ELECTRO-OPTICAL CHARACTERIZATION OF GaAs SOLAR CELLS*

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This paper concerns electro-optical characterization of MOCVD GaAs p/n solar cells. The objectives of these studies are to identify and understand basic mechanisms which limit the performance of high efficiency GaAs solar cells. The approach involves conducting photoresponse and temperature dependent current-voltage measurements, and interpretation of the data in terms of theory to determine key device parameters. Depth concentration profiles are also utilized in formulating a model to explain device performance.

CELL FABRICATION AND PERFORMANCE

Solar cell structures studied are described by figure 1. MOCVD film structures were grown according to specifications by industrial suppliers. Metallization, cap removal, and AR layer deposition are done at the Center. SiN_x deposited by plasma-enhanced CVD (PECVD) is utilized as a single AR coating. AM1 efficiencies in the range of 17% to 18% have been achieved with cells fabricated as discussed. Cells are typically 1.5 cm x 1.5 cm.

PHOTORESPONSE

Spectral photoresponse studies are used to determine values for the front recombination velocity, S(F), the emitter minority diffusion length, L(F), and the base minority carrier diffusion length, L(B). We typically find L(F) to be 3 to 5 μm, and S(F) in the range of 10^4 to 10^5 cm/sec. The devices under study are emitter dominated cells. As a result, the internal photoresponse is rather insensitive to the base diffusion length. Two particularly interesting results have been obtained, namely: a light biasing effect; and the apparent existence of a 'dead layer' in the p-GaAs region, adjacent to the AlGaAs layer.

The internal photoresponse is plotted for a cell under dark and biased conditions in figure 2. Under dark conditions, the surface recombination velocity is on the order of 10^6 cm/sec. With the cell illuminated by approximately AM1 illumination, the internal photoresponse indicates S(F) = 10^4 cm/sec. The light biasing effect is observed to occur after SiN_x deposition. Prior to silicon-nitride deposition, the value of S(F) is typically in the range of 10^4

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to 10^5 cm/sec, and is the same under both dark and illuminated conditions. Depth concentration profiles taken by Auger spectroscopy indicate that a significant level of oxygen exists at the SiN_x-AlGaAs interface after silicon-nitride deposition. A possible explanation for the light biasing effect is that excess oxygen exists at the GaAs-AlGaAs interface giving rise to recombination centers that saturate when cells are subjected to AM1 illumination. We are not aware of any other reports of this light biasing effect in GaAs cells.

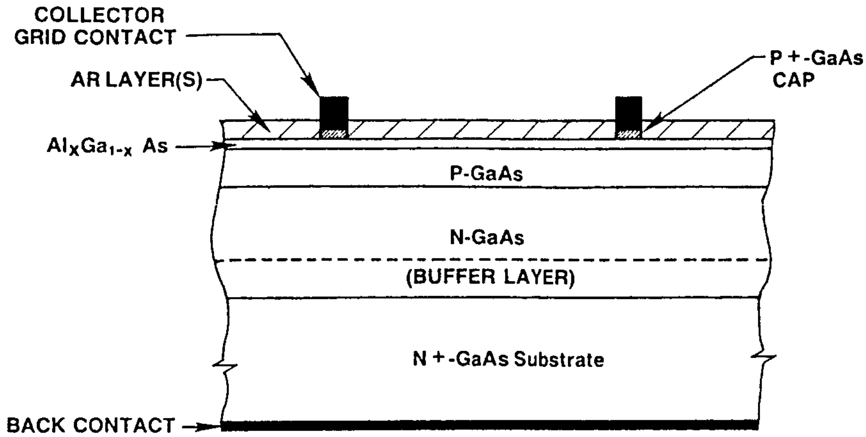
Figure 3 describes calculated internal photoresponse curves assuming S(F) = 2×10^5, L(F) = 5 µm, and four thicknesses for the 'dead layer'. Referring to figure 4, layer 2A is the so-called dead layer. It is assumed that this region of GaAs is characterized by a negligible minority carrier lifetime. As indicated in figure 3, it is found that the experimental curve for the internal photoresponse can only be fit by selecting a finite value for the dead layer thickness. We interpret this result as indicating that the transition region between GaAs and AlGaAs is very defective. This conclusion is supported by depth concentration profiles obtained by Auger spectroscopy.

T-I-V ANALYSES

Current-voltage analyses have been carried out at various temperatures between 250°K and 400°K. Data are taken under dark and illuminated conditions. A computer based data acquisition system is utilized to obtain data points as desired at each temperature. Data are then interpreted in terms of theory. We find that I vs. V under dark conditions and I_{LOSS} vs. V (where $I_{LOSS} = I_{PH} - I$) under illuminated conditions can be interpreted in terms of two current mechanisms acting in parallel, one dominant at low voltages and one dominant at high voltages. Figure 5 describes typical results for the loss current vs. voltage measured under illuminated conditions. The two mechanisms are apparent. The low voltage mechanism can usually be interpreted as involving multiple-step tunneling. The upper mechanism is due to minority carrier injection or space charge recombination. In cases for which the high voltage mechanism is due to minority carrier injection, $n = 1.00$ and $J_0 \simeq 3 \times 10^{-19}$ A/cm^2. When space charge recombination is dominant, n takes on values anywhere between 1.0 and 2.0, indicating that a wide range of recombination levels may be active in the junction regions. These investigations suggest that the device edges are the sources of loss currents due to multiple-step tunneling, as well as loss currents resulting from space charge recombination.

