Progress Toward High Efficiency Thin Film Photovoltaics

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ABSTRACT

This report summarizes the first Phase of an effort to produce high efficiency, III-V photovoltaics on low cost flexible substrates. This Phase I activity was focused on proving the viability of the new substrate technology. The long-term objective is a significant reduction in PV energy cost while reducing the use of constrained raw materials relative to state of the art thin film cells. A flexible polycrystalline substrate has been produced with typical grain boundary misorientations below five degrees. This "Virtual Single Crystal", terminates in a crystallographically aligned germanium surface, lattice matched to GaAs. Parallel experiments demonstrate encouraging performance in GaAs devices produced on polycrystalline Ge thin films.

1. Objectives

The primary goal of this effort is to enable a significant reduction in the cost of solar electricity by transferring the very high efficiency of III-V multijunction cells to a low cost, large area, flexible substrate. A significant benefit to this approach is the potential for elimination or reduction in the use of toxic (e.g. Cd, Se) and naturally constrained (e.g. In, Te) raw materials.

Higher cell efficiency and lower mass/watt provide downstream cost benefits through reduced module and installation costs. This approach supports major Solar Program Multi-Year Program Plan objectives; to make PV cost-competitive with central generation, to enhance building integration, and to enable new capabilities such as solar hydrogen production.

2. Technical Approach

Multijunction III-V photovoltaic cells exhibit the highest efficiency of any commercial cell, exceeding 30% AM1.5, 1 sun. However, III-V devices are very expensive due in part to the cost, size and fragility of the Ge or GaAs single crystal wafers on which they are produced. Transferring the high efficiency III-V MJ cells to a robust, flexible, large area substrate could enable new opportunities in both government and commercial PV by reducing cost, mass, and area per watt.

Previous work has demonstrated polycrystalline (poly-) GaAs single junction with 20% AM1.5 efficiency on a poly-Ge wafer[1] and NASA has recently demonstrated a similar cell estimated at 17% AM0 efficiency[2].

These results indicate that a polycrystalline III-V cell is viable, though the poly-Ge wafer provides little benefit relative to a single crystal wafer. We are translating the poly-GaAs results to a flexible thin film by a) introducing a metal foil substrate that reduces the impact of the grain boundaries (GB) and b) demonstrating GaAs growth on a random poly-Ge thin film. The two approaches converge in the future.

The influence of GB is drastically reduced if the crystallographic orientation of adjacent grains is closely aligned[3]. Large grain sizes also reduce the total GB volume. Our approach is to produce a low-cost, flexible metal foil substrate with large grains and with GB misorientations in the range of 3-5 degrees. A series of magnetron sputtered buffer layers is used to provide both chemical compatibility and a lattice transition to a germanium surface film that acts as the lattice-matched growth template for a III-V cell.

In addition, Ge films were deposited by magnetron sputtering on polished Mo wafers. Large Ge grains with random crystalline orientation were produced by thermal recrystallization prior to GaAs growth.

GaAs p/i/n single junctions were grown by OMVPE at NASA Glenn and processed into multiple device structures. Cells and diodes were characterized by optical and scanning electron microscopy, photoluminescence and I-V measurement.

3. Results and Accomplishments

GaAs devices were produced on biaxially textured Ge film on 35-micron metal foil by scalable large area processes and high quality GaAs was demonstrated on a poly-Ge thin film during this Phase I project.

3.1 Virtual Single Crystal Substrate

The VSC substrate consists of a specially processed metal foil and a series of epitaxial buffer layers. The surface quality of the base metal foil therefore controls the ultimate performance of the III-V film and the final device.

A high quality base metal foil exhibits relatively large and uniform grain size and the crystalline orientation of all grains is closely coordinated. Each grain will be nominally (001) out of plane and with the (100) in-plane directions closely aligned. The degree of alignment is assessed by x-ray diffraction pole figure analysis. The commercial objective is a full-width-at-half-maximum (FWHM) of less than 5°, and over 99% of the grains with the preferred alignment.

Wakonda has established a commercial source for substrate materials that approach the quality required for production. The pole figure exhibits about 5.5° FWHM and 98% preferred alignment (Fig. 1). A log-scale plot highlights secondary texture components.

