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A V-Grooved GaAs Solar Cell

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SUMMARY

V-grooved GaAs solar cells promise the benefits of improved optical coupling, higher short-circuit current, and increased tolerance to particle radiation compared to planar cells. A GaAs homojunction cell was fabricated by etching a V-groove pattern into an n epilayer (2.1×10^{17} cm^{-3}) grown by MOCVD on an n+ substrate (2.8×10^{18} cm^{-3}) and then depositing an MOCVD p epilayer (4.2×10^{18} cm^{-3}). Reflectivity measurements on cells with and without an antireflective coating confirm the expected decrease in reluctance of the microgrooved cell compared to the planar structure. The short circuit current of the V-grooved solar cell was 13 percent higher than that of the planar control.

INTRODUCTION

Geometrically structured surfaces have become increasingly important in raising the efficiency of silicon cells (refs. 1 and 2). Similar benefits are anticipated in GaAs solar cells including reduced reflectance, oblique passage of light through the cell, and light trapping. The net effect of the microgrooved structure is an increase in total absorptivity, radiation tolerance, and short-circuit current of the solar cell.

Anisotropic wet chemical etching has been shown to provide a simple, inexpensive method for fabricating structures with less than 2 μm spacings (ref. 3). In previous work we demonstrated GaAs and AlGaAs MOCVD growth on V-grooved surfaces (refs. 3 and 4). Anisotropic etching in GaAs is more complicated than on silicon due to the polar nature of the lattice (ref. 5), thus careful orientation of the photolithographic mask is required (ref. 6). Figure 1 shows a representative solar cell structure.

V-GROOVE FABRICATION

Substrates for the cell fabrication were (100) n-type wafers with a carrier concentration of 2.8×10^{18} cm^{-3}. Prior to the V-groove etching process,

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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 and epitaxial n base layer of 4.5 μm thickness with doping $2.1x10^{17}$ cm^{-3} was grown.

The process of etching V-grooves in the n base epilayer consists of the first masking the surface with a photoresist pattern of parallel 4 μm lines and 3 μm spaces, aligned in the $(01\bar{1})$ direction. Figure 2 shows a scanning electron micrograph of the surface after the photoresist step. Next the grooves were etched 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 reference 3. Figure 3 shows the grooves formed by etching for 150 sec in the Caros etchant at 24 °C. The micrograph in Figure 4 shows the resultant V-grooved structure after removal of the photoresist.

Reflectance of the V-grooved substrate after AR coating 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 for the microgrooved structure. Figure 5 shows the reflectivity as a function of wavelength from 400 to 900 nm.

To reach limit efficiencies on very thin material, future GaAs solar cells may need to incorporate geometrical light-trapping structures. To demonstrate the feasibility of forming optical confinement structures on GaAs, we fabricated a cross-grooved structure (ref. 2), where V-grooves are formed on both front and back sides of the wafer, with the back-side grooves perpendicular to the front grooves. Theoretical analysis shows this structure to be highly effective in increasing the optical pathlength with the material (ref. 8). Table I shows the experimental increase in absorption measured for weakly absorbed (950 nm) light for the cross-grooved structure compared with specular (polished both sides) and lambertian (polished front, roughened back) samples from the same wafer. The samples had no AR coating or back surface reflector. Absorption by the cross-grooved structure has been enhanced by nearly a factor of seven compared to the planar control.

CELL FABRICATION

The active cell layers were epitaxially grown in a horizontal, cold wall, sub-atmospheric pressure MOCVD reactor. Growth temperature was 620 °C; the V/III ratio was 46; the 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 $2.1x10^{17}$ 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 dopant. All other reactor parameters were identical to the base deposition. A 0.1 μm thick p epilayer with a carrier concentration of $4.2x10^{18}$ cm^{-3} was grown on the V-grooves. Figure 6 illustrates the epilayer growth on the V-grooves. The epilayer thickness varies slightly from the bottom to the top of the groove.

