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A V-Grooved AlGaAs/GaAs Passivated PN Junction

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A V-GROOVED AlGaAs/GaAs PASSIVATED PN JUNCTION

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SUMMARY

A passivated, V-grooved GaAs solar cell offers important advantages in terms of improved optical coupling, higher short-circuit current, and increased tolerance to particle radiation when compared to the planar cell configuration. An AlGaAs epilayer has been deposited on a p-type GaAs epilayer grown on an n-type V-grooved GaAs surface using MOCVD. A wet chemical etching process was used to produce a V-pattern with a 7.0 μm periodicity. Reflectivity measurements substantiate the expected decrease in solar reflectance. Scanning electron microscopy techniques were used to confirm the presence of the AlGaAs layer and verify the existence of a pn junction.

INTRODUCTION

Recent advances in silicon solar cell performance (ref. 1) indicate the importance of improved optical design coupled with enhanced electronic characteristics in increasing solar cell efficiencies. A passivated V-grooved GaAs solar cell offers important advantages in terms of improved optical coupling, higher short-circuit current, and increased tolerance to particle radiation when compared to the planar cell configuration. The microgrooved structure has recently been achieved for a GaAs pn junction (ref. 2). The next step in fabricating an efficient GaAs V-grooved solar cell is to passivate the front surface of the structure with an AlGaAs layer. Planar AlGaAs/GaAs heteroface solar cells have the highest efficiency of any GaAs solar cells reported to date (ref. 3). In this paper results are presented confirming the metalorganic chemical vapor deposition (MOCVD) epitaxial growth of a passivating AlGaAs layer on a microgrooved GaAs pn junction.

The microgrooved structure has several advantages when compared to the planar cell structure. The improved optical coupling reduces reflective losses by 70 percent (ref. 4). In addition to this, the sawtooth geometry permits absorption of light closer to the location of the pn junction which results in a larger effective absorption coefficient, α (ref. 5). An increase in the product αL, where L is the minority-carrier diffusion length, increases the collection efficiency of generated carriers and thus the short-circuit current of the cell. The high effective α also helps to mitigate the effects of decreased diffusion length on the short-circuit current when the cell is exposed to particle radiation. It is therefore expected that this configuration will show improved radiation resistance. The net effect of the microgrooved structure is then an increase in the total absorptivity, radiation tolerance, and short-circuit current of the device. By orienting the grid fingers perpendicular to the grooves a small emitter series resistance can be maintained.

FABRICATION

The structure of the microgrooved heteroface device is shown in figure 1. Fabrication of the device began with a silicon-doped GaAs substrate with a carrier concentration of $2 \times 10^{18}/cm^3$. A standard photolithographic process was used to transfer a photoresist pattern consisting of parallel 4-μm lines and 3-μm spaces from a chromium and quartz mask to the GaAs n-type substrate. Figure 2 is a photograph of a section, including a portion of the contact finger, of the photoresist pattern on the substrate prior to etching.

Several wet chemical etchants were investigated under various etching conditions. The best grooves were obtained using the $H_2SO_4:H_2O_2:H_2O$ etchant system in the ratio of 5:1:1. Figure 3 shows the grooves formed by etching for 2 min in the above solution at 28 °C with manual agitation.

The scanning electron microscope (SEM) micrograph indicates that the etchant undercut the photoresist lines to produce a very regular sawtooth surface with a period of 7 μm. Figure 3 illustrates the results of anisotropic etching consistent with those obtained by other investigators (ref. 6). The SEM micrograph in figure 4 shows incomplete etching resulting in a flat (001) oriented top.

A p-epilayer of 0.22 μm thickness with a carrier concentration of 10^{17} to $10^{18}/cm^3$ was grown using a standard SPI-MOCVD 450 reactor. The gallium arsenide film was produced b the decomposition of trimethylgallium in the presence of an arsine atmosphere at 700 °C. Zinc, the p-type dopant, was introduced as dimethyl zinc. In the same run, a p-type $Al_{.85}Ga_{.15}As$ layer of 0.17 μm thickness with a carrier concentration of 10^{18} to $10^{19}/cm^{-3}$ was grown on the GaAs p-epilayer, followed by a 570 Å GaAs cap layer with a carrier concentration of $10^{19}/cm^{-3}$. The aluminum was produced by the decomposition of trimethyl aluminum. This is the first reported simultaneous growth of AlGaAs on the (111) Ga, ($\bar{1}\bar{1}1$) Ga, and (100) 2° towards the (110) GaAs crystal planes. The micrographs in figures 5 and 6 show the differing contrast of the p and n regions after growth of the GaAs and AlGaAs epilayers. The micrograph in figure 7 shows a greater growth rate on the flat surfaces, (001) orientation, produced by incomplete etching of a substrate as in figure 4.

