

Peeled Film GaAs Solar Cells for Space Power

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Abstract

Gallium arsenide (GaAs) peeled film solar cells have been fabricated by Organo-Metallic Vapor Phase Epitaxy (OMVPE), incorporating an aluminum arsenide (AlAs) parting layer between the device structure and the GaAs substrate. This layer was selectively removed by etching in dilute hydrofluoric (HF) acid to release the epitaxial film. Test devices exhibit high series resistance due to insufficient back contact area. A new design is presented which uses a coverglass superstrate for structural support and incorporates a coplanar back contact design. Devices based on this design should have a specific power approaching 700 W/Kg.

Introduction

Gallium arsenide (GaAs) solar cells have demonstrated the highest one sun, single junction conversion efficiency to date. However, several inherent problems associated with GaAs solar cells have inhibited their widespread use. The first problem is the extremely fragile nature of GaAs. This fragility forces manufacturers to use thick substrates in order to reduce breakage losses to acceptable levels. Since GaAs has approximately twice the density of silicon, conventional thick GaAs solar cells are several times heavier than their silicon solar cell counterparts. Another problem with GaAs is the high cost of single crystal substrate material suitable for solar cell fabrication. The cost and mass differential between GaAs and Si could outweigh the benefits of using the higher efficiency and more radiation resistant GaAs devices.

An extremely thin epitaxial GaAs cell, separated from a reusable substrate, could exhibit greatly decreased weight and cost characteristics. High efficiency (20% AM0) cells, approximately 5 microns thick, could have a specific power approaching 700 W/Kg including coverglass, as compared to 150 W/Kg for conventional GaAs solar cells. Several techniques have been developed to fabricate

thin film GaAs solar cells, the most successful being the Cleaved Lateral Epitaxial Films for Transfer (CLEFT) technique⁽¹⁾, which uses a pre-growth patterning of the substrate to produce a preferred cleavage path for cell separation. Upon separation, the substrate is repolished and patterned for reuse.

In this TM, we discuss an alternate technique for fabrication of GaAs thin films, previously described by Yablonovitch et. al.⁽²⁾, whereby epitaxial thin films of GaAs are peeled from their host substrate. This technique takes advantage of the extremely selective ($>10^6$ difference in etch rate between GaAs and AlAs) etching nature of aluminum arsenide (AlAs) over GaAs in dilute hydrofluoric acid (HF). The peeled film technique eliminates the patterning and post-growth polishing required by the CLEFT technique. Peeled film solar cells are grown with a thin, ≤ 50 nm, AlAs layer between the GaAs substrate and the solar cell structure (fig. 1). Pivotal to the peeled film process is the application of Apiezon type "W" wax to the epilayer surface. The wax provides protection for the antireflective (AR) coating and aluminum gallium arsenide ($\text{Al}_x\text{Ga}_{1-x}\text{As}$) window layer from the selective etchant. When properly cured, the wax also imparts a compressive stress to the epilayers. This stress causes the cell to lift as it is undercut by the etching of the AlAs parting layer (fig. 2). The lifting action increases the diffusion of etchant and reaction products to and from the active etching regions. We have successfully peeled large area epitaxial films ($>12 \text{ cm}^2$) in a matter of hours using this technique. The intent of this research is to demonstrate the feasibility of using the peeled film technique to fabricate high efficiency, low mass GaAs solar cells.

Device Growth

The initial efforts focused on growth of the parting layer structure. Our current experimental cell design is shown in figure 3. The structure is grown in a horizontal, sub-atmospheric pressure OMVPE reactor. The growth parameters are as follows: chamber pressure 50 torr, AlAs growth temperature 750 °C, GaAs growth temperature 620°C, V/III = 50, and H_2 carrier gas flow rate 5.7 slm. The AlAs growth rate is 0.5 microns/hr. and the GaAs growth rate is 3 microns/hr. under these conditions. Diethylzinc ($\text{Zn}(\text{C}_2\text{H}_5)_2$) and hydrogen sulfide (H_2S) were used as the p- and n-dopants respectively. We have found the pregrowth substrate preparation required for good epitaxy to vary from vendor to vendor. Our current material is extremely well polished, requiring only rinsing in deionized water and drying with nitrogen gas. The substrates are then baked at 750°C under a hydrogen and arsine ambient to remove the native surface oxides. After growth, the wafer is cleaved to the approximate device size and front contacts are fabricated using standard photolithographic and electron beam evaporation techniques. The cells are then mesa etched to define the active device area.

Device Peeling

Initial peeling experiments were carried out on a single epilayer structure using the procedure described by Yablonovitch et al.⁽²⁾. Although these experiments were successful, several problem areas were identified. The first of these was the method of wax application. We experimented with painting the wax solution onto the devices using various brushes, spinning the wax solution onto the devices using a standard photoresist spinner, and air-brushing the solution onto the epilayers. Our best results were achieved using the air-brush technique, as we were able to reproducibly deposit uniform, thin wax layers onto the epilayer surface.