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 planar and V-groove cells which are compared were fabricated simultaneously. However, the MOCVD growth rates are slightly different on the (100) and the (111) crystallographic planes. We expect an uncertainty of a few percent due to this variation in fabrication. V-grooved surfaces appear more susceptible to imperfections in their structure, possibly due to the more extensive processing necessary to produce a V-groove solar cell. As a result, large area grid finger contacts on our V-grooved structures have often tended to create a shunt path from the emitter to the base, effecting the open circuit voltage of our cells. Consequently, our best V has only approached 800 mV. In contrast, most of the small area test diodes (40 by 40 μm) located around each of our solar cells do not exhibit shunting. This is an indication that with optimized processing, we will be able to avoid this shunting problem in our larger area front contracts.

Examination of the dark current-voltage characteristics of the test diodes has revealed that a reverse saturation current density (J_O) of about $1x10^{-18}$ A/cm^2 (total area) is readily achievable with these solar cells, assuming a diode ideality factor of one. We have already been able to attain a short circuit current density of 27.5 mA/cm^2, with Ta_205 as the AR coating, with our V-grooved solar cells. The thickness of the AR coating has not been optimized. This represents a 13 percent increase over the comparable planar cell. This with the J_O value cited above translates to a V_{OC} of about 980 mV. The current solar cell structure with the increased V-grooved area does not appear to effect the open circuit voltage of these cells significantly. Figure 7 shows the quantum efficiency comparison for the planar and V-groove cells.

CONCLUSIONS

The work presented demonstrates 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.

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3. S.G. Bailey, G.A. Landis, and D.M. Wilt, "Anisotropic Etching and OM-CVD Growth on GaAs," presented at the State of the Art Program on Compound Semiconductors-IX, Electrochemical Society Fall Meeting, Chicago, IL, Oct. 1988.

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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

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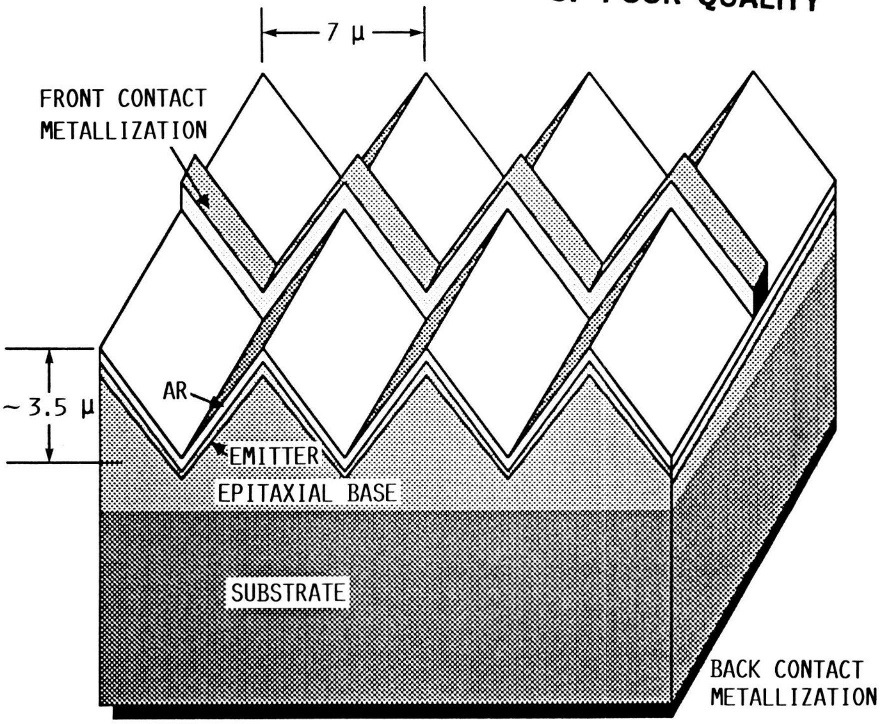

FIGURE 1. - SCHEMATIC OF V-GROOVE GEOMETRY GALLIUM ARSENIDE SOLAR CELL (NOT TO SCALE).

