NASA Technical Memorandum 102104

GaAs Solar Cells With V-Grooved Emitters

(NASA-TM-102104) THE GaAs SOLAR CELLS WITH V-GROOVED EMITTERS (NASA. Lewis Research Center) 6 p CSCL 10A

N89-26291

Unclas
G3/44 0217629

S.G. Bailey
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

N. Fatemi
Sverdrup Technology, Inc.
NASA Lewis Research Center Group
Cleveland, Ohio

D.M. Wilt, G.A. Landis, and R.D. Thomas
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

Prepared for the
European Space Power Conference
sponsored by the European Space Agency
Madrid, Spain, October 2-6, 1989

NASA

S.G. Bailey
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

N. Fatemi
Sverdrup Technology, Inc.
NASA Lewis Research Center Group
Cleveland, Ohio 44135

and

D.M. Wilt, G.A. Landis,* and R.D. Thomas
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

ABSTRACT

Geometrically structured surfaces have become increasingly important to solar cell efficiency improvements and radiation tolerance. We have fabricated GaAs solar cells with a V-grooved front surface which demonstrate improved optical coupling and higher short-circuit current compared to planar cells. GaAs homojunction cells were fabricated by organometallic chemical vapor deposition (OMCVD) on an n+ substrate. V-grooves were formed on the surface with an anisotropic etch, and an n-type buffer and p-type emitter were grown by OMCVD, followed by ohmic contacts. Reflectivity measurements show significantly lower reflectance for the microgrooved cell compared to the planar structure. The short circuit current of the V-grooved solar cell is consistently higher than that of the planar controls.

INTRODUCTION

Significant advances in the efficiency of silicon solar cells have occurred due to the use of novel device geometries (Ref. 1,2). Similar benefits in GaAs promise reduced reflectance, oblique passage of light through the cell, and light trapping. An optimized microgrooved cell will have the advantages of increased total absorptivity, higher short-circuit current, and increased radiation tolerance.

Anisotropic wet chemical etching has been shown to provide a simple, inexpensive method to fabricate structures with less than two micron spacings (Ref. 3). Due to the polar nature of the lattice, anisotropic etching in GaAs is more complicated than in silicon. By careful orientation of the photolithographic mask, we obtained the desired structure shown in Figure 1 (Ref. 4). Previously we have reported a microgrooved GaAs pn junction and AlGaAs passivated pn junction (Ref. 5, 6).

*National Research Council - NASA Research Associate.

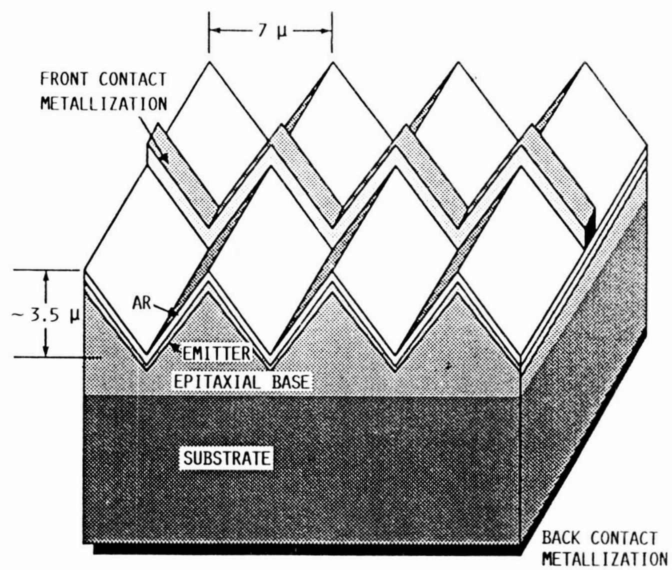

Figure 1. Schematic of V-grooved gallium arsenide solar cell (not to scale).

V-GROOVE FABRICATION

Fabrication of the solar cell began with (100) n-type substrates with a carrier concentration of $2.8 \times 10^{18} cm^{-3}$. The substrate was loaded as received from the supplier into the MOCVD reactor and subjected to a high temperature bake under a H_2 and AsH_3 ambient. Following the bake an epitaxial n+ buffer layer of .3μm thickness with doping of $1.5 \times 10^{18} cm^{-3}$ was grown followed by a 4μm epitaxial n base layer with doping of $2.1 \times 10^{17} cm^{-3}$.

