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Selective rear contact for $Ga_{0.5}In_{0.5}P$- and GaAs- based solar cells

Sun-Tae Hwang, Taehyun Hwang, Sangheon Lee, Bumjin Gil, Byungwoo Park*

WCU Hybrid Materials Program, Department of Materials Science and Engineering, Research Institute of Advanced Materials, Seoul National University, Seoul 08826, South Korea

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ABSTRACT

The light management strategy was applied in III-V solar cells for the maximum utilization of incident photon, namely the selective rear contact was adopted in $Ga_{0.5}In_{0.5}P$- and GaAs- based solar cells. By etching the rear contact layer (*p*-GaAs) with photolithography, the distinctive morphological structures consisting of polka-dot patterns were formed, which led to increased reflection and thereby the device performance. Furthermore, the photolithography was controlled to find the optimum contact ratio between the back-surface field and the rear contact. Consequently, the conversion efficiency was increased from η = 15.5% to 16.3% for the $Ga_{0.5}In_{0.5}P$-based single-junction solar cell, and from η = 21.1% to 21.9% for the GaAs-based one, both at the contact ratio of 10%, compared to the cells with full (100%) rear contact ratio. Finally, the selective rear contact was applied to double-junction solar cells ($Ga_{0.5}In_{0.5}P$- and GaAs- based), exhibiting that this straightforward rear-contact strategy has enabled reaching the efficiency of η = 30.6% with an anti-reflective coating.

1. Introduction

Group III-V solar cells, particularly GaAs-based ones, are the best candidates to achieve the Shockley-Queisser efficiency limit, owing to their high mobility and absorption coefficient [1–4]. The world-best single-junction GaAs-based solar cell has a conversion efficiency of 28.8% [5,6], far exceeding other competitors such as silicon, quantum dots, and organometal perovskites [7–10]. However, ~ 4% deficit still remains compared to the Shockley-Queisser efficiency limit for the single-junction solar cell (~ 33.5%).

Recent reports emphasize that light extraction is the main reason limiting the conversion efficiency of III-V solar cells [1,11,12]. In particular, the internal luminescence efficiency, mainly affected by the reflectance in front and rear surfaces, is considered as a crucial factor to be improved, toward the multiple photon recycling [11,12]. Increasing the internal luminescence efficiency from 90% to 100% leads to ~ 7% gain in the conversion efficiency of the GaAs solar cells. Moreover, both the open circuit voltage (V_{oc}) and the conversion efficiency (η) can be enhanced by ~ 3% by increasing the rear reflectivity from 90% to 100% [1].

Passivated emitter with rear locally-diffused cell (PERL), a well-known structure in the silicon solar cell industry, is an example to increase the rear reflectivity [13–15]. In this structure, an oxide layer is incorporated to increase the internal luminescence efficiency by improved rear reflection, with a rear point electrode to maintain ohmic contact, leading to an increase in the V_{oc} and short-circuit current density (J_{sc}) of the device.

In III-V solar cells, several approaches have been reported to increase the rear reflectivity [7,16,17]. These mainly utilize dielectric materials of which the refractive index differs largely from that of adjacent III-V material for the back reflection of light into the absorption layer. However, these approaches normally require additional processes such as sputtering and atomic layer deposition to deposit dielectric materials [16,17]. In addition, the absorption of dielectric materials itself also limits the complete utilization of light.

In this study, the rear contact layer is selectively etched in the III-V based solar cells to minimize the absorption loss from the rear contact layer, without any additional deposition processes. The reflection properties of the III-V based solar cells are investigated as the fraction of the selective rear contact (called contact ratio) is modified. Thereby, the performances of the III-V solar cells are logically optimized in GaAs-based single-junction, $Ga_{0.5}In_{0.5}P$-based single-junction, and $Ga_{0.5}In_{0.5}P$- and GaAs- based (top and bottom, respectively) double-junction solar cells.

2. Experimental section

Each layer of the GaAs solar cell was deposited on the GaAs substrate by reacting some of the following precursors via metal-organic chemical vapor deposition (MOCVD): trimethylgallium (TMGa), arsine (AsH_3), trimethylaluminium (TMAl), phosphine (PH_3), and trimethylindium (TMIn). Disilane (Si_2H_6) and dimethylzinc (DMZn) were used

* Corresponding author.
E-mail address: byungwoo@snu.ac.kr (B. Park).

