Combined MBE-MOCVD process for high-efficiency multijunction solar cells

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***Abstract*—Wepresent a fabrication method for high-efficiencyGaInP/GaAs/GaInNAs triple junction solar cells, employing molecular beam epitaxy (MBE) and metal-organic chemical vapor deposition (MOCVD) processes. The method combines the advantages of both epitaxial techniques, the high quality of MBE-grown dilutenitrides and fast growth rate offered by MOCVD for standard III-V compounds. The GaInNAs bottom junction is first grown by MBE and then the rest of the structure is deposited by MOCVD. Triple-junction cells with conversion efficiency of ~29% at AM0 are demonstrated, opening a new perspective on cost-effective fabrication of high-efficiency multijunction solar cellsfor space and concentrated photovoltaic applications.**

Keywords—multijunction solar cell; molecular beam epitaxy;metal-organic chemicalvapor deposition; dilute nitride semiconductors

MBE has recently emerged as the preferred alternative for the development of multi-junction solar cells incorporating dilute nitride heterostructures, i.e. family of GaInNAs-based compounds. This material system has already shown to perform very well as a bottom junction of triple junction solar cells. However, it is currently hard for MBE to compete with MOCVD in terms of growth rates or throughput in fabrication of III-V triple junction solar cells. To tackle this challenge, we have developed a mixed approach in which the best parts of the two different epitaxial growth methods are combined to realize high-efficiency GaInP/GaAs/GaInNAs solar cells.

First, the bottom GaInNAs junction consisting of a simple n-GaAs/i-GaInNAs/p-GaAs/p-GaInP/p-GaAsn-i-p diode structure with a transfer interface for MOCVD overgrowth process was grown on a p^+-GaAs(100) substrate by VEECO GEN20 MBE system (see schematic shown in Fig. 1, left).The details of the MBE process for the GaInNAs junctionare discussedelsewhere.[1,2]Then, the wafers were transferred to an MOCVD reactor for the subsequent growth steps (see schematic in Fig. 1, right).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. First, a nucleation layer was grown to maintain a good morphology. Then, an (Al)GaAs-based tunnel junction was grown followed by the GaAs junction, the second tunnel junction and the GaInP top junction.[3]

The overgrown wafers were first processed to small areasolar cells (2 cm × 2 cm) and were characterized at AM0 conditions. The prototypes exhibited excellent external quantum efficiency (EQE), shown in Fig. 2a, andcurrent-voltage (*I-V*) characteristics, shown in Fig. 2b. A good uniformity across the wafers was achieved. Furthermore, the process was found to be robust and have a good repeatability from one growth run to another. The small size cell had an efficiency of slightly over 29%.Moreover, larger area cells were prepared; the best 4 cm x 7 cm solar cell exhibited only marginally lower efficiency (~29%) compared to the bestsmall area cell. The average efficiencies of 10 and 20 best large area cells in a batch of 36 processed cells were 28.3% and 27.5%, respectively.Further optimization of the GaInP/GaAs/GaInNAs structure will likely boost their efficiency over 31% at AM0 and over 43% at concentrated sunlight.

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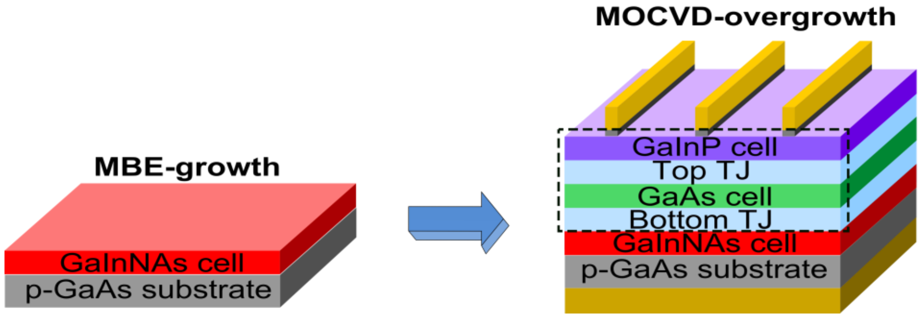

Figure 1.Schematics of the combined MBE-MOCVD fabrication process.

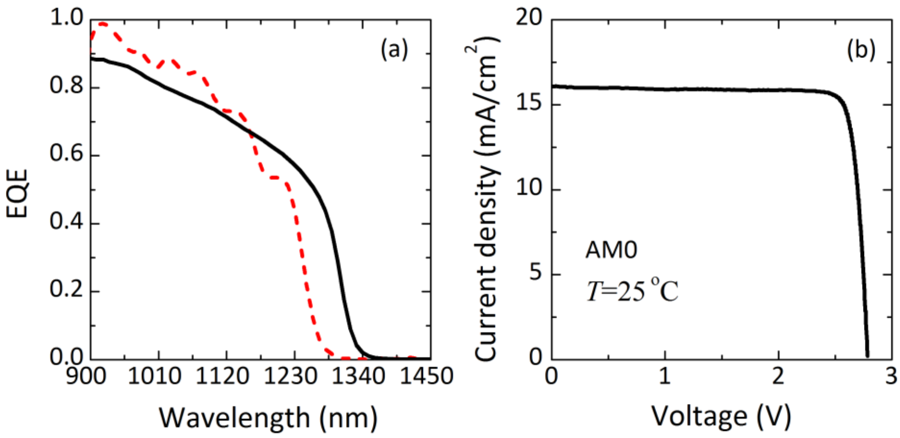

Figure 2. (a) EQE of the GaInNAs sub-junction before (black solid line) and after (red dashed line) MOCVD overgrowth. (b) Electrical characteristics (*I*-*V* measurement) of a small areaGaInP/GaAs/GaInNAs solar cellprepared using the combined MBE-MOCVD growth method.