PHYSICAL CHARACTERIZATION

Depth concentration profiles for the same device for which internal photoresponse data is described in figure 2 are depicted in figure 6. The GaAs-AlGaAs transition region appears to be on the order of 400 Å wide. Furthermore, as noted above, a relatively high concentration level of oxygen exists in the top layers of the device. In particular, these results suggest that a relatively high level of oxygen may exist in the GaAs-AlGaAs transition region. It is proposed that the wide transition region and oxygen impurity level are responsible for both the light biasing effect and the dead layer.



LAYER	LAYER DESCRIPTION	DOPANT CONCENTRATION (cm^{-3})	LAYER THICKNESS
4	CAP : GaAs (P)	$>10^{18}$	.10
3	Al_xGa_{1-x}, x=.85	$>10^{18}$	.025
2	GaAs (P)	10^{18}	1.0
1	GaAs (N)	10^{18}	3.0
SUBSTRATE	GaAs (N)	$>10^{18}$	15 mils

Figure 1. GaAs Solar Cell Structure.

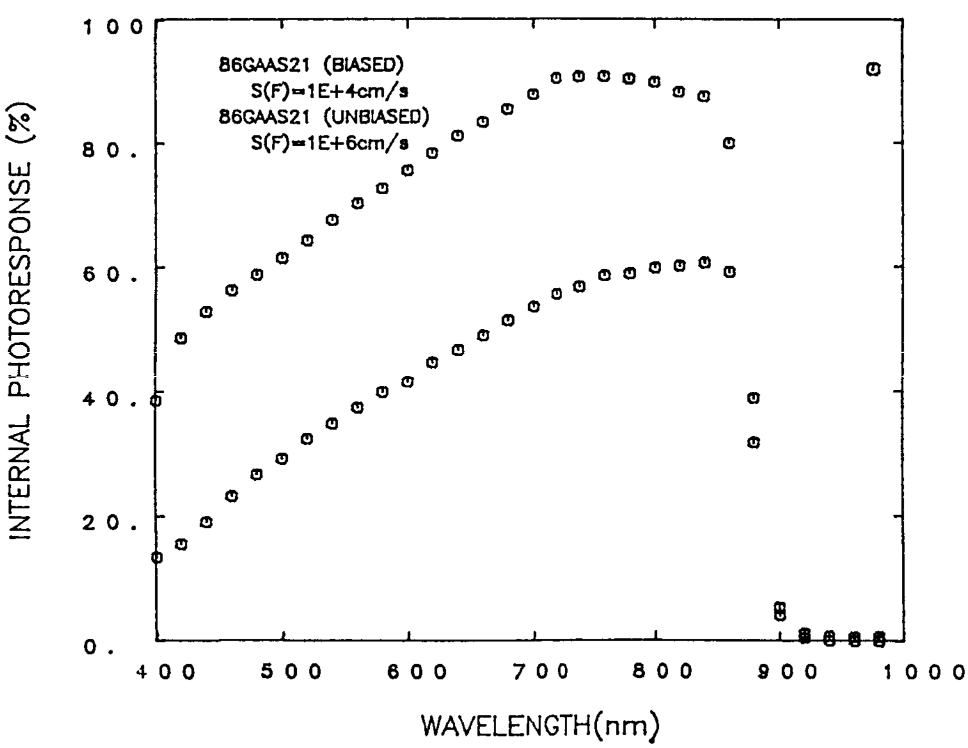


Figure 2. Internal Photoresponse of GaAs Cell Exhibiting Light Biasing Effect.