ANALYSIS

Reflectance measurements made on a Perkins-Elmer Lambda 9 UV/VIS/NIR spectrophotometer confirm the reduction in reflectivity for the microgrooved structure. The total reflectance in percent is shown in figure 8 as a function of wavelength from 200 to 2500 nm. The integrated AMO total solar reflectance (ref. 7) is 0.353 for the planar GaAs substrate and 0.155 for the AlGaAs/GaAs V-groove structure. The reflectance of the V-grooved structure would be decreased even further if an anti-reflective coating were added.

In figure 9 an SEM micrograph shows a cross section of the device; the plane of the picture is the (011) cleavage plane which is perpendicular to the plane where crystal growth occurred. Measurements from this type of micrograph give a junction depth of 0.45 μm. The electron beam induced current (EBIC) intensity for the position noted by the horizontal line in figure 10 confirms the presence of a pn junction. The micrograph in figure 11 contains a line scan of both secondary electron intensity and EBIC intensity superimposed on the V-groove structure. Higher magnification micrographs of the V-groove permit analysis of the AlGaAs/GaAs interface by use of the superposition technique. Figure 12 shows a change in the EBIC magnitude at the AlGaAs/GaAs interface. The micrograph in figure 13 indicates passivation of the emitter reflecting no change in the EBIC magnitude at the interface.

CONCLUSION

We have demonstrated the growth of an AlGaAs epilayer on a p-type GaAs epilayer which was grown on an n-type GaAs microgrooved substrate. Epitaxial growth on microgrooved surfaces could have an important impact on photovoltaic technology by allowing for more innovative device designs. This advance permits fabrication of solar cells that utilize advantageous optical geometries while maintaining the best electronic and materials properties of MOCVD grown GaAs cells.

ACKNOWLEDGMENTS

The authors would like to acknowledge Spire Corp., Bedford, Massachusetts for their expertise in growing the MOCVD epilayers. They would also like to express their gratitude to Dr. W.D. Williams for the use of the microlithography facilities, to Dr. D.A. Gulino for his participation in the reflectance measurements, and to N. Fatemi for depositing contacts for EBIC measurements.

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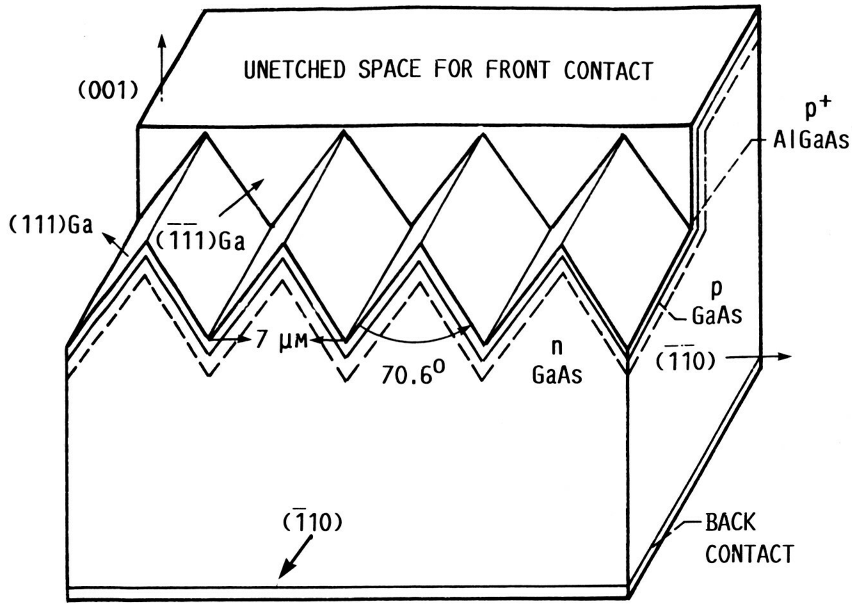

FIGURE 1. - SCHEMATIC DIAGRAM OF A MICROGROOVED PASSIVATED EMITTER AlGaAs/GaAs HETEROFACE pn JUNCTION.