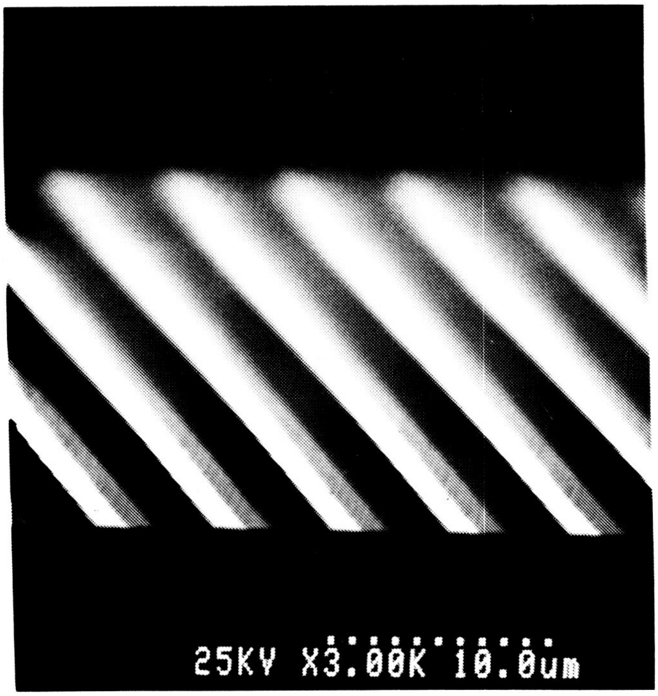

FIGURE 2. - SEM MICROGRAPH OF PHOTO-RESIST PATTERN ON GaAs BASE EPILAYER.

FIGURE 3. - MICROGRAPH AFTER 150s ETCH IN CAROS ETCHANT AT 24 °C.

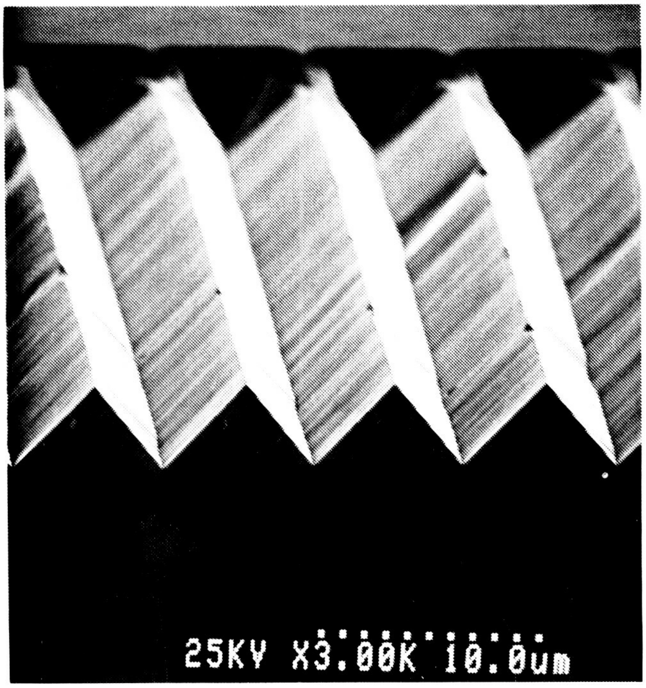

FIGURE 4. - MICROGRAPH OF V-GROOVED GaAs SURFACE BEFORE EMITTER GROWTH.

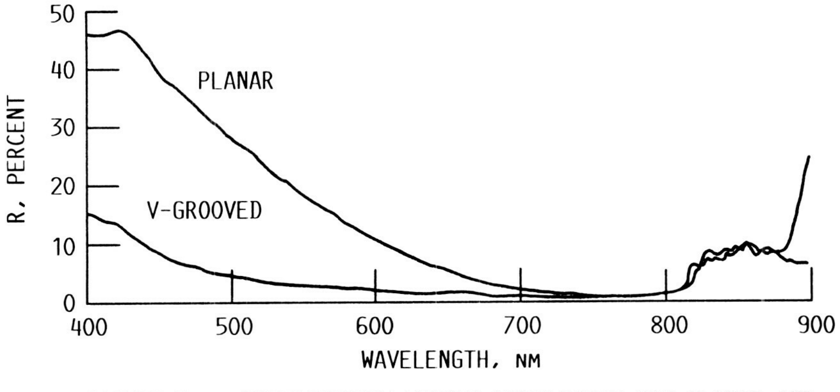

FIGURE 5. - REFLECTIVITY VERSUS WAVELENGTH FOR PLANAR AND V-GROOVED GaAs (AFTER AR COATING).