The second problem involved achieving complete edge exposure to allow the film to lift as it was undercut. Our attempts at edge grinding and cleaving were inconsistent, but cleaning the edge with trichloroethylene (TCE) and cotton swabs, although tedious, produced acceptable edge exposure. The third problem was handling of the films once they had been peeled. For small samples, the preferred transfer method is by means of a gentle vacuum tweezer. Larger films ($> 1 \text{ cm}^2$) have been lifted out of the solution by the substrate to which they will be attached or with a piece of filter paper. The samples transferred by filter paper may be allowed to dry, then transferred with vacuum tweezers. The wax solution is prepared by dissolving Apiezon type "W" wax in trichloroethylene (TCE) (10 gm wax: 40 ml TCE). Once the sample has been cleaved to the desired size and cleaned with boiling TCE, the wax solution is air-brushed onto the device. The wax is then cured for 30 min. at room temperature followed by a 30 min. cure at 160°C . This curing process generates the compressive force critical to the peeled film process. The edges of the wafer are cleaned in order to expose $\sim 1 \text{ mm}$ of the epilayer surface using TCE and cotton swabs. A selective etchant ($\text{H}_2\text{O}_2:\text{NH}_4\text{OH}$ 20:1) is then used to remove the exposed portion of the GaAs epilayers. We have found this selective etching technique to be the best method for assuring complete edge exposure of the AlAs layer.

The sample is then placed in the selective etchant ($\text{HF}:\text{H}_2\text{O}$ (1:10)), and allowed to stand overnight. The peeled film will generally float to the surface of the etchant once the AlAs release layer is completely removed. Deionized water is then carefully added to the etchant to dilute the HF and rinse both the substrate and the peeled film. Once rinsed, the device is transferred to the perforated silicon substrate using vacuum tweezers and allowed to dry. When the sample is placed on a clean flat substrate, such as polished silicon or glass, the sample will secure itself to the substrate by formation of Van der Waals bonds. This attachment is sufficiently strong to allow additional device processing. The wax is removed by vapor degreasing using TCE as the solvent. The solar cell back contact is deposited by electron beam evaporation through the holes in the silicon.

The measured AM0, I-V characteristic of a peeled film GaAs solar cell test structure is shown in figure 4. Total thickness of the GaAs cell is 7 microns. The film fractured during processing, thus no efficiencies or short circuit current densities can be reported due to inaccuracies of device area measurement. The high series resistance seen in the I-V curve is primarily due to high back contact resistance.

Future Work

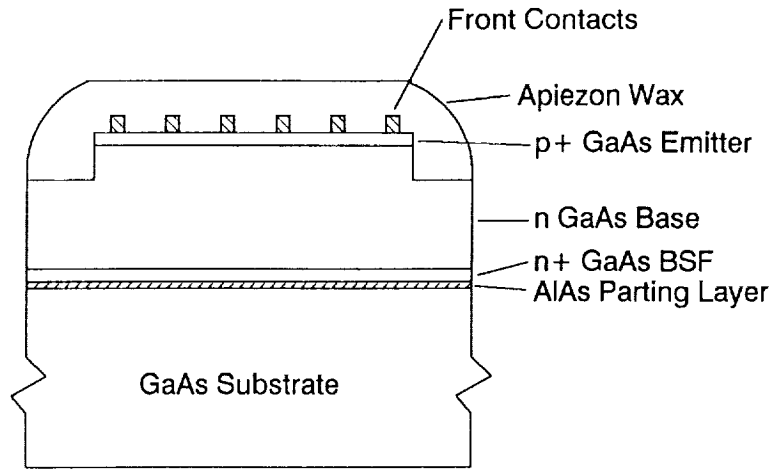
To take full advantage of the thin film technology, the silicon substrate must be eliminated. The proposed cell design (fig. 5) utilizes a transparent glass cover as the superstrate support. The design uses a "coplanar" back contact scheme which should simplify cell fabrication and module construction. This cell will be grown emitter down, allowing all contacting to be done through the base before peeling. Emitter contacting will be accomplished using photolithographic patterning and one of several photo driven, type selective etching processes. Once separated, the cell can be AR coated and glued to a coverglass superstrate. Although the emitter contacts will not be visible from the front of the cell, grid shadowing will exact losses from the device. This problem may be overcome using prismatic cover glass technology. Mass is saved due to the absence of a substrate and cell interconnecting is simplified due to the coplanar contact design. The etching rate for $\text{Al}_x\text{Ga}_{1-x}\text{As}$ by the HF etchant is extremely slow for $x < 0.4$, thus it should be possible to incorporate an AlGaAs window layer with a direct band gap of 1.93 eV into the cell structure.

Conclusion

Peeled film GaAs solar cells show great promise for use in weight and area sensitive missions. The cost of additional manufacturing complexity should be offset by the savings realized through reusable substrates. These cells may also find uses in mechanically stacked cascade solar cell structures. The ability to integrate a highly efficient GaAs solar cell into the cascade design without the complexity and detrimental performance effects associated with lattice mismatched heteroepitaxy could bring these devices from laboratory oddities to flight qualified devices.