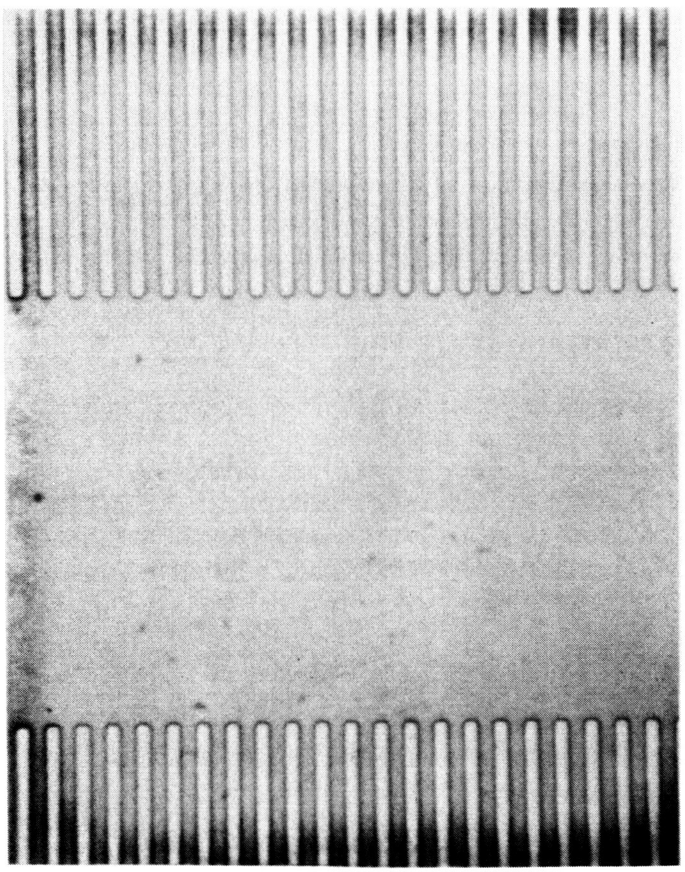

FIGURE 2. - PHOTORESIST PATTERN ON A GaAs SUBSTRATE PRIOR TO THE WET ETCHING PROCESS.

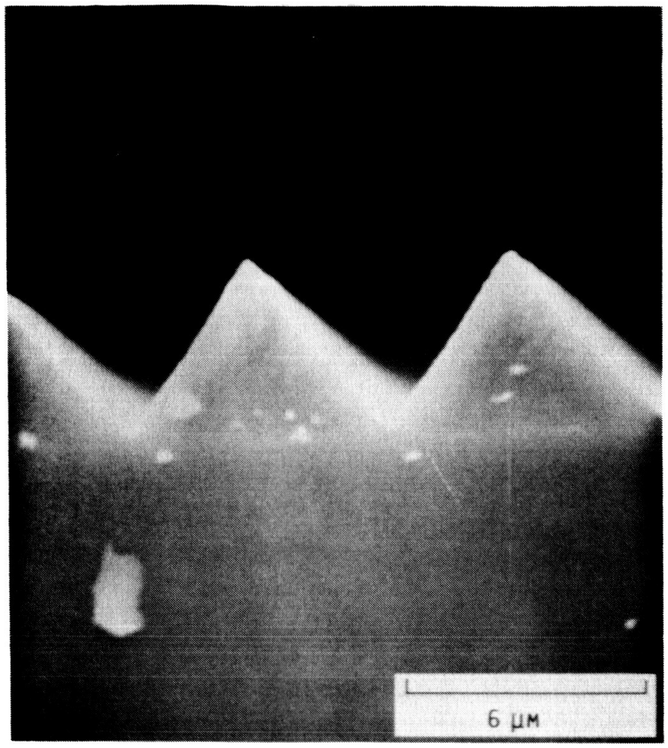

FIGURE 3. - ETCHED GROOVES ON A GaAs SUBSTRATE.