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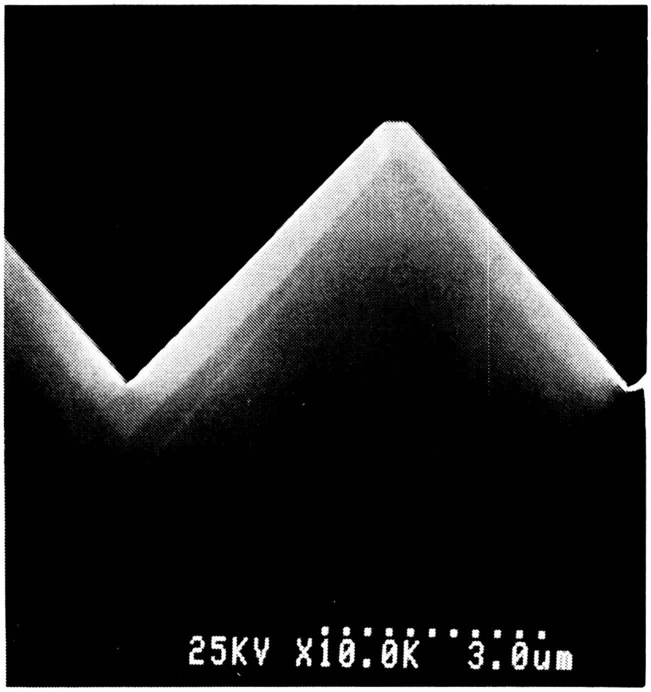

FIGURE 6. - MICROGRAPH OF CLEAVED CROSS-SECTION OF EPITAXIAL p-n JUNCTION ON V-GROOVED GaAs SURFACE.

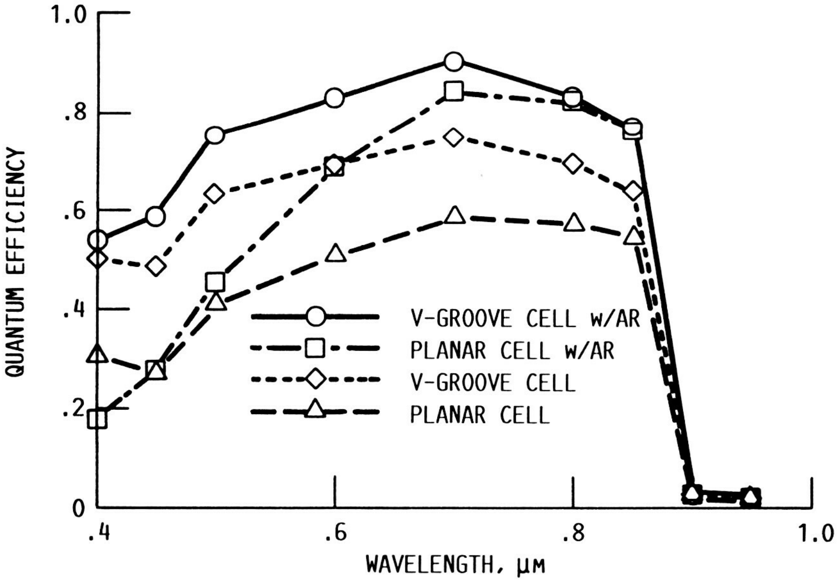

FIGURE 7. - QUANTUM EFFICIENCY AS A FUNCTION OF WAVELENGTH FOR THE V-GROOVE AND PLANAR CELL WITH AND WITHOUT AN AR COATING.

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16. Abstract

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