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To cite this article: K U Shugurov et al 2018 J. Phys.: Conf. Ser. 1124 041021

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Influence of hydrogen plasma passivation on electrical and spectral characteristics of GaN nanowires / Si solar cells

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Abstract. Volt-ampere and spectral characteristics of the series of GaN nanowires/Si solar cells differing in interface layer preparation are obtained. Influence of hydrogen plasma passivation on electrical and spectral curves is analyzed. It is demonstrated that the interface passivation significantly affects the characteristics of the studied cells.

1. Introduction
Today, search and implementation of new ways to increase the photoelectric conversion efficiency of the modern solar cells is the research area of interest. At the same time researchers attempt not only to provide high solar cell (SC) efficiency, but also to achieve as low production cost of the SCs as possible. One of the most promising approach for development of photoconverters today is semiconductor heterostructural SCs.

One of the main features that affects the heterojunction SC characteristics is the presence of a heterointerface [1] containing a certain density of the surface states. Minority carriers crossing the interface can be trapped by these states, resulting in significant reduction of the photoelectric conversion efficiency. Recombination processes at the surface states in the case of indirect-band based SCs, for example silicon or germanium, are practically the major limiting factor affecting SCs efficiency. Thus, interface passivation can play an important role in SCs efficiency improvement [2].

It should also be noted that A\textsubscript{III}B\textsubscript{V} compounds have several advantages over the other compounds, and the use of group III nitrides is dictated with a number of their important properties including high crystal quality and growth in the absence of catalyst [3].

The work is devoted to the investigation of hydrogen plasma passivation influence of the GaN / Si heterointerface on SCs electrical and spectral characteristics.

2. Experimental details
In our previous work [4] the characteristics of the SCs based on n-GaN nanowires (NWs) on p-Si substrate were obtained. The study has shown that the interface preparation method significantly influences the samples spectral and electrical curves. Poor characteristics of the obtained SCs can be concerned with high surface recombination level at the interface [5]. Traditionally, to decrease the effects of this phenomenon, passivation of the surface is used to reduce the density of dangling bonds at the heterointerface.
A series of samples differing from each other with the interface layer preparation technique was investigated. Here we demonstrate characteristics of the most efficient samples. The first sample had no special buffer layer during the growth (native-grown SiN₀ sample with the NWs grown on bare Si surface), while another one had (buffer SiNₓ, this sample was intentionally nitridated prior to GaN deposition).

Typical view of the GaN NWs grown by using molecular beam epitaxy is presented in Fig. 1. The presence of an emitter layer in the form of n-GaN NWs array provides good antireflection properties without the use of expensive multilayer coatings [6].

![Diagram](image)

**Figure 1(a, b).** (a) schematics of the SC; (b) SEM image of the synthesized NWs

The front surface of the grown sample was treated with hydrogen plasma in PECVD machine. Hydrogen was chosen to passivate the substrate surface because of its small atom, allowing efficient penetration between crystal lattice atoms.

At the next technological step a back Al contact was fabricated on each of the synthesized GaN/Si heterostructures by thermal vacuum deposition and further thermal annealing. Using various methods of post-growth treatment, a dielectric insulating layer was deposited over the emitter layer, while tips of the NWs were left uncovered and then a conductive transparent indium-tin oxide (ITO) coating was applied via magnetron sputtering. On the basis of these heterostructures solar photoconverters with a photoactive region in the form of a circular meze 2.5 mm in diameter were fabricated.

Current-voltage characteristics (I-V characteristics) were measured using a Keithley 2400 SourceMeter multimeter and thermo-stabilized stage under illumination conditions of the AM 1.5G solar spectrum.

Spectral dependence of external quantum efficiency (EQE) was measured in the 350 – 1200 nm wavelength range using M266 (Laser Solar) monochromator and calibrated silicon photodiode with known spectral characteristics. The temperature during electric and spectral measurements was maintained at 25°C.

### 3. Results and discussion

The samples I-V curves measured before and after the passivation are shown in Fig. 2 demonstrating that hetero-interface passivation has significantly affected the curves. It can be also noticed that there is a big gain of short-circuit current (up to 26mA/cm²) and double open-circuit voltage increase (up to 0.3V). The curve inclination at the reverse voltages before passivation (Fig. 2a) indicates the low shunt resistance presence, however, it is insufficient after the passivation. The dominance of hetero-interface recombination is the most likely reason the obtained I-V curve form (Fig. 2a) [7]. The practically
linear shape of the forward part of I-V characteristic (Fig. 2b) indicates the presence of parasitic series resistance. Hydrogen passivation is seen to have no effect on the series resistance.

**Figure 2(a, b).** (a) Light and dark I-V characteristics before hydrogen passivation; (b) after hydrogen passivation

Fig. 3 demonstrates the samples spectral dependencies of external quantum efficiency (EQE) before and after passivation. The passivation influence can be easily noticed.

**Figure 3.** Experimental spectral characteristics before and after the passivation.
The obtained curves demonstrate drop of the EQE in the infrared part of spectrum. However, this effect can be observed both before and after the passivation. So we can conclude that this phenomenon can be concerned not with the heterointerface. Low EQE values in longwave range are dictated by recombination in the SC base and therefore low minority carriers lifetime in p-Si [8, 9]. This effect can be explained with bottom Al contact annealing at high temperature which might have increased the number of defects at the Si/Al interface. Thus IR-photons could be trapped by these defects more effectively.

4. Summary
In the course of the work, the characteristics of a series of n-GaN NWs / p-Si heterostructures synthesized at various technological parameters, before and after passivation, were compared. To determine the electrical and spectral characteristics of these structures, ohmic contacts were fabricated by thermal vacuum deposition of metals, magnetron sputtering and thermal annealing methods. I-V curves of the samples were obtained using the AM1.5G solar spectrum imitator. Spectral dependencies of external quantum efficiency (EQE) were obtained in the 300 – 1200 nm range. It is concluded that hydrogen passivation reduces current losses at the interface.

Acknowledgments
This work was carried out with the support of the Russian Federation President grants (MK-6492.2018.2, MK-3632.2017.2 and SP-2324.2018.1), the Russian Foundation for Basic Research (16-32-60094 mol_a_dk, 163200560 mol_a and 18-32-00899 mol_a), the leading universities of the Russian Federation (grant 074U01), grant of government of the Russian Federation (3.9796.2017/8.9 and 16.2593.2017/4.6).

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