Chapter 10
Low–Cost III–V Compound Semiconductor Solar Cells: Progress and Prospects

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ABSTRACT
The prospects for cost-effective flat plate (non-concentrator) solar cells based on III-V compound semiconductors (e.g., GaAs, InP, AlAs, and their alloys) are reviewed. Solar cells made in III-V materials are expensive, but outperform solar cells in every other materials system. The relatively high cost of compound semiconductor wafers necessitates a means to eliminate their use as substrates for epitaxial growth of conventional III-V solar cells. There are several approaches to this end, including thin-film solar cells on low-cost, dissimilar substrates such as glass, ceramics, and metal sheets; III-V solar cells epitaxially grown on silicon wafers; film transfer ('epitaxial lift off') techniques that allow re-use of the seeding substrate; and assembled arrays of small III-V solar cells on low-cost substrates. Grain boundary effects in polycrystalline III-V films can severely degrade solar cell performance, and impede the application of established thin-film technologies, as developed for amorphous silicon and II-VI semiconductor photovoltaics, to III-V semiconductor-based solar cells. The nearly fifty years of effort in developing thin-film III-V solar cells has underscored the difficulty of achieving large-grain sizes and/or low recombination grain boundaries in polycrystalline films of III-V semiconductors.

INTRODUCTION
One of the more promising thin-film approaches utilizes the epitaxial growth of an (Al)GaAs solar cell on a recrystallized germanium seeding layer deposited on a thermal-expansion matched (inexpensive) substrate such as alumina ceramic. Recent developments related to ‘assembled’ arrays of millimeter-sized III-V solar cells made by inkjet and contact printing, parallel transfer, robotic pick and place, and fluidic self-assembly, are in early stages but offer several avenues for high-efficiency III-V solar cells with much reduced costs. These designs often use integrated optics...
to improve light coupling to the array solar cells, and employ a low-cost, flexible polymer substrate.

In this review, we survey the prospects for cost-effective III-V compound semiconductor solar cells for terrestrial power generation. The III-V semiconductors include the binary compounds GaAs, InP, GaN, AlAs, AlP, and InAs, as well as ternary and quaternary alloys between these binaries, e.g., AlGaAs, InGaAs, InGaN, and AlGaAsSb. Currently, high-efficiency III-V solar cells are used as standard equipment for powering satellites and other space vehicles. High-efficiency III-V compound solar cells may also prove essential for economically-viable terrestrial concentrator photovoltaic systems. Our primary focus here, however, is on solar cells for lower-cost, non-concentrator systems—so called flat plate arrays with minimal tracking and external optics. In other words, III-V solar cells that might compete directly with silicon solar cells on cost and performance in, for example, stand-alone or grid-connected roof-top solar electric systems. By non-concentrator, we are excluding systems with external optics and/or tracking, but not flat-plate systems that use integral optics, such as lensed cover plates or gratings to effect focusing and concentration within the solar cell module.

BACKGROUND

The main attraction of III-V solar cells is their superior performance. III-V solar cells in the form of sophisticated epitaxial multi-junction device structures have demonstrated the highest conversion efficiencies (~40%) of any photovoltaic technology to date. The relevant performance data of various III-V solar cell technologies are summarized in Table 1, along with silicon solar cells that provide a performance benchmark. Secondary advantages of III-V solar cells relative to silicon solar cells include higher radiation resistance (crucial for space power, but not an over-riding consideration for terrestrial photovoltaics); more tolerance of increased operating temperatures, and higher operating voltages which reduce series resistance losses. It should be kept in mind that the best commercial silicon solar cells are already at ~20% efficiency (e.g., Sanyo HIT crystalline/amorphous silicon solar cell (Taguchi et al. 2005), and therefore, the areal cost of alternative single-junction III-V solar cells with similar efficiencies—and without the leveraging effect of optical concentration—will have to be comparable to that of the current premium single-crystal silicon solar cell technology. By the same reckoning, it can be inferred as a corollary that III-V solar cells that cost more than silicon on an areal basis will need to have a substantially higher conversion efficiency than the best silicon solar cells in order to challenge the predominance of silicon photovoltaics.

Given the intrinsically higher materials and processing costs of conventional III-V solar cells, one might reasonably ask whether such a cost goal is even possible, let alone worth the effort. Ultimately, a low-cost format for III-V solar cells is of interest because it could serve as a basis for subsequent adaptations to very high-efficiency multijunction solar cells. The III-V semiconductor alloys provide ‘tunable’ bandgaps, carrier confinement, various hot carrier effects, and efficient luminescence (for photon recycling), as well as thermophotovoltaic or thermionic operating modes that can be exploited in innovative solar cell designs commonly termed “Third Generation” photovoltaics, with predicted efficiencies in the 30-60% range (Green 2002; Coniber 2007]. Many of these effects and design options are not readily available, nor as well developed with silicon-based devices nor other semiconductors. Such high efficiencies would dramatically reduce balance-of-systems costs for solar electric installations, and also permit use where deployment is limited by available area such as urban rooftops. Novel solar cell design configurations may be enabled by alternative fabrication techniques developed for low-cost III-V solar cells, or alter-