The wafers were then removed from the MOCVD reactor and a standard photolithographic process was used to form a photoresist pattern of parallel 4μm lines and 3μm spaces, aligned in the $(0\bar{0}1)$ direction. Figure 2 shows a scanning electron microscope (SEM) micrograph of the surface after the photoresist step.

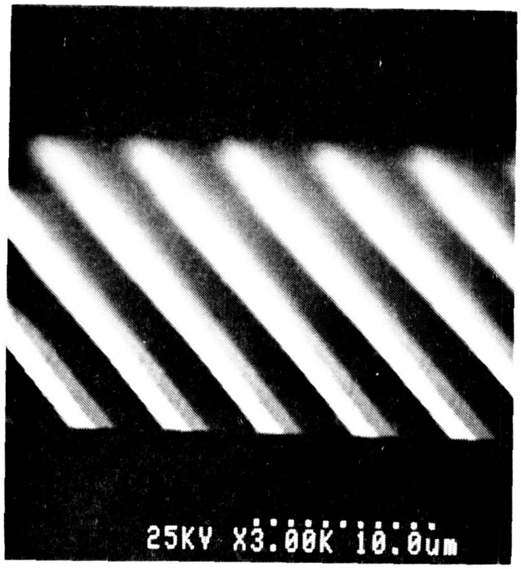

Figure 2. SEM micrograph of photoresist pattern on GaAs base epilayer

V-grooves were etched in the GaAs using the H_2SO_4:H_2O_2:H_2O Caros etchant (Ref. 7) in the ratio of 5:1:1. Further details on the etching process are discussed in Ref. 3. Figure 3 shows the grooves formed by etching for 150 seconds in the Caros etchant at 24°C. The etchant undercut the photoresist lines to produce a very regular sawtooth surface with sharp peaks and a period of 7μm.

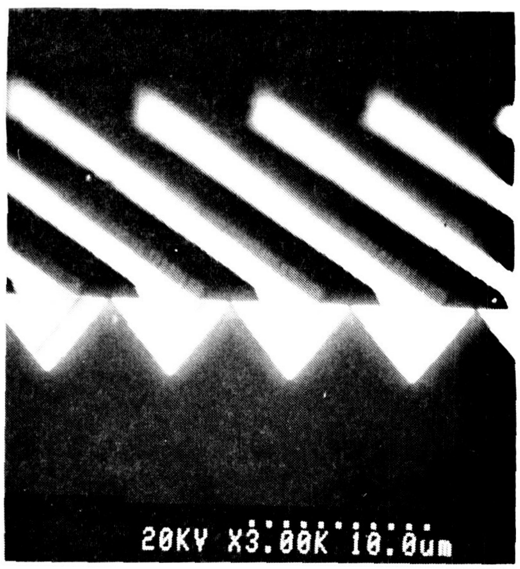

Figure 3. Micrograph of GaAs and photoresist after 150s in Caros etchant at 24°C

The micrograph in Figure 4 shows the resultant V-grooved structure after removal of the photoresist.

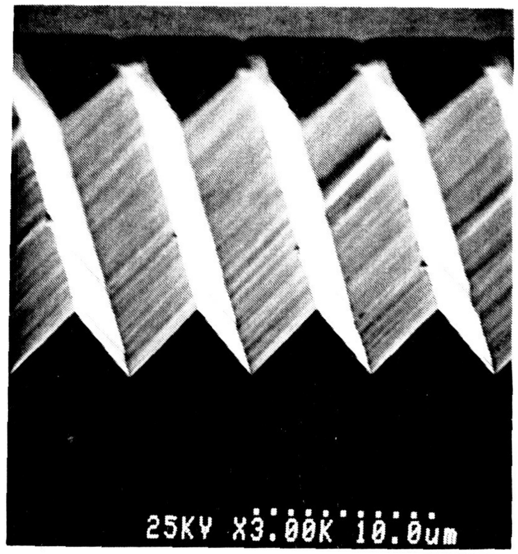

Figure 4. Micrograph of V-grooved GaAs surface before emitter growth

REFLECTANCE AND LIGHT TRAPPING

Reflectance of the V-grooved substrate as a function of wavelength both before and after an antireflective (AR) coating of Ta_2O_5 was measured on a Perkin-Elmer Lambda 9 uv/vis/nir spectrophotometer. A comparison of the reflectance of the V-grooved surface with a planar sample shows the expected reduction in reflectivity over the spectral range of interest. The reflectivity as a function of wavelength from 400-900nm is shown in Figure 5.

