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Nobel materials and structures for super high efficiency multi-junction solar cells

Y. Ohshita*, H. Suzuki, N. Kojima and M. Yamaguchi

Toyota Technological Institute, 2-12-1 Hisakata, Tempaku, Nagoya, 468-8511, Japan
y_ohshita@toyota-ti.ac.jp

* Corresponding author.

Abstract – III-V compound multi-junction solar cells have great potential for space and terrestrial applications because they have high efficiency potential of more than 50% and superior radiation-resistance. As a result of developing wide bandgap InGaP double hetero structure tunnel junction for sub-cell interconnection, InGaAs middle cell lattice-matched to Ge substrate, and InGaP-Ge heteroface structure bottom cell, we have demonstrated 38.9% efficiency at 489-suns AM1.5 with InGaP/InGaP/Ge 3-junction solar cells. In order to realize 40% and 50% efficiency, new approaches for novel materials and structures are being studied.

The conversion efficiency of sunlight to electricity is limited around 25%, when we use single junction solar cells. In the single junction cells, the major energy losses arise from the spectrum mismatching. One way of reducing these losses is fabricating tandem or stacked solar cells. Merely stacking the more number of cells with different bandgap can increase the conversion efficiency. III-V compound multi-junction solar cells, such as InGaP/GaAs/Ge, have the potential for achieving high conversion efficiencies that are promising for space and terrestrial applications. One of the important issue for realizing the high conversion efficiency is the optically and electrically low-loss interconnection of each sells. A degenerately impurity doped tunnel junction, which is thin and wide-bandgap, is an attractive one, and a double hetero structure is useful for preventing impurity diffusion during overgrowth of the top cell. Another issue is a lattice matching. Since there is a slightly difference in the lattice constant between Ge substrate and GaAs, the misfit dislocations are generated in thick GaAs layers and the electrical properties degrade. To prevent this problem, InGaAs is applied as a middle cell material, which is lattice matching to the Ge substrate. So far, the conversion efficiency of InGaP/InGaAs/Ge has been improved up to 29-30% (AM0) and 31.7% (AM1.5G)(Fig. 1). The concentrator cells achieved the higher conversion efficiency up to 40.1% under 240 suns by lattice match system and 41.4% under 454% by lattice mismatch system. For realizing a future multi-junction solar cell with higher conversion efficiency, InGaAsN and related materials are investigated, because it can be grown lattice matched to GaAs with a band gap in the range of 0.9 - 1.4 eV. When we adopt the InGaP/GaAs/InGaAsN/Ge cell structure, the high conversion efficiency over 40% (AM1.5G) will be expected. However, the minority carrier diffusion length in the present InGaAsN crystal is too short to realize the tandem solar cells with the expected high performance. To solve this problem, we have been developing the chemical beam epitaxy (CBE) method (Fig. 2). The films are grown using organic gas molecules as sources under a high vacuum condition (10^{-2} Pa). Because of the ultra low pressure, the reactions between the source gas molecules in the gas phase are suppressed and the reactions occur only on a growing surface, which allow using active source gases that decompose at low temperatures. GaAsN thin films are grown using monomethylhydrazine as an N source with narrow X-ray diffraction peaks at growth temperatures in the 380-420C range. In the present talk, we will review the progress of high conversion efficiency tandem-solar cells and discuss some of our recent results.

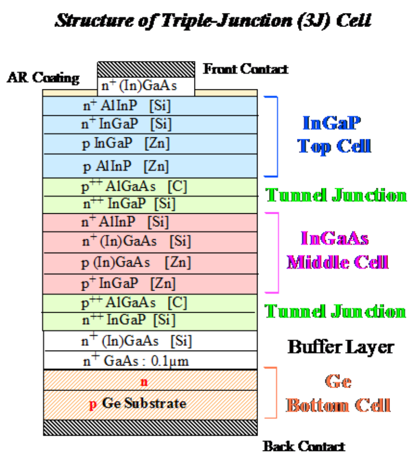

Fig. 1 Structure of triple-junction cell.

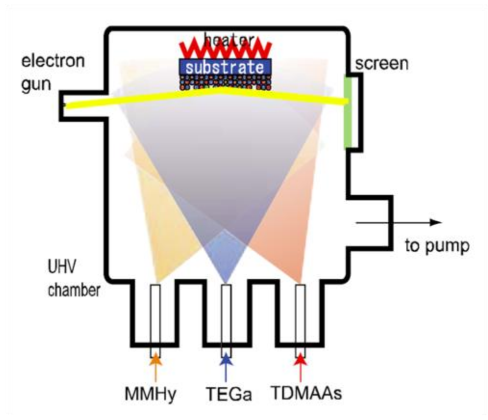

Fig. 2 Schemcatial image of chemical beam epitaxy.