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1. Introduction

Molecular beam epitaxy (MBE) has recently emerged as the preferred alternative for the development of multi-junction solar cells incorporating dilute nitride heterostructures, i.e. family of GaInNAsSb/GaAs compounds. Despite the proven potential of this material system for demonstrating lattice-matched tandem cells with four or more junctions, a certain level of pessimism remains in respect with the potential for large scale deployment of MBE, as cost-effective manufacturing approach of III-V solar cells. While there are clear cost advantages regarding the use of metal-organic chemical vapor deposition (MOCVD), largely linked to the high growth rates and throughput, there are no fundamental limits that would prevent emergence of MBE as a cost-effective manufacturing technology for solar cells with 4 or more junctions. As an intermediate step towards wider use of MBE dilute-nitride technology for solar cell applications, we propose a novel approach combing the best parts of the MOCVD and MBE techniques.

2. Fabrication method and results

The fabrication method is based on growing the bottom dilute nitride sub-junction by MBE and the top junctions (thicker region) by MOCVD (see schematic shown in Fig. 1, left). Proof-of-concept triple junction solar cells were fabricated on 4” p-GaAs(100). The MBE part was deposited with a VEECO GEN20 MBE system and comprised of a dilute nitride p-i-n structure with a transfer interface for the MOCVD process. The MBE process of dilute nitride junction is described elsewhere [1]. After the MBE process, the samples were transferred to the MOCVD system. The MOCVD deposition was done in an industrial VEECO reactor able to process up to 13 wafers with diameter of 4” in a single growth run. After a nucleation layer, optimized to maintain a good morphology between MBE and MOCVD steps, a tunnel diode was deposited consisting of a highly doped (Al)GaAs n++/p++ diode. The GaAs and GaInP sub-junctions were kept quite thin with respect to a standard triple junction solar cell [2] to match the current of the GaInNAs junction and to decrease the effect of thermal induced degradation. An interesting observation is that the external quantum efficiency corresponding to the 1 eV dilute nitride solar cells increased upon overgrowth by MOCVD.

The wafers were processed to individual cells with a size of 2 cm × 2 cm. The prototype devices exhibited excellent *I-V* characteristics (see Fig. 1, right) and good uniformity across the wafers. The short-circuit current density corresponding to dilute nitride junction was estimated by integrating the EQE characteristic and had a value of about 17 mA/cm^2. Based on the performance of individual cells, we estimate that optimized tandem design could lead to efficiency over 43% when using 500-sun concentrators (AM1.5D). Detailed characteristics of the cells will be described together with a comparison of main features of MBE and MOCVD technologies that should be consider for volume production.

References

[1] A. Aho et al., “Composition dependent growth dynamics in molecular beam epitaxy of GaInNAs solar cells”, Solar Energy Materials and Solar Cells, 124, pp.150–158 (2014).

[3] Roberta Campesato, Maria Cristina Casale, Giuseppe Gabetta, Gabriele Gori,” Electron and proton Irradiation on High efficiency III-V solar cells based on three and four junctions” EU PVSEC Proceeding (2013).

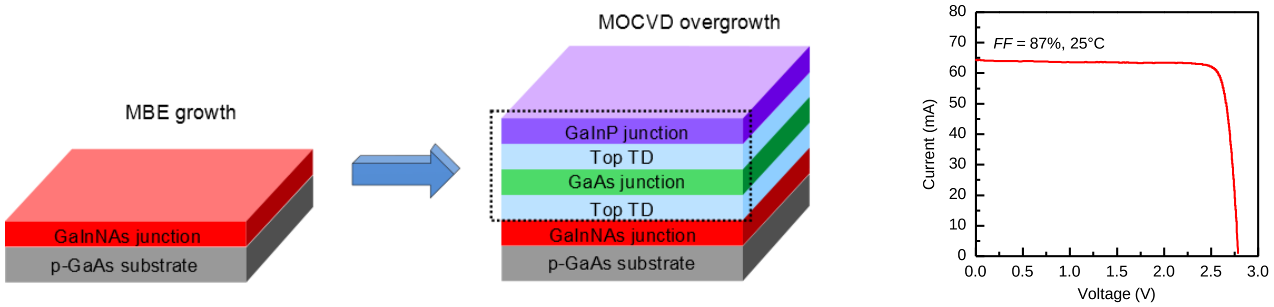

Figure 1. Schematics of the fabrication process (left) and electrical characteristic of the GaInP/GaAs/GaInNAs solar cell (right).