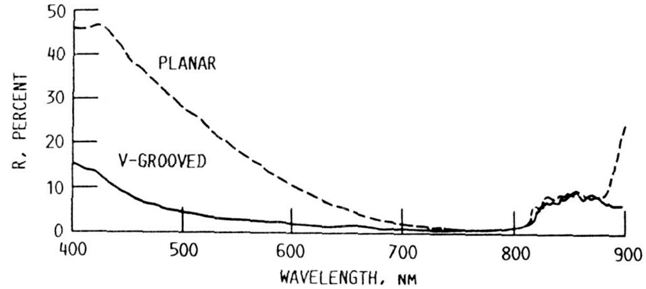

Figure 5. Reflectivity versus wavelength for AR coated planar and V-grooved GaAs

Future improvements in GaAs solar cells may well incorporate the thin, light-trapping structures that have recently been demonstrated on silicon. The ability to make double heterostructure carrier confinement in GaAs makes ultrathin, light-trapping structures especially attractive. If the optical pathlength is increased, the active thickness of the cell can be correspondingly decreased, resulting in an increase in the open circuit voltage and greatly improved radiation tolerance. For a cell with an optical pathlength enhancement of a factor of 50, near the theoretical isotropic limit, an open circuit voltage improvement of kT ln(50), or 100mV, could be obtained at optimum thickness. The required wafer thickness could be very thin, possibly less than a micron. While such thin substrates are not feasable using current technology, new technologies such as peeled-film GaAs (Ref. 8), or thin CLEFT material (Ref. 9), may make such devices possible.

One of the most effective light-trapping geometries is the cross-grooved structure (Ref. 10), where perpendicular grooves are formed on both the front and back surface. Theoretical analysis show this structure to be highly effective in increasing the optical pathlength in the material (Ref. 2). We fabricated the cross-grooved structure on a GaAs water to test the effectiveness of light trapping. The light trapping for weakly absorbed light was measured and compared with a Lambertian (random) light-trapping geometry and with a planar substrate. None of the structures measured had AR coatings or back-surface reflectors (BSR). Table 1 shows the measured results. The results confirmed the effectiveness of light trapping in the cross-grooved structure, with absorption enhanced by nearly a factor of seven compared to the planar control.

TABLE I. - OPTICAL MEASUREMENTS OF LIGHT-TRAPPING STRUCTURES IN GaAs, MEASURED FOR WEAKLY-ABSORBED (950 nm) LIGHT (NO AR COATING OR BSR).

Structure	Transm., percent	Reflect., percent	Absorp., percent
Specular	44.1	45.1	10.8
Cross-grooved	3.8	24.6	73.5
Lambertian	9.8	36.5	53.7

CELL FABRICATION

The active cell layers were epitaxially grown in a horizontal, cold wall, sub-atmospheric pressure MOCVD reactor. Gowth temperature was 620°C; the V/III ratio was 46; the n dopant was a 500 ppm mixture of H_2S in UHP H_2; and the chamber pressure was 100 torr. A thin buffer layer was first deposited and then a thick n base layer was grown with a carrier concentration of $2.1 \times 10^{17} cm^{-3}$.

The emitter growth was again preceded by a high temperature bake under a H_2 and AsH_3 ambient. The V-grooves were oriented parallel to the gas flow and DEZn was the p dopent. All other reactor parameters were identical to the base deposition. A 0.1μm thick p epilayer with a carrier concentration of $4.2 \times 10^{18} cm^{-3}$ was grown on the V-grooves.

ORIGINAL PAGE IS
OF POOR QUALITY

Electrochemical capacitance voltage (ECV) measurements using a Polaron *PN4200 profile* plotter were performed on an adjacent planar section after completion of the V-grooved cell. The carrier concentration profile is shown in Figure 6.