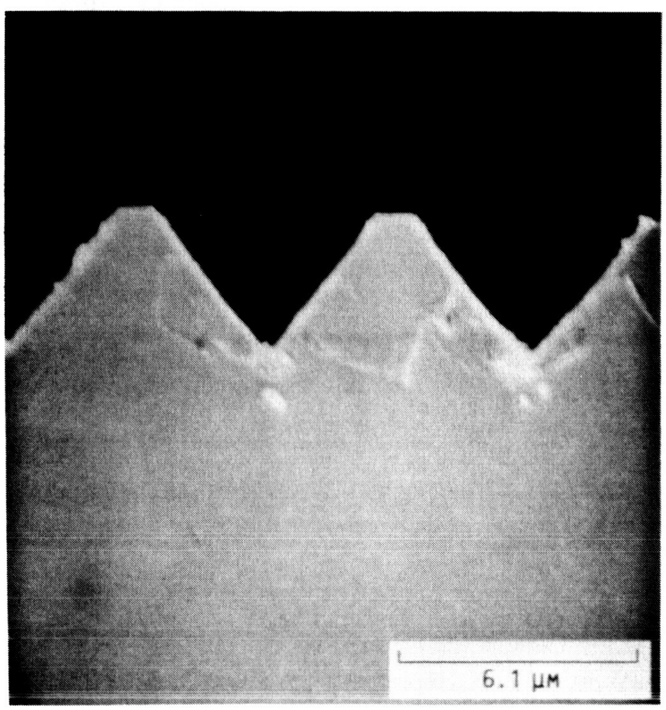

FIGURE 4. - GROOVES ON A GaAs SUBSTRATE SHOWING INCOMPLETE ETCHING.

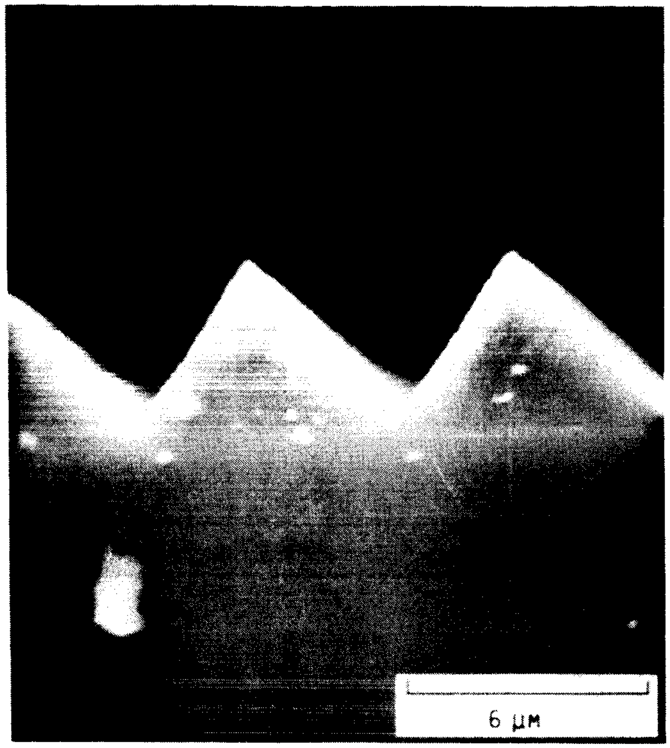

FIGURE 3. - ETCHED GROOVES ON A GaAs SUBSTRATE.

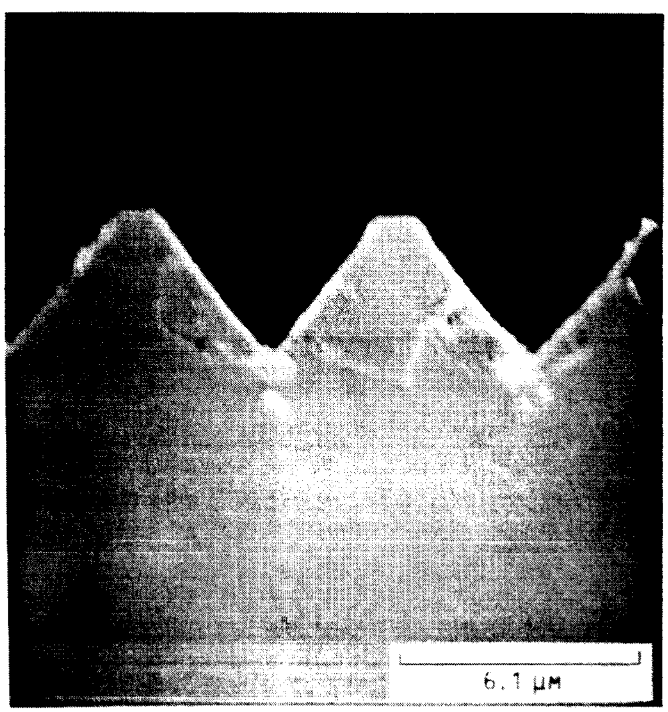

FIGURE 4. - GROOVES ON A GaAs SUBSTRATE SHOWING INCOMPLETE ETCHING.