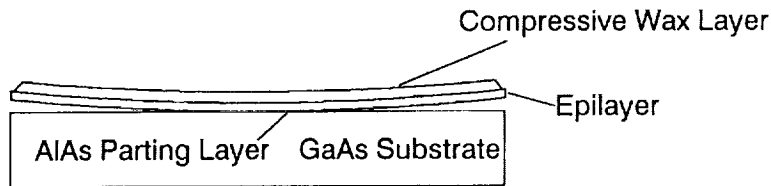
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1. R.P. Gale, R.W. McClelland, B.D. King, and J.V. Gormley, Conf. Record of the 20th Photovoltaic Specialists Conference (New York: IEEE, 1988).
2. E. Yablonovitch, T. Gmitter, J.P. Harbison, and R. Bhat, Appl. Phys. Lett. 51, 26, p.2222 (1987).



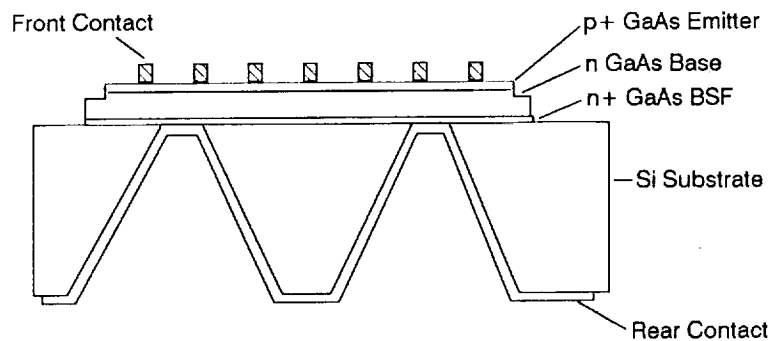
Peeled Film GaAs Solar Cell Shown After Front Surface Processing, Prior to Peeling.

Figure 1



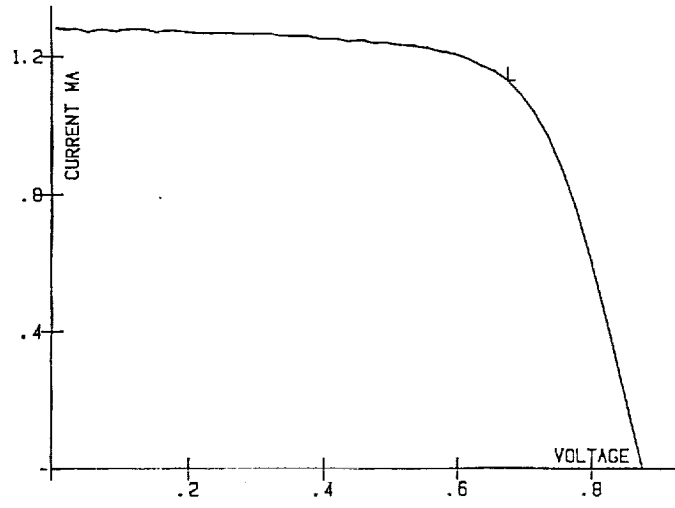
A Cross-Sectional View of The Peeling Process. As the AIAs Parting Layer is Selectively Etched, the Compressive Wax Layer Lifts the Epilayer. This Peeling Geometrically Enhances the Diffusion of Etchant into and Reaction Products Away From the Active Etching Regions.

Figure 2



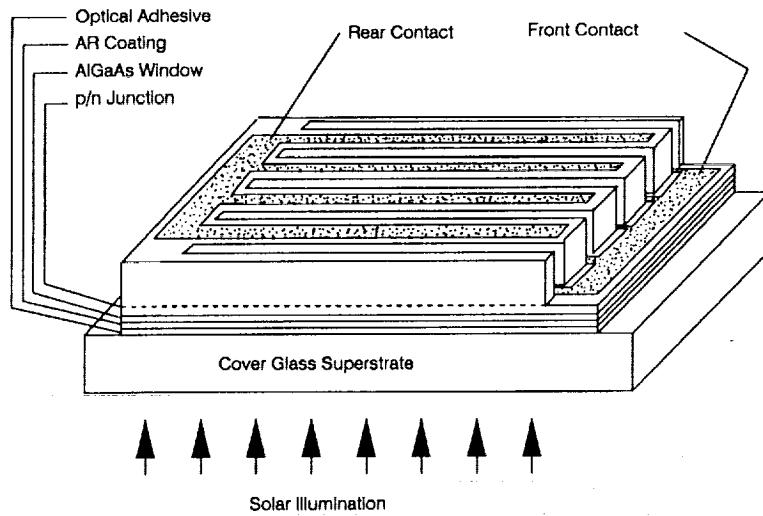
Peeled Film GaAs Solar Cell Test Structure. After Peeling, the Cell is van der Waals Bonded to the Perforated Silicon Substrate.

Figure 3



AMO I-V Characteristic of a Peeled Film GaAs Solar Cell

Figure 4



Advanced Back Contact Peeled Film GaAs Solar Cell Design

Figure 5

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