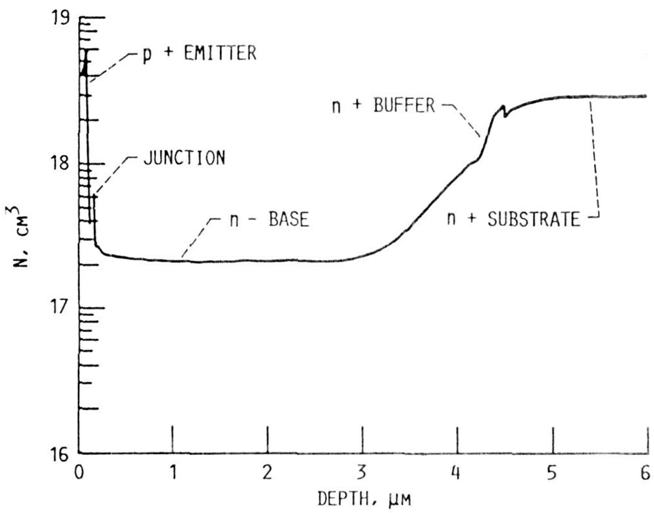

Figure 6. Measured carrier concentration ECV profile

Figure 7 illustrates the epilayer growth on the V-grooves. The epilayer thickness varies slightly from the bottom to the top of the goove.

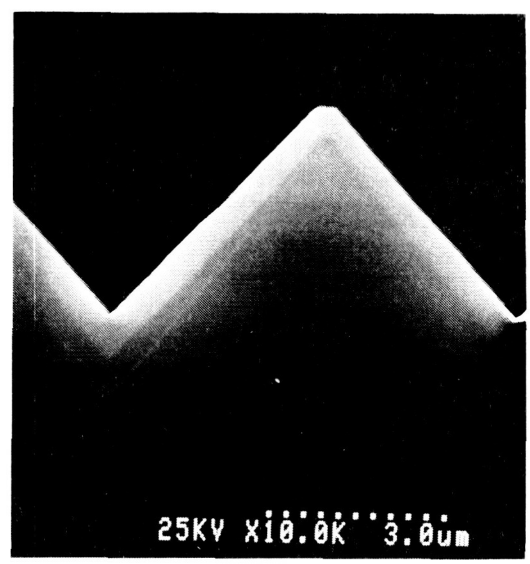

Figure 7. Micrograph of cleaved cross-section of epitaxial pn junction on V-grooved GaAs surface

E-beam evaporated Au-Zn contacts were applied at a slight angle to the grooves in the p emitter. Au-Ge-Ni contacts were utilized on the n base. The as deposited contacts were ohmic and no subsequent sintering was required.

ANALYSIS

The V-grooved solar cells were fabricated simultaneously with control planar solar cells in our MOCVD reactor. Due to the slight difference in the growth rate on the (111) and the (100) planes, however, these cell structures are not identical. In addition, the V-grooved surfaces are more susceptible to imperfections due to the more extensive and more complicated processing steps required in their fabrication, as compared to the planar surfaces. Particularly, we speculate that the microlithographic imperfections on the surface of the cells upon etching can result in strange geometric surface shapes. This in turn may lead to non-uniform MOCVD growth of the cell structure. As a result, the large area front grid contacts of the V-grooved cells have often created shunt paths from the emitter to the base, limiting the best observed V_{OC} to about 800mV. On the other hand, small area (44 by 44μm) test diodes located on the grooved emitter just outside the active area of the V-grooved cells often show no sign of shunting, which indicates that the problem with shunting caused by the front grid contacts is not inherent with the V-grooved structure, and that optimized processing should alleviate it.

We have observed a short circuit current density of 27.5 mA/cm^2 with non-opimized AR coating for our V-grooved cells. This represents a 13 percent increase over the planar control cells, which demonstrates the superior optical coupling of the V-grooved structure. The measured quantum efficiency comparison for planar and V-grooved solar cells is shown in Figure 8. In order to be able to study the effect of increased surface area (by a factor of $\sqrt{3}$) on the open circuit voltage of the V-grooved structure, we have estimated the reverse saturation current density (J_0) for these cells, using the dark current-voltage characteristics of the test diodes which did not exhibit shunting. Our calculations show that J_0 values as low as 8E-19 A/cm^2 (total area) are readily available with V-grooved cells. The J_0 translates to a V_{OC} of about 980 mV for the V-grooved structure, which is comparable to the V_{OC} of our control planar cells.