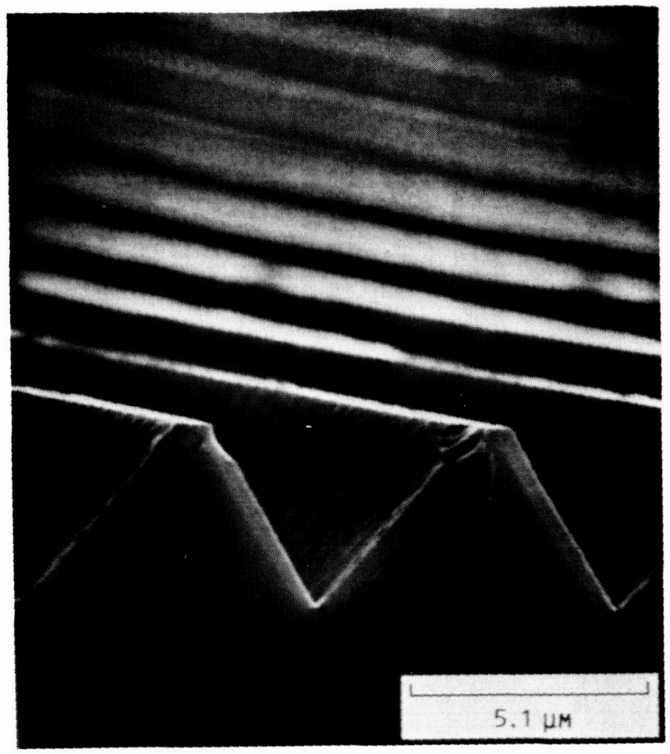

FIGURE 5. - GaAs SAWTOOTH JUNCTION WITH AlGaAs WINDOW LAYER.

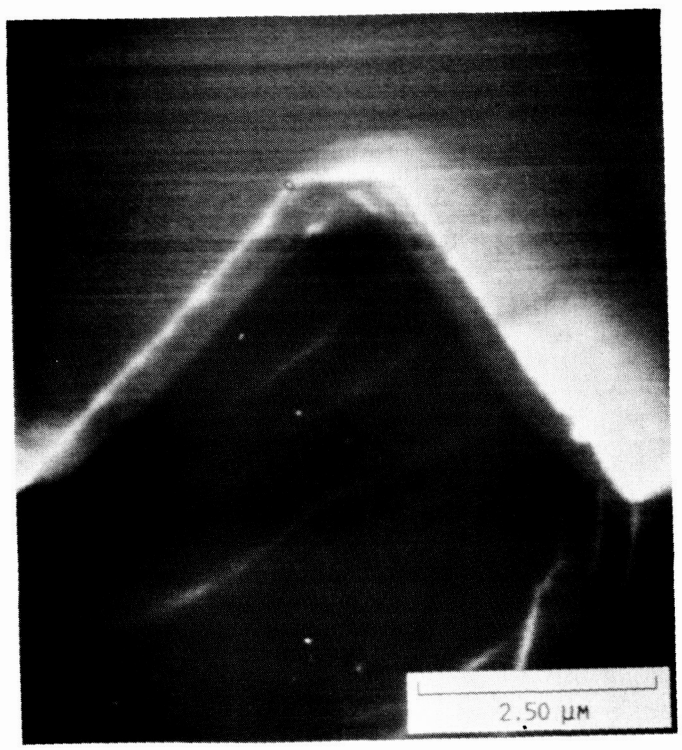

FIGURE 6. - MICROGRAPH OF A SINGLE AlGaAs/GaAs SAWTOOTH.