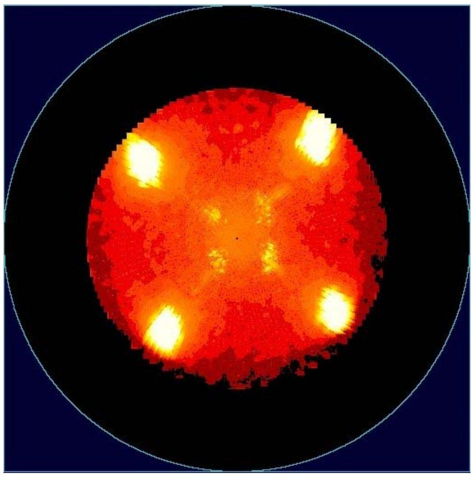

Figure 1 Log-scale pole figure of base metal foil.

The average grain size, measured by scanning electron microscopy is 100 μm. A grain boundary misorientation histogram calculated for the imaged area reveals that the majority of the grain boundaries are within 5° of the desired (001)<100> orientation.

The epitaxial buffer layers have two primary functions, they provide a lattice transition between the substrate and the III-V junction and they ensure chemical compatibility with the III-V materials.

The buffer layers culminate in a germanium layer that is intended to mimic the crystalline orientation and grain size of the underlying base metal foil. In practice, buffer layers engineered during this Phase I project improve the crystalline orientation.

The Ge pole figure (Fig. 2) shows a FWHM below 3°, substantially narrower than the substrate. The small amount of non-preferred grain alignment is reproduced in the Ge layer, attesting to the quality of the epitaxial growth process.

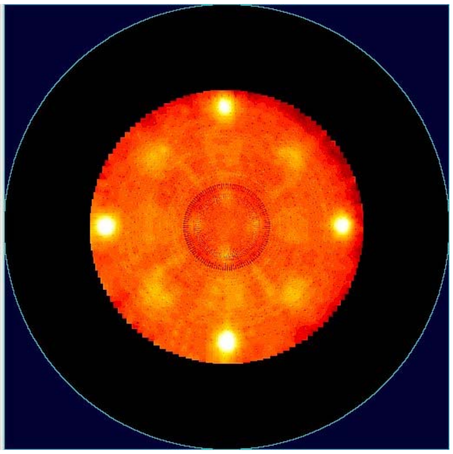

Figure 2 Log-scale pole figure of Ge surface.

The buffer layer sequence developed during this project also exhibits metallic conductance, allowing the substrate to be used directly as the cell back contact.

3.2 Polycrystalline Ge Thin Films

Polycrystalline Ge films exhibited grain sizes of over 100 microns after recrystallization. In these first trials, one-cm^2 cells measured less than 1% AM0 efficiency. However, photoluminescence characterization indicated high quality GaAs. SEM evaluation revealed that recrystallization nucleated at distributed extrinsic defects resulting from local chemical reactions and handling artifacts. Mesa diode measurements (Fig. 3) confirm that performance approaches the single crystal with no apparent influence of grain boundaries or shunting defects for smaller diode sizes. These data indicate that the extrinsic defects, eliminated in subsequent trials, may be the cause of localized shunting, accounting for the low PV performance.

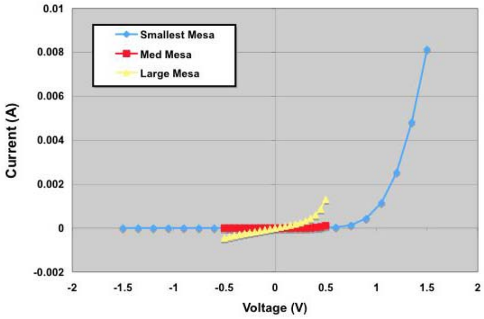

Figure 3 Poly-GaAs mesa diode performance.

4. Conclusions

This project has shown that a biaxially textured Ge film can be produced on a flexible metal foil substrate with grain boundary misorientations angles below five degrees. The materials and processes used in virtual single crystal substrate production are directly scalable to large area roll-to-roll production. In parallel testing, high quality GaAs junctions have been produced on polycrystalline Ge thin films. While significant additional work is required to produce a manufacturable product, the results indicate the potential for a new approach to high efficiency thin film photovoltaics.

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