# Chapter 108
# Super High Efficiency Multi-Junction Solar Cells and Concentrator Solar Cells

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## ABSTRACT

*While single-junction solar cells may be capable of attaining AM1.5 efficiencies of up to 29%, Multi-Junction (MJ, Tandem) III-V compound solar cells appear capable of realistic efficiencies of up to 50% and are promising for space and terrestrial applications. In fact, the InGaP/GaAs/Ge triple-junction solar cells have been widely used in space since 1997. In addition, industrialization of concentrator solar cell modules using III-V compound MJ solar cells have been announced by some companies. This chapter presents principles and key issues for realizing high-efficiency MJ solar cells, issues relating to development and manufacturing, and applications for space and terrestrial uses.*

## INTRODUCTION

Multi-Junction (MJ, Tandem) solar cells are composed of multi-layers with different bandgap energies are shown in Figure 1 and have the potential for achieving high conversion efficiencies of over 50% and are promising for space and terrestrial applications due to wide photo response. Figure 2 shows theoretical conversion efficiencies of single-junction and Multi-Junction (MJ) solar cells in comparison with experimentally realized efficiencies.

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Tandem solar cells were proposed by Jackson (1955) and Wolf (1960). Table 1 shows progress of the III-V compound multi-junction solar cell technologies. MIT group (Fan, Tsaur, & Palm, 1982) encouraged R&D of tandem cells based on their computer analysis. Although AlGaAs/GaAs tandem cells, including tunnel junctions and metal interconnectors, were developed in the early years, a high efficiency close to 20% was not obtained (Hutchby, Markunas, & Bedair,

*Figure 1. A schematic structure of a multi-layer solar cell*

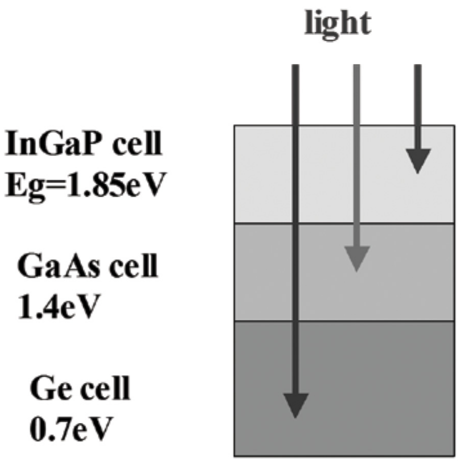
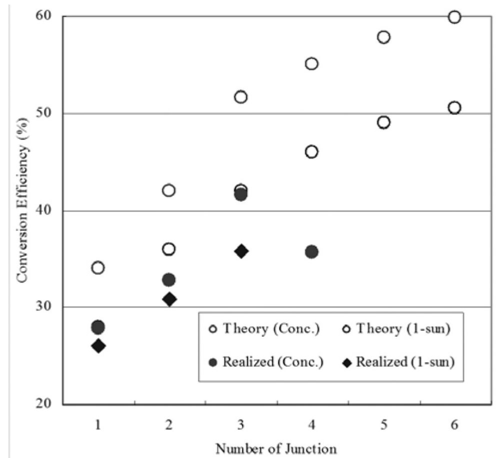



*Figure 2. Theoretical conversion efficiencies of single-junction and multi-junction solar cells in comparison with experimentally realized efficiencies*




1985). This is because of difficulties in making high performance and stable tunnel junctions, and the defects related to the oxygen in the AlGaAs materials (Ando, Amano, Sugiura, et al., 1987). A Double Hetero (DH) structure tunnel junction was found to be useful for preventing diffusion from the tunnel junction and improving the tunnel junction performance by the authors (Sugiura, Amano, Yamamoto, & Yamaguchi, 1988). The authors demonstrated 20.2% efficiency AlGaAs/GaAs 2-junction cells (Amano, Sugiura, Yamamoto, & Yamaguchi, 1987). An InGaP material for the top cell was proposed by NREL group (Olson, Kurtz, & Kibbler, 1990). As a result of performance improvements in tunnel junction and top cell, over 30% efficiency has been obtained with InGaP/GaAs 2-junction cells by the authors (Takamoto, Ikeda, Kurita, et al., 1997).

InGaP/GaAs-based MJ solar cells have drawn increased attention for space applications because superior radiation-resistance of InGaP top cells and materials have been discovered by the authors (Yamaguchi, Okuda, Taylor, et al., 1997). and those have the possibility of high conversion efficiency of over 30%. In fact, the commercial satellite (HS 601HP) with 2-junction GaInP/GaAs-on Ge solar arrays was launched in 1997 (Brown, Goldhammer, Goodelle, et al., 1997).

More recently, InGaP/GaAs-based MJ solar cells have drawn increased attention for terrestrial applications because concentrator operation of MJ cells have great potential of providing high performance and low-cost solar cell modules. For concentrator applications, grid structure has been designed in order to reduce the energy loss due to series resistance, and 38.9% (AM1.5G, 489-suns) efficiency has been demonstrated by Sharp (Takamoto, Kaneiwa, Imaizumi, & Yamaguchi, 2005). Most recently, 41.6% efficiency has been reported with InGaP/GaAs/Ge 3-junction concentrator cells by Spectrolab (King, Boca, Hong, et al., 2009). In addition, the authors have realized high-efficiency and large-area (5,445cm$^2$) concentrator InGaP/InGaAs/Ge 3-junction solar cell modules of an outdoor efficiency of 31.5% (Araki, Uozumi, Egami, et al., 2005). as a result of developing high-efficiency InGaP/InGaAs/Ge 3-junction cells, low optical loss Fresnel lens and homogenisers, and designing low thermal conductivity modules. Some companies including Sharp (Tomita, 2006) have announced to commercialise

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