Photocurrent Enhancement in GaPNAs-based Solar Cells With Si Nanowire Array Substrate

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***Abstract* - A numerical simulation of GaPNAs-based solar cells deposited on silicon nanowire (NW) array was done. It is shown that single-junction solar cell consisting of GaPNAs-based p-i-n junction with a band gap of 1.78 eV and minority charge carrier lifetime in i-layer of 0.1 ns on Si-based NW template can reach short-circuit current values of 16.5 mA/cm^2 and efficiency of 11.8% under AM1.5D 100 mW/cm^2. The influence of the i-layer thickness, minority carrier lifetime and NW length on solar cell's characteristics was shown.**

I. Introduction

There is a growing interest in renewable energy, particularly in solar and wind which can supply electricity to remote regions and also contribute to decrease carbon dioxide emission. Nowadays efficiency of conventional multijunction solar cells is close to theoretical limit. New materials and design approach should improve solar cell efficiency. A new promising material for solar cell - GaPNAs - it has a wide variable band gap and lattice constant parameters. There are some publication dedicated to applying of this material in multijunction GaPNAs/Si heterostructure solar cells [1-3]. But the main problem with this material is its low crystal quality due to incorporation of nitrogen. The carriers lifetime of the best GaPNAs samples is less 10 ns [4] and it results it low short-circuit current values due to high recombination rate. Thereby applying of GaPNAs in multijunction solar cells at the moment is limited. An approach is the use of Si nanowire array as a template for GaPNAs-based solar cell (Fig. 1). In this case is expected an increasing of light absorption and reducing optical reflection due to surface roughness.

II. Modelling

The computer simulation was performed using Silvaco-Atlas software. The calculation was made in terms of a 2D model by the Newton method with Fermi–Dirac statistics. In the model we developed, the top and bottom contacts were considered to be ohmic. A top contact's absorption coefficient was zero. To determine the maximum achievable efficiencies of solar light conversion, the reflectance from the top surface of the solar cell was also taken to be zero. A simple GaPNAs-based p-i-n structures were formed on flat and nanowire array Si-templates with Athena. GaP was used as p- and n-layers.

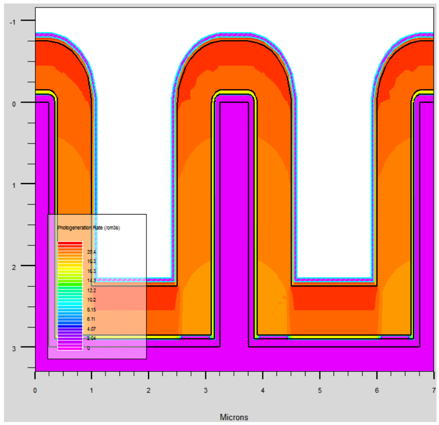

Fig. 1. Schematic of GaPNAs-based solar cells With Si NW array substrate

According to the experimental data reported in [4], the hole mobilities in doped GaPNAs (E_g = 1.78 eV) at 300 K reach values of 100-150 cm^{2}V^{-1}s^{-1}. In our calculation, the electron and hole mobilities of undoped layers were taken to be 100 cm^{2}V^{-1}s^{-1}. In estimating the maximum achievable conversion efficiencies, we assumed that the minority carrier lifetime in GaPNAs layers is limited by radiative recombination. Accordingly, the minority carrier lifetime for GaPNAs layers was set at the level of the experimental radiative-recombination lifetimes measured for dilute nitrides (0.01–1 ns) [4]. By default, this value was taken to be 0.1 ns. Absorption data for GaPNAs layers were taken from [5].

NW template was formed in Athena by etching Si substrate. NW's length, thickness and distance were varied. Quantum effects in NW were not considered to simplify the calculations. Simulation details can be found in [1].

III. Results

The solar cell efficiency is strongly affected by such an important parameter of the material as the minority carrier lifetime (τ). Fig. 2 shows how short current (J_{SC}) of a flat GaPNAs-based p-i-n single junction solar cell depend on the i-type layer carrier lifetime. It can be seen that, with increasing minority carrier lifetime in the active layer, the J_{SC} increases.