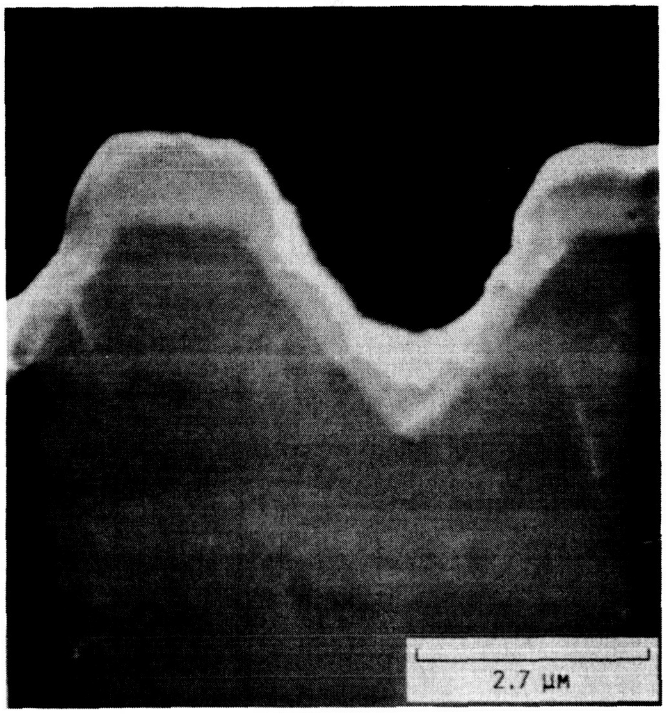

FIGURE 7. - AlGaAs/GaAs EPILAYER GROWTH ON AN INCOMPLETELY ETCHED GaAs SUBSTRATE.

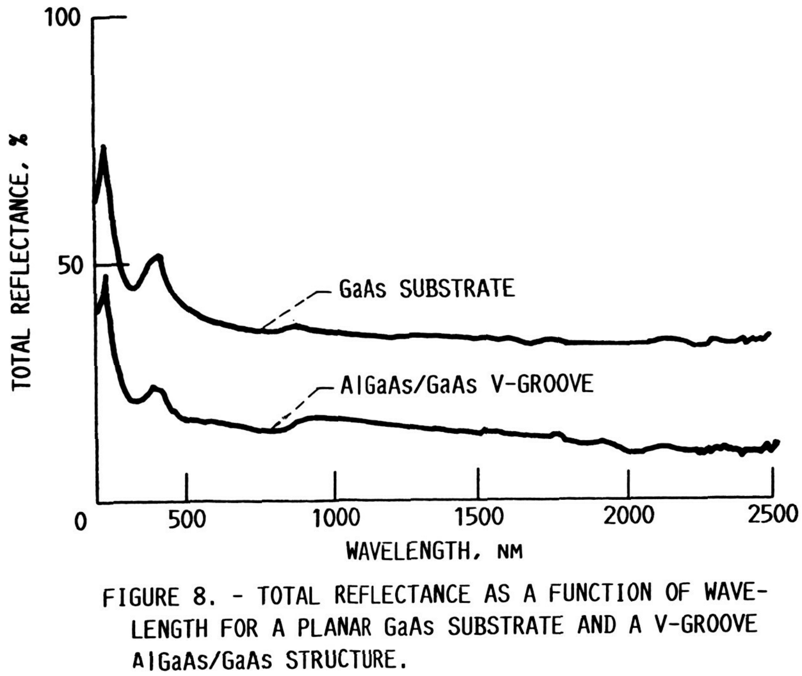

FIGURE 8. - TOTAL REFLECTANCE AS A FUNCTION OF WAVELENGTH FOR A PLANAR GaAs SUBSTRATE AND A V-GROOVE AlGaAs/GaAs STRUCTURE.

