Passivation of GaInP and AlInP surfaces for III-V solar cells

TOPIC 4: CONCENTRATOR AND SPACE PHOTOVOLTAICS
4.1 III-V-based Devices for Terrestrial and Space Applications

Passivation of GaInP and AlInP surfaces for III-V solar cells

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Aim and approach used

The quality of the III-V semiconductor surfaces plays a significant role in the performance of the photovoltaic (PV) devices. Surface states, which cause non-radiative surface recombination and loss of photo-generated charge carriers, can lead to degradation in solar cell performance. Therefore, appropriate surface passivation is required. Passivation involves removal or neutralization of undesired surface states [1], which can be realized either by surface treatments or by depositing passivating layers.

High-efficiency III-V solar cells usually employ a so-called window layer forming the top surface and having a larger bandgap than the pn-junction underneath. The purpose of the window layer is to provide surface passivation by forming a potential barrier for minority carriers and thus carrier recombination on the surface [2]. For instance, GaInP and AlInP can be used as window layers in GaAs and (Al)GaInP solar cells, respectively. Thick window layers work better in preventing minority carrier flow to the surface, but on the other hand, they should be as thin as possible to minimize the absorption of short-wavelength radiation. However, when the thickness of the window is reduced, the probability for surface recombination increases due to carrier tunneling through the potential barrier. Then this issue can be mitigated by employing surface passivation by termination of the dangling bonds or by inactivating other surface defects. In the extreme case, assuming excellent passivation of the surface, the entire window layer could be removed revealing the underlying pn-junction material. Therefore, finding an optimal non-absorbing surface passivation technique is critical.

Multiple passivation techniques have been studied for III-V semiconductor surfaces so far. These include, e.g., liquid passivation techniques, such as ammonium sulfide, which is suggested to passivate through sulfur atoms terminating the dangling bonds and thus prevent oxygen from adsorbing on the surface [3]. Various plasma-assisted methods have also been applied for III-V surface passivation [1], including for example NH_3 plasma nitridation of GaAs [4] and NH_3/N_2 plasma passivation of AlInP facets of red laser diodes [5]. Al_2O_3 films grown by atomic layer deposition (ALD) have gained attention due to passivating properties for silicon, recently applied on black silicon solar cells [6]. In addition, metalloid and metal oxide based passivating coatings have been applied successfully on PV devices [7]. The purpose of the work is to study and optimize practical surface passivation methods for GaInP and AlInP surfaces and assess their influence on solar cell operation.

Scientific innovation and relevance

Thinner window layer or even removing it completely, followed by surface passivation, enables reduced unwanted ultraviolet absorption within the window layer leading to higher solar cell conversion efficiencies. Especially, thinner AlInP window could be beneficial for multijunction solar cells incorporating top-junctions with increased bandgap. Moreover, for GaAs based solar cells similar beneficial effects are expected for GaInP window layers. In this study, we apply different passivation techniques on GaInP and AlInP surfaces. The effect of passivation is assessed using single-junction GaInP solar cells and GaInP/GaAs/GaInNAs multijunction solar cells, characterized by current-voltage measurements.

Preliminary results and conclusions

The schematic illustration of the cell structure under investigation is shown in Fig. 1. To investigate the passivation of the GaInP surface, the contact GaAs and the AlInP window layers were removed entirely after metal contact deposition by electron beam evaporation. The active area short-circuit current density (J_{sc}), open-circuit voltage, and fill factor dropped from 9.3 mA/cm^2, 1.16 V, and 77% to 3.3 mA/cm^2, 1.10 V, and 51%, respectively.

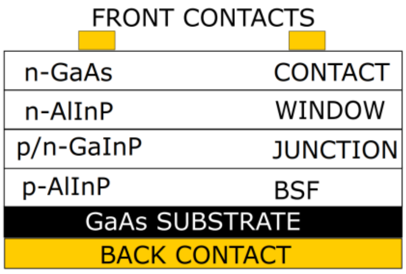

Figure 1. *Schematic of a solar cell structure under investigation. The lattice-matched structure was grown by molecular beam epitaxy.*

The effect of N_2 and N_2/NH_3 plasma treatments and plasma-enhanced chemical vapor deposition (PECVD) of either thin SiO_2 or SiN_x cap were investigated. N_2 and N_2/NH_3 plasma treatments were found to increase the J_{sc} considerably (see Fig. 2) when compared to solar cell performance before treatments, which is an indication of passivation effect. The increase in the J_{sc} values were 52% and 60%, for N_2 and N_2/NH_3 plasma treatments, respectively. Moreover, the PECVD-grown SiO_2 cap layer was found to have a slight passivation effect on GaInP surface, for which the increase in J_{sc} was 30%. The SiN_x layer did not show any passivation effect on the GaInP surface, but instead the J_{sc} decreased from 3.3 mA/cm^2 to 0.4 mA/cm^2. Other passivation methods are currently investigated.

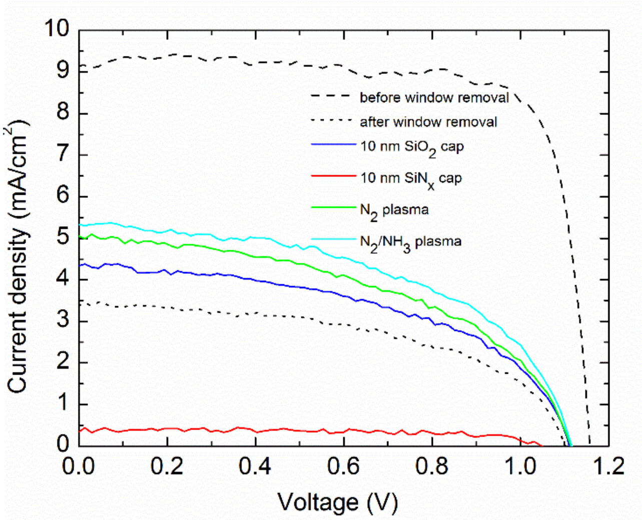

Figure 2. *Current-voltage performance of 1J GaInP solar cells before and after AlInP window removal (before passivation) and after passivation of the GaInP surface with a SiO_2 cap, a SiN_x cap, N_2 plasma treatment, and N_2/NH_3 plasma treatment. Antireflection coatings were not applied.*

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