solar cells". *Nanotechnology*, vol. 19, 295-302, 2008.

[7] M.A. Tsai, P.C Tseng., H.C. Chen, H.C. Kuo, P.C. Yu, "Enhanced conversion efficiency of a crystalline silicon solar cell with frustum nanorod arrays". *Optics Express*, vol. 19, A28-35, 2011.

[8] X.D. Pi, Q. Li, D.S. Li, D.R. Yang, "Spin-coating silicon-quantum-dot ink to improve solar cell efficiency". *Solar Energy Mater. Solar. Cells*, vol. 95, 2941- 2949, 2011.

[9] V.L. Berkovits, T.V. L'vova, V.P. Ulin, "Nitride chemical passivation of a GaAs (100) Surface: Effect on the electrical characteristics of Au/GaAs surface-barrier structures". *Semiconductors*, vol. 45, 1571-1580, 2011.

[10] Z.A. Mansurov, M. Auyelkhankyzy, B.T. Lesbayev, D.I. Chenchik, K.K. Dikhanbayev, N.G. Prikhodko, T.I. Taurbayev, A.V. Saveliev, "Increase of the Power of Solar Elements Based on Nanoparticles of Nickel Oxides Synthesized in Flame". *Advanced Materials Research*. vol. 486, 140 – 144, 2012.