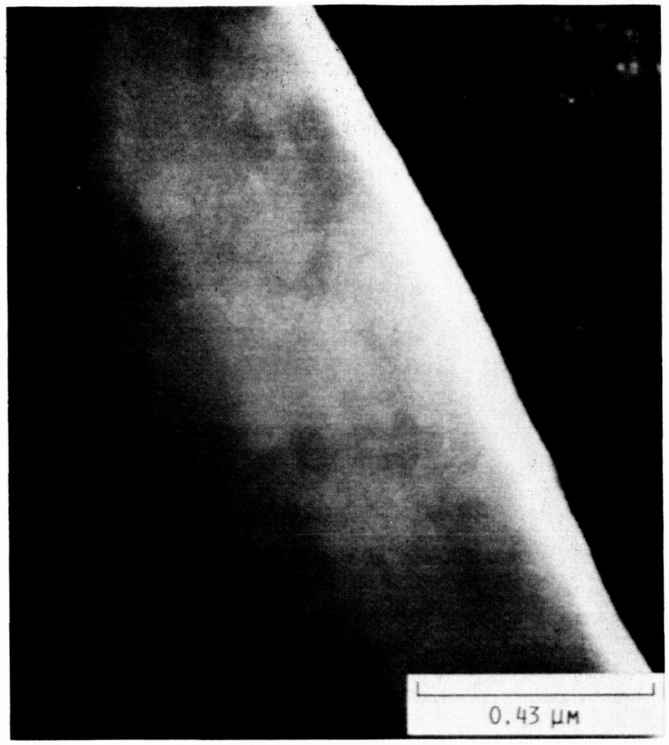

FIGURE 9. - HIGH MAGNIFICATION SEM MICROGRAPH SHOWING PORTION OF V-GROOVE WITH EPILAYERS.

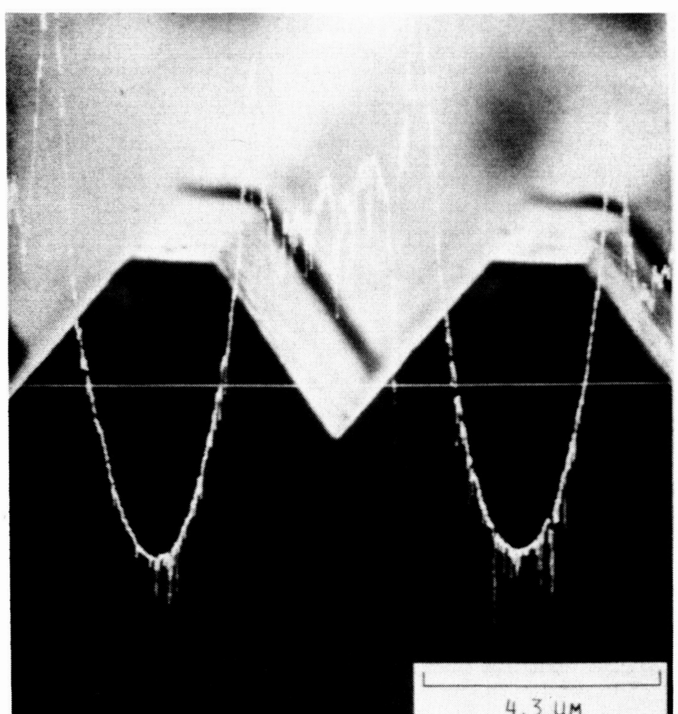

FIGURE 10. - ELECTRON BEAM INDUCED CURRENT SUPERIMPOSED ON THE V-GROOVE STRUCTURE AT THE POSITION NOTED BY THE HORIZONTAL LINE.

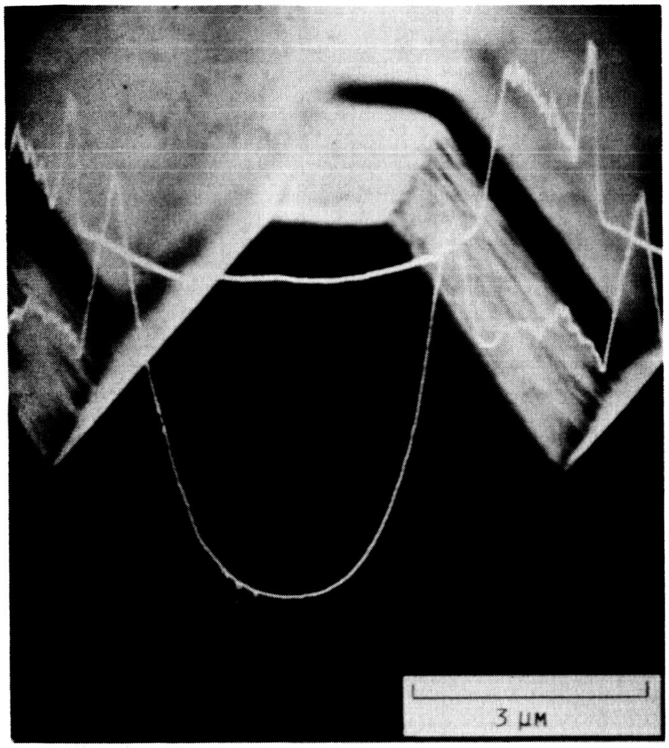

FIGURE 11. - LINE SCANS OF SECONDARY ELECTRON INTENSITY AND EBIC INTENSITY SUPERIMPOSED ON V-GROOVE STRUCTURE.

