STRAINED SUPERLATTICE, QUANTUM WELL, MULTIJUNCTION PHOTOVOLTAIC CELL*

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ABSTRACT

A novel lattice-matched multijunction cell is proposed. The cell makes use of the electronic and mechanical properties of the Strained-Layer Superlattice (SLS). With the SLS is it possible to vary the lattice constant and bandgap of a semiconductor independently. Experimental demonstration of the technology building blocks of such a cell are shown.

INTRODUCTION

Monolithic multijunction solar cells have shown great promise for theoretically improved efficiency for several years. Realistically, however, one has yet to be built with an efficiency equal to that of the best single junction concentrator cells. This failure has been primarily due to materials defects produced when one tries to marry two different lattice mismatched materials together, or when one works in difficult and relatively exotic binary and ternary compound semiconductors, trying to achieve the proper bandgap and lattice constants for a two-junction cell. Figure 1 shows the lattice constant and bandgap of the more common compound semiconductors and their alloys. A two-junction cell requires bandgaps in the vicinity of 1.7 eV for the upper cell and ~ 1 eV for the lower cell (1). Figure 1 shows that no common binary compound semiconductors meet the requirement of proper bandgap and identical lattice constants and one needs to use ternary or quaternary materials to meet these requirements. There is also a further constraint that the host substrate must also be lattice matched to these alloys. Use of these exotic materials systems have resulted in stacked cell efficiencies that do not equal those of the best single junction cells.

This paper describes a solution to this problem using Strained-Layer Superlattice (SLS) semiconductor materials for the active junction regions of the device. SLS materials consist of several thin alternating layers of single crystal material with different lattice constants (see Figure 2). The thin layers accommodate the resulting strain and do not produce defects; in fact, they actually can remove defects in the starting substrate. We have shown that the SLS class of materials also allows independent control of energy bandgap and lattice constant due to the quantum mechanical effects produced by the thin layers. Thus using the SLS material one can make a monolithically stacked junction solar cell with lattice matched, low defect material.

APPROACH

The Strained-Layer Superlattice represents a broad new class of semiconductor materials whose properties (bandgap, lattice constant, etc.) can be adjusted by controlling layer thickness and material types (2). As an example, Figure 3 shows the bandgaps and lattice constants that can be achieved by interleaving thin layers of GaAsP (gallium arsenide phosphide) alloys of two types ($0 \leq x \leq 1$, $0 \leq y \leq 1$). This shaded region of SLS parameters should be compared to the ternary alloy line GaP-GaAs on Figure 1. The SLS material shown in Figure 3 can achieve bandgaps of 1.4-2.1 eV with a fixed lattice constant of ~ 5.5 Å. This type of behavior is also achieved in other systems (such as InGaAs--indium gallium arsenide).

The basic concept of our new cell design is shown in Figure 4. This figure shows a multijunction cell constructed in a single ternary system. By controlling the alloy ratios and layer thicknesses, the bandgap is varied while lattice constant remains fixed. This system also has the advantage that the strained layers remove dislocation defects present in the substrate and result in high quality layers (3).

EXPERIMENTAL DATA

Fabrication of a novel cell structure such as proposed by this paper requires several technological achievements. First--growth of these thin strained semiconductors. This has been done by both MBE and MOCVD and a typical cross section

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is shown in Figure 5. Second--formation of a high quality p-n junction within the SLS material was needed. This was done using the structure shown in Figure 6. Figure 7 shows the I-V characteristic of the structure in Figure 6. The low reverse leakage current and near perfect (1.95) ideality factor indicate that this is a high quality p-n junction, in spite of the 48 material interfaces contained in the SLS. The quantum response of this device is shown in Figure 8. This figure shows a peak quantum efficiency of about 45% with no A-R coating. This quantum efficiency is very high considering the active layer is ~ 0.6 microns thick and is made of materials ($GaAs_{.2}P_{.8}$ and GaP) that are indirect in their bulk form. This is in part due to the fact that many bulk indirect semiconductors exhibit direct-like properties when made into an SLS.

CONCLUSIONS

We have proposed a new type of multijunction solar cell made from a Strained-Layer Superlattice (SLS) materials. This new type of cell design potentially overcomes the lattice mismatch and material defect problems associated with prior monolithic multijunction cells. Experimental evidence is presented on the building blocks (the SLS and SLS-pn junction) needed for the fabrication of such a cell.

References

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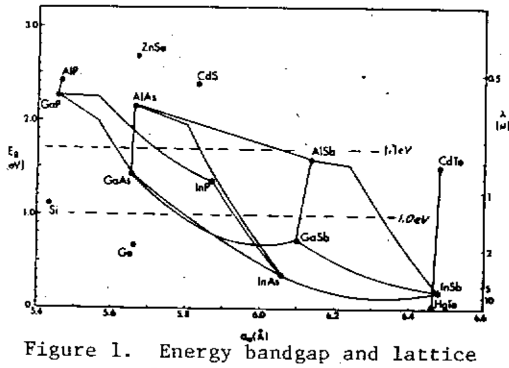

Figure 1. Energy bandgap and lattice constant of common compound semiconductors.