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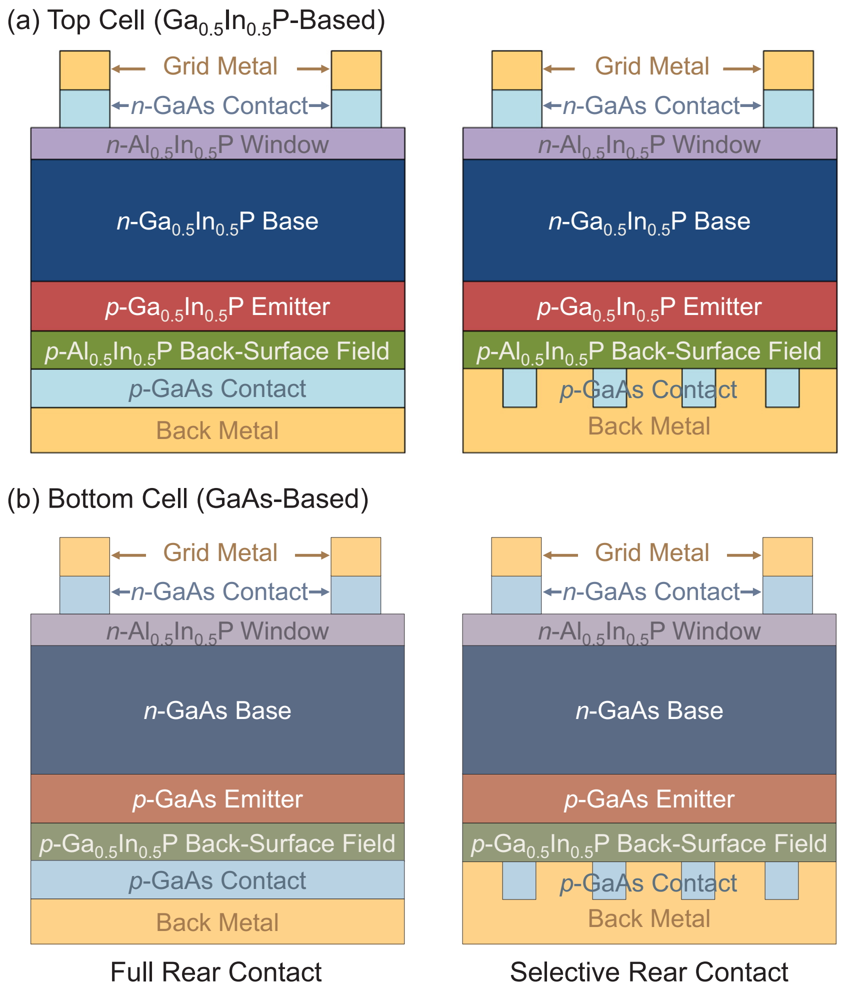

Fig. 1. Schematics of the single-junction $Ga_{0.5}In_{0.5}P$- and GaAs- based solar cells, with full or selective rear contact between *p*-GaAs-contact and back-metal layers. (a) $Ga_{0.5}In_{0.5}P$-based top cell, and (b) GaAs-based bottom cell.

as Si and Zn sources for the *n*-type and *p*-type doping layers, respectively. Tetrabromomethane (CBr_4) was utilized as carbon source for the *p*-type doped tunnel junction layer.

The *p*-GaAs rear contact layer (deposited on each solar cell) was selectively etched by photolithography. Remaining rear contact layer formed a polka-dot pattern, each dot of which had a diameter of 15 µm. The contact ratio, defined as the fraction of the rear contact area left after etching to the initial area, was determined to be 33%, 10%, and 5%, from the gap between dots in each pattern (25, 45, and 65 µm, respectively).

The GaAs substrate was removed by epitaxial-layer liftoff processes. Other processes such as deposition of the anti-reflective coating (ARC) layers were carried out as previously reported [18]. All solar cells were characterized as the size of 1 cm^2 by the mesa etching. For mesa etching, arsenide layers were etched by a mixture of ammonia and hydrogen peroxide, and phosphide layers were etched by hydrochloric acid. The front grid and back-contact metals were Pd/Ge/Au stack and Au, respectively. The conversion efficiency was measured using a solar simulator (Wacom) under the standard test conditions (AM 1.5, 1 sun or 100 mW cm^{-2} at 25 °C). The reflectivity was analyzed by the spectrophotometer (JASCO V-670).

3. Results and discussion

3.1. The structures of the solar cells and their rear contact layers

To investigate the effect of selective rear contact, several solar cell structures were considered in this study. As the simplest one, GaAs-based single-junction solar cell is shown with full or selective rear-contact configuration (Fig. 1). Detailed explanation of this structure has been previously reported [18]. The structure of the $Ga_{0.5}In_{0.5}P$-based single-junction solar cell is also investigated, with full or selective rear-contact configuration. Selective rear contact is also employed in the III-V based double-junction solar cells, whose light-absorbing base layers were $Ga_{0.5}In_{0.5}P$ and GaAs for the top and bottom cells, respectively (Fig. 2). Distinctively, double-junction solar cells have additional heavily-doped tunnel junction layers between the single-junction cells.

The optical microscope images after the selective etching of rear contact *p*-GaAs layer are displayed (Fig. 3), demonstrating the formation of artificial patterns as intended by facile photolithography. After the selective etching, the subsequent layer (*p*-$Ga_{0.5}In_{0.5}P$ back-surface field) was exposed at the etched regions, whereas *p*-GaAs contact layer was protruded from the *p*-$Ga_{0.5}In_{0.5}P$ surface. The polka-dot pattern was clearly observed due to the different contrasts of *p*-GaAs and *p*-$Ga_{0.5}In_{0.5}P$, arising from their different dielectric constants. The diameter of each circle was 15 µm as designed for the photolithography, and the ratios of the remaining region (contact ratio) were controlled.