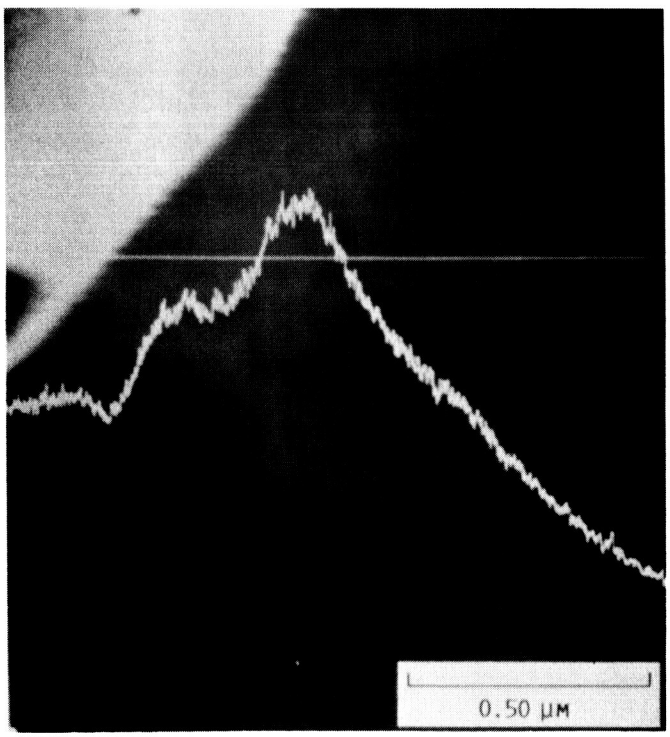

FIGURE 12. - SEM MICROGRAPH OF V-GROOVE AND LINE SCAN OF EBIC MAGNITUDE SHOWING A CHANGE IN THE COLLECTED CURRENT AT THE AlGaAs/GaAs INTERFACE.

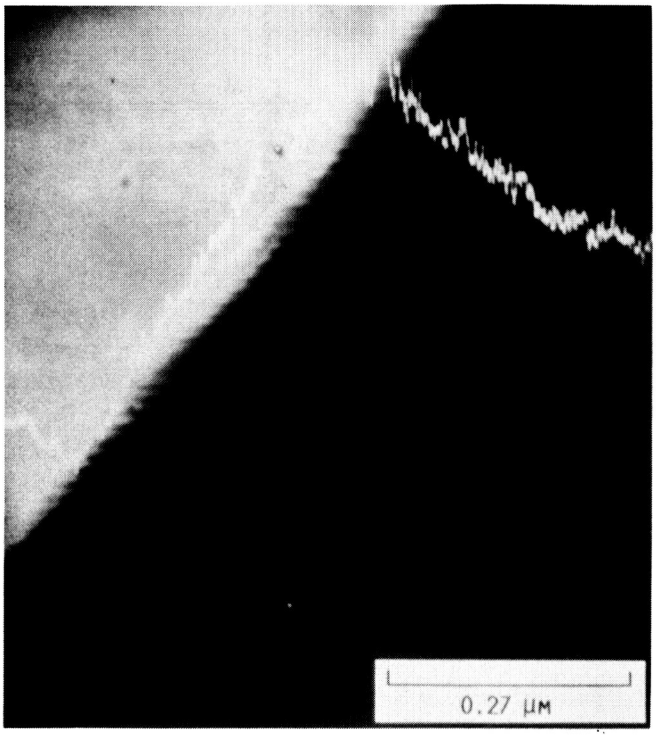

FIGURE 13. - V-GROOVE MICROGRAPH WITH LINE SCAN OF EBIC MAGNITUDE INDICATING PASSIVATION OF THE p-TYPE GaAs EMITTER.

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15. Supplementary Notes

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16. Abstract

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