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Super high-efficiency multi-junction and concentrator solar cells

Masafumi Yamaguchi[a,*], Tatsuya Takamoto[b], Kenji Araki[a,c]

[a]*Toyota Technological Institute, 2-12-1 Hisakata, Tempaku, Nagoya 468-8511, Japan*
[b]*Sharp Corporation, 282-1 Hajikami, Shinjo, Nara 639-2198, Japan*
[c]*Daido Steel Corporation, 2-30 Daido-cho, Minami, Nagoya 457-8545, Japan*

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Abstract

III–V compound multi-junction (MJ) (tandem) solar cells have the potential for achieving high conversion efficiencies of over 50% and are promising for space and terrestrial applications.

We have proposed AlInP–InGaP double hetero (DH) structure top cell, wide-band gap InGaP DH structure tunnel junction for sub cell interconnection, and lattice-matched InGaAs middle cell. In 2004, we have successfully fabricated world-record efficiency concentrator InGaP/InGaAs/Ge 3-junction solar cells with an efficiency of 37.4% at 200-suns AM1.5 as a result of widening top cell band gap, current matching of sub cells, precise lattice matching of sub cell materials, proposal of InGaP–Ge heteroface bottom cell, and introduction of DH-structure tunnel junction. In addition, we have realized high-efficiency concentrator InGaP/InGaAs/Ge 3-junction solar cell modules (with area of 7000 cm^2) with an out-door efficiency of 27% as a result of developing high-efficiency InGaP/InGaAs/Ge 3-junction cells, low optical loss Fresnel lens and homogenizers, and designing low thermal conductivity modules.

Future prospects are also presented. We have proposed concentrator III–V compound MJ solar cells as the 3rd-generation solar cells in addition to 1st-generation crystalline Si solar cells and 2nd-generation thin-film solar cells. We are now challenging to develop low-cost and high output power concentrator MJ solar cell modules with an output power of 400 W/m^2 for terrestrial applications and high-efficiency, light-weight and low-cost MJ solar cells for space applications.

Keywords: Multi-junction solar cells; III–V compounds; Concentrator solar cells; Concentrator modules; High conversion efficiency; Tunnel junction

*Corresponding author. Tel.: +81 52 809 1875; fax: +81 52 809 1879.
E-mail address: masafumi@toyota-ti.ac.jp (M. Yamaguchi).

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1. Introduction

III–V compound multi-junction (MJ) solar cells have the potential for achieving conversion efficiencies of over 50% [1] as shown in Fig. 1 and are promising for space and terrestrial applications. One of the authors has started his researches on AlGaAs/GaAs 2-junction solar cells since 1982 and his group has demonstrated 20.2% efficiency by proposing double hetero (DH) structure tunnel junction as a sub cell interconnection in 1987 [2]. In Japan, based on such an activity, R&D project for "Super-high Efficiency MJ Solar Cells" has been conducted under support by NEDO since fiscal year (FY) 1990 [3] as a long-term target to the early 21st century, in which challenges and efforts are made in the development of super-high-efficiency solar cell technology, aiming at a dramatic increase in conversion efficiency of over 40% and developing innovational technologies. We have proposed AlInP–InGaP DH structure top cell, wide-band gap InGaP DH structure tunnel junction for sub cell interconnection, and lattice-matched InGaAs middle cell. As a result of the above technology developments, the mechanically stacked InGaP/GaAs/InGaAs 3-junction cells (1 cm^2) have reached the highest (1-sun world-record) efficiency of 33.3% at 1-sun AM1.5G following joint work by Japan Energy Co., Sumitomo Electric Co. and Toyota Tech. Inst. in 1997 [4]. A Japanese project supported by NEDO has made a great contribution to the progress of conversion efficiency.

The concentrator system must be a powerful tool to enable MJ cells to be used in terrestrial application because the system reduces the cell cost and increases the production scale dramatically according to the concentration ratio [5]. In order to develop high-efficiency and low-cost concentrator MJ solar cell and modules, the R&D project for "Concentrator MJ Solar Cells and Modules" has started under NEDO support since FY2001.

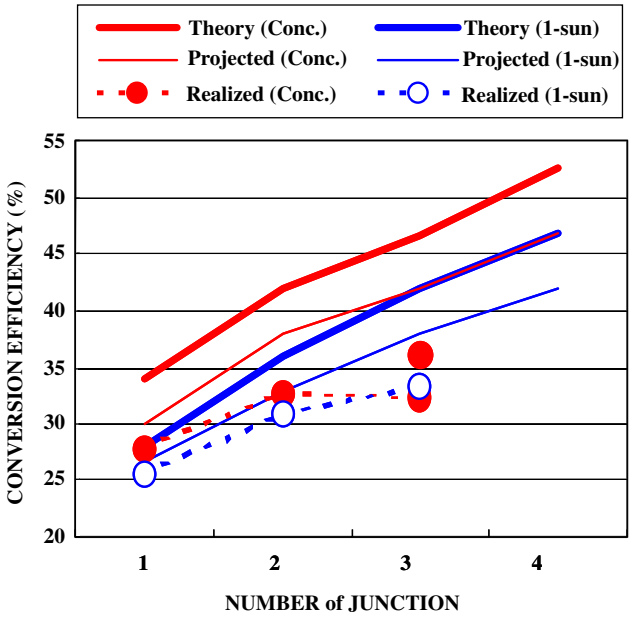

Fig. 1. Theoretical and realistically expected conversion efficiencies of single-junction and multi-junction solar cells in comparison with experimentally realized efficiencies under 1-sun and concentration conditions.