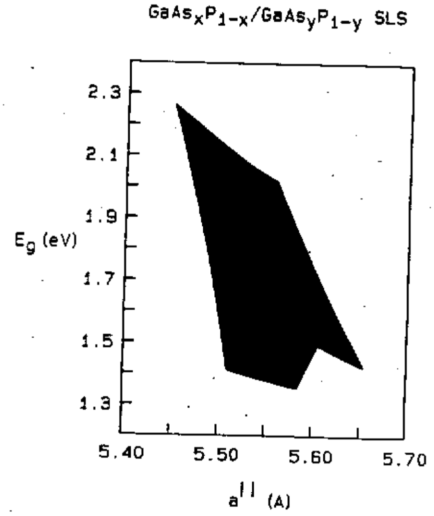

Figure 3. Range of energy bandgap and lattice for a GaAsP Strained Layer Superlattice.

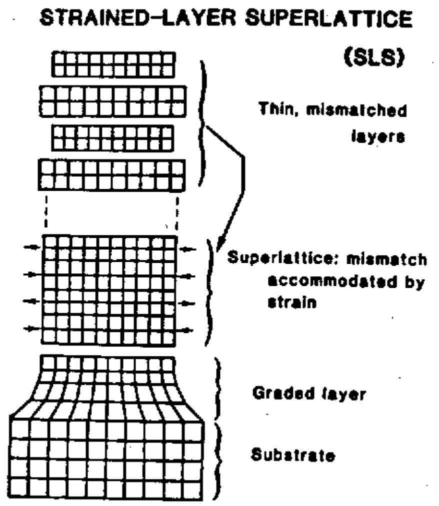

Figure 2. Composition of a typical Strained Layer Superlattice.

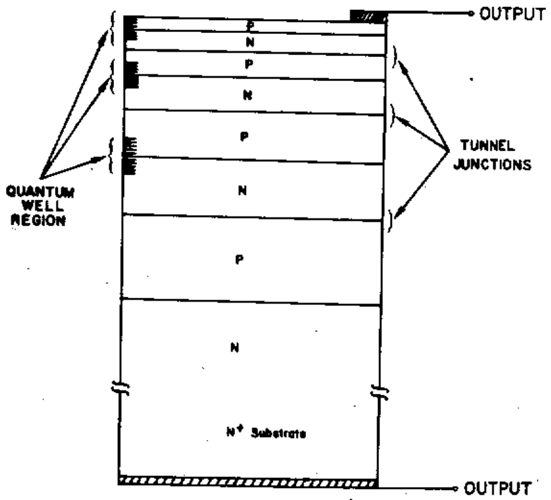

Figure 4. Proposed structure for Quantum Well Multijunction Photovoltaic Cell.

Figure 5. Actual TEM cross section of GaAsP/GaP Strained Layer Superlattice.

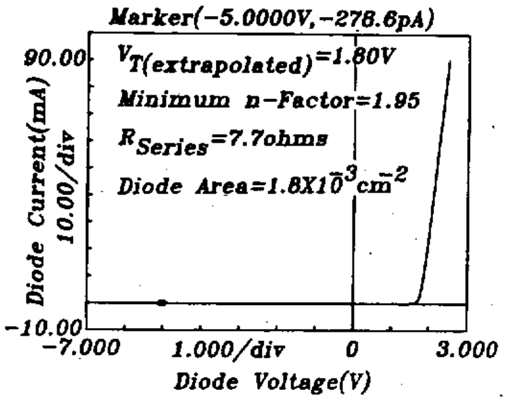

Figure 7. I-V characteristics of SLS diode.

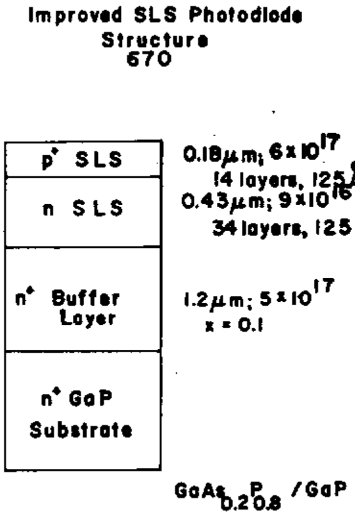

Figure 6. Structure of experimental SLS diode.

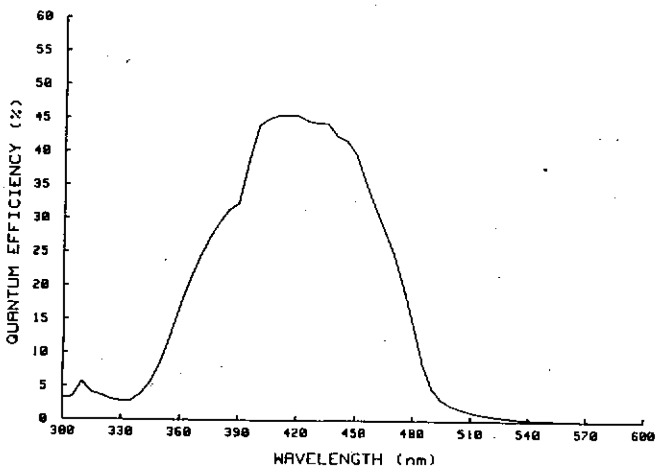

Figure 8. Measured quantum efficiency curve of photodiode shown in Figure 7.