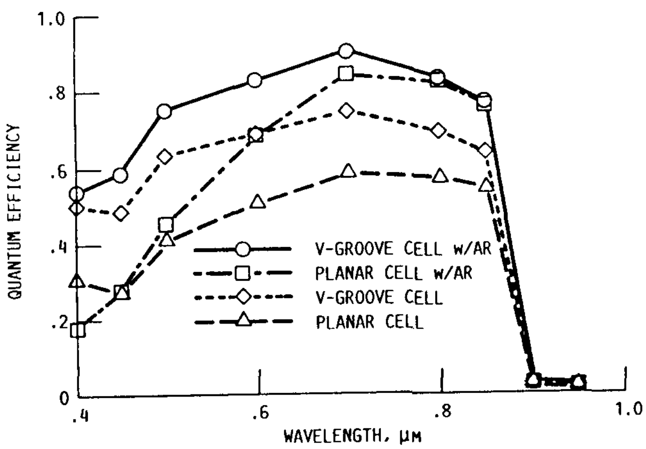

Figure 8. Quantum efficiency as a function of wavelength for the V-groove and planar cell with and without an AR coating

CONCLUSIONS

The results presented demonstrate the feasibility and potential for V-grooved GaAs solar cells. The V-grooved geometry permits utilization of advantageous optical characteristics while maintaining the best electronic and materials properties of MOCVD grown GaAs solar cells.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to Dr. R. Leonard and the staff of the microlithography facility for their assistance, to R. Hart and Dr. D. Brinker for the electrical measurements, and to V. Weizer for informative discussions.

REFERENCES

1. Green M A et al 1987, Recent advances in high efficiency silicon solar cells, Nineteenth IEEE Photovoltaic Specialists Conference, 6-12.

2. Campbell P et al 1987, Light trapping properties of pyramidally textured surfaces, J. Appl. Phys. 62 (1), 243-249.

3. Bailey S G et al 1988, Anisotropic etching and OMCVD growth on GaAs, State of the Art Program on Compound Semiconductors-IX, Electrochemical Society Fall Meeting.

4. Bailey S G et al 1988, Chemical etching and OMCVD on varied geometries of GaAs, Space Photovoltaic Research and Technology Conf., 272-287.

5. Bailey S G et al 1987, A V-grooved AlGaAs/GaAs passivated pn junction, Nineteenth IEEE Photovoltaic Specialists Conference, 421-426.

6. Leon R P et al 1986, Formation of a pn junction on an anisotropically etched GaAs surface using MOCVD, Appl. Phys. Lett. 49, 945-947.

7. Adachi S et al 1983, Chemical etching characteristics of (001) GaAs, J. Electrochemical Soc. 130, 2427-2435.

8. Yablonovitch E et al 1987, Extreme selectivity in the lift-off of epitaxial GaAs films, Appl. Phys. Lett. 51 (26), 2222-2224.

9. Gale R P et al 1983, Lateral epitaxial overgrowth of GaAs and GaAlAs OMCVD, Inst. Phys. Conf. Ser. No. 65, 101-108.

10. Landis G A 1986, Cross grooved solar cell, U.S. Patent 4,608,451.

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-102104		

4. Title and Subtitle	5. Report Date
GaAs Solar Cells With V-Grooved Emitters	
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
S.G. Bailey, N. Fatemi, D.M. Wilt, G.A. Landis, and R.D. Thomas	E-4870
	10. Work Unit No.
	506-41-11
9. Performing Organization Name and Address	11. Contract or Grant No.
National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135-3191	
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Technical Memorandum
National Aeronautics and Space Administration Washington, D.C. 20546-0001	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared for the European Space Power Conference sponsored by the European Space Agency, Madrid, Spain, October 2-6, 1989. S.G. Bailey, D.M. Wilt, and R.D. Thomas, NASA Lewis Research Center; N. Fatemi, Sverdrup Technology, Inc., NASA Lewis Research Center Group, Cleveland, Ohio 44135; G.A. Landis, National Research Council—NASA Research Associate.

16. Abstract

Geometrically structured surfaces have become increasingly important to solar cell efficiency improvements and radiation tolerance. We have fabricated GaAs solar cells with a V-grooved front surface which demonstrate improved optical coupling and higher short-circuit current compared to planar cells. GaAs homojunction cells were fabricated by organometallic chemical vapor deposition (OMCVD) on an n+ substrate. V-grooves were formed on the surface with an anisotropic etch, and an n-type buffer and p-type emitter were grown by OMCVD, followed by ohmic contacts. Reflectivity measurements show significantly lower reflectance for the microgrooved cell compared to the planar structure. The short circuit current of the V-grooved solar cell is consistently higher than that of the planar controls.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Solar cell Photovoltaic GaAs V-groove	Unclassified – Unlimited Subject Category 44

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No of pages	22. Price*
Unclassified	Unclassified	6	A02

NASA FORM 1626 OCT 86

*For sale by the National Technical Information Service, Springfield, Virginia 22161