InGaAs(P) ternary and quaternary compounds have been extensively used in optical communication devices because their energy bandgaps can cover the operating windows, 1.3 and 1.55 µm wavelengths. Recently their usage have been extended to the photovoltaics application, especially multiple junction solar cells which 46% conversion efficiency of InGaP/GaAs/InGaAsP/InGaAs 4-junction structure has been reported [1]. Hence, the development of InGaAs an InGaAsP subcells on InP substrates has become one of intensive research interests of III-V semiconductor solar cells. In this study, 0.74-eV InGaAs and 1.04-eV InGaAsP n-p solar cells were successfully grown in a planetary metalorganic vapor phase epitaxy (MOVPE) reactor. Tertiarybutylarsine (TBAs) and tertiarybutylphosphine (TBP) were utilized as alternative group V precursors to extremely hazardous arsine (AsH$_3$) and phosphine (PH$_3$).

This study shows that the growth temperature is a very important parameter in order to realize good crystal quality and smooth surface morphology of InP, InGaAs, and InGaAsP. A low growth temperature was necessitated to overcome the predecomposition of group V precursors and to prevent the gas-phase parasitic reactions. In contrast, a high growth temperature was favorable in the case that the enhancement of the surface migration of adatoms, especially In, was required. Owing to these understandings, epitaxial InGaAs, and InGaAsP layers lattice-matched to InP were realized with excellent crystal properties. In-situ wafer’s curvature, photoluminescence (PL) and X-ray diffractometer (XRD) measurements were used in order to evaluate the composition of In and P in InGaAs(P). The free carrier concentrations in Zn-doped and S-doped epitaxial layers were evaluated by electrochemical capacitance-voltage (ECV) technique.

Figures 1(a) and 1(b) shows the I-V characteristics under AM1.5 illumination and external quantum efficiency (EQE) spectra of the 0.74-eV InGaAs and 1.04-eV InGaAsP n-p solar cells, respectively. The thickness of p-InGaAs and p-InGaAsP base layers were 2-µm and 1-µm thick, respectively. The band gap-voltage offset ($E_g/q V_{oc}$) [2] of the InGaAs cell was 0.36 V, while that of the InGaAsP cell was 0.40 eV. These values indicated that the nonfundamental recombination due to Shockley-Read-Hall (SRH) process in the InGaAs sample was slightly lower than that in the InGaAsP cell. This fact can most likely be explained by a higher defect density in the InGaAsP sample grown at a relatively lower temperature. Nevertheless, the InGaAs(P) ternary and quaternary alloys have been successfully grown using TBAs and TBP, and their photovoltaic application has been demonstrated. The further research topics are focusing on the fabrication of InGaAsP/InGaAs dual junction cells and the direct wafer bonding between GaAs and InP substrates for multijunction solar cells.

[1] F. Dimroth et al., J. Photovoltaics 6, 2016; 343, DOI: 10.1109/JPHOTOV.2015.2501729