978-1-4799-3682-3/14/$31.00

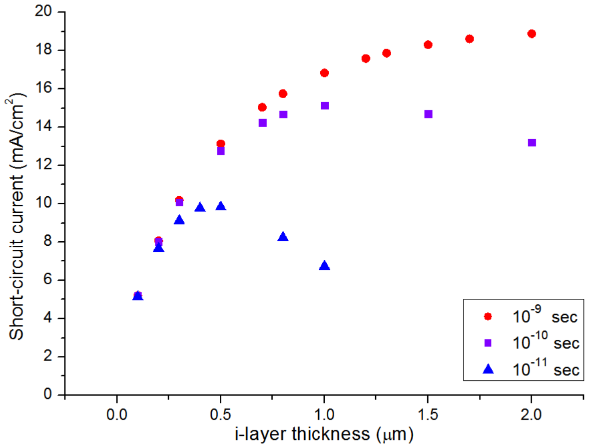

Fig 2. Effect of the thickness and carriers lifetime of the i-type GaPNAs layer on short-circuit current of a flat p-i-n solar cell

At τ > 1 ns in the GaPNAs layer the value of J_{SC} becomes saturated. For smaller τ it can be seen maximums on J_{SC}–thickness curves.

Increasing surface roughness due to Si-NW forming leads to significant increase of J_{SC} and efficiency of the solar cells. The dependences of J_{SC} and efficiency on Si-NW length at fixed i-layer thickness (0.6 mkm) and distance between NWs (3 mkm) are presented in Fig. 3. Minority carrier lifetime in the i-layer was fixed at 0.1 ns. Increasing in short-circuit current is caused by increasing in light absorption in GaPNAs deposited on NW.

Fig. 4 shows a compare of optimized NW based and flat p-i-n solar cell. NW optimized parameters are: NW length 3 μm, NW thickness 0.5 μm, distance between NW 3 μm. It can be seen an photocurrent enhancement in GaPNAa-based solar cells with Si nanowire array substrate by 6.5% relatively flat p-i-n solar cell.

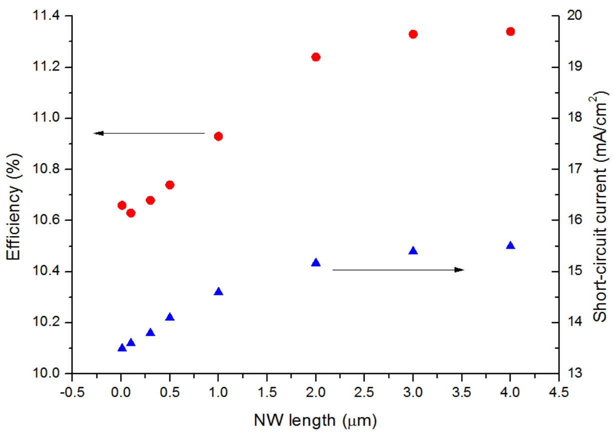

Fig 3. Effect of the Si-NW length on short-circuit current and efficiency of p-i-n GaPNAs-based solar cells with Si nanowire array substrate

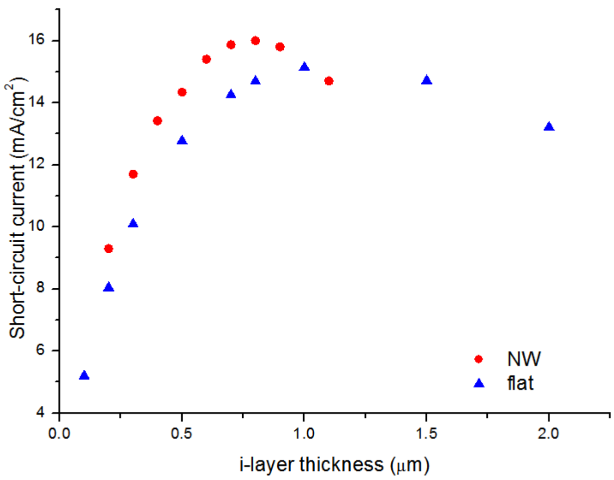

Fig 4. Effect of the thickness of the i-type GaPNAs layer on short-circuit current of a flat and optimized NW-based p-i-n solar cell

Other photoelectrical properties of simulated solar cells are shown in Table 1. Results were sorted based on maximum solar cells efficiency. It can be seen an efficiency increase by 14% relative flat p-i-n structure and by 60% relative p-n based solar cell with τ in the GaPNAs-layer of 0.1 ns.

TABLE I
Photoelectrical properties of simulated solar cells

Type	Uoc, V	Jsc, mA/cm^2	FF, %	Efficiency, %
p-n	1.17	8.18	77	7.39
Flat p-i-n	1.04	14.25	69.4	10.32
NW p-i-n	1.01	16.49	70.9	11.8

IV. Conclusion

Optimized NW based GaPNAs solar cells with carrier lifetime equal to 0.1 ns show photocurrent enhancement by 6.5% relatively flat p-i-n solar cell.

Acknowledgment

This research was partially supported by the RFBR project №12-08-33013 and DFG project SI1893/4-1.

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