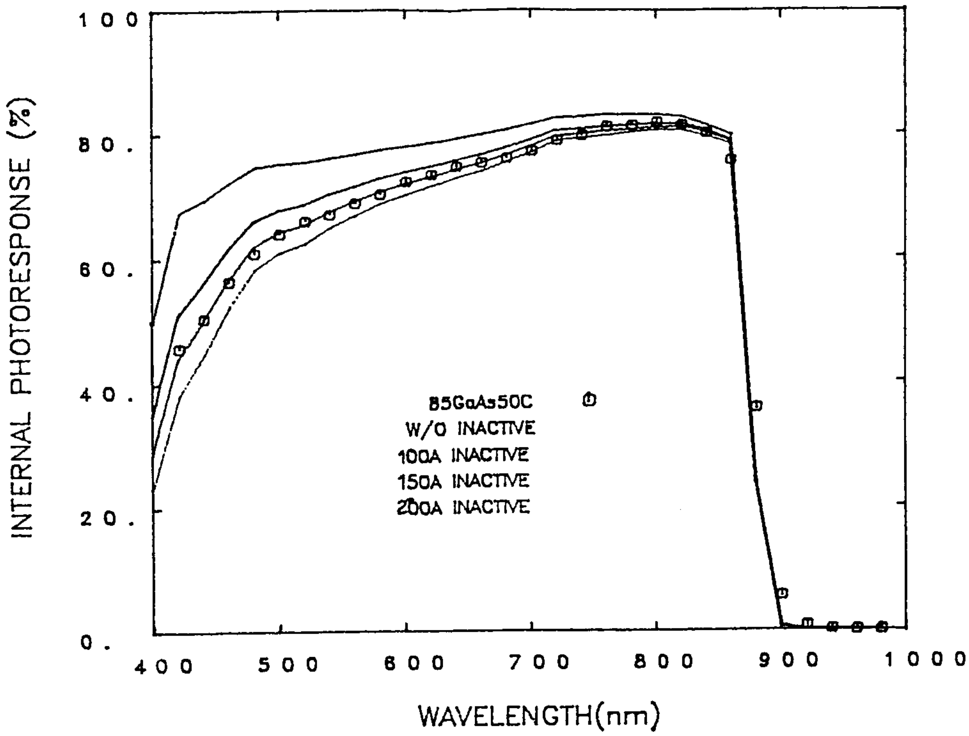


Figure 3. Effect of 'Dead Layer' on Fitting of Photoresponse Data.

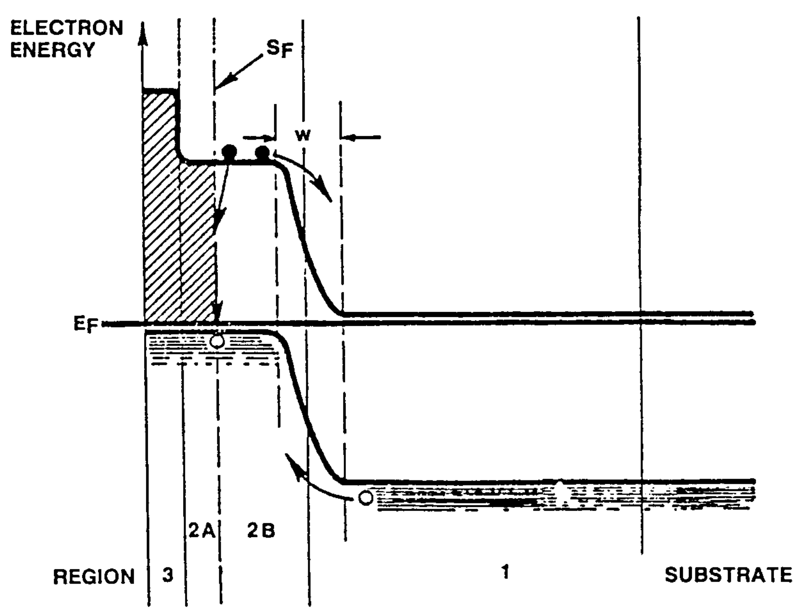


Figure 4. Electron Band Diagram Showing Location of 'Dead Layer'.

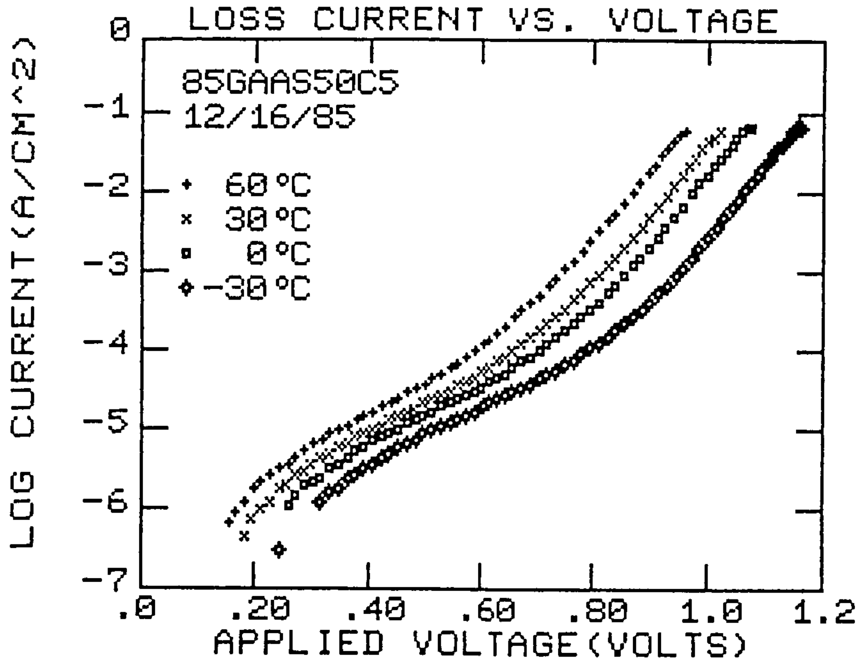


Figure 5. T-I-V Data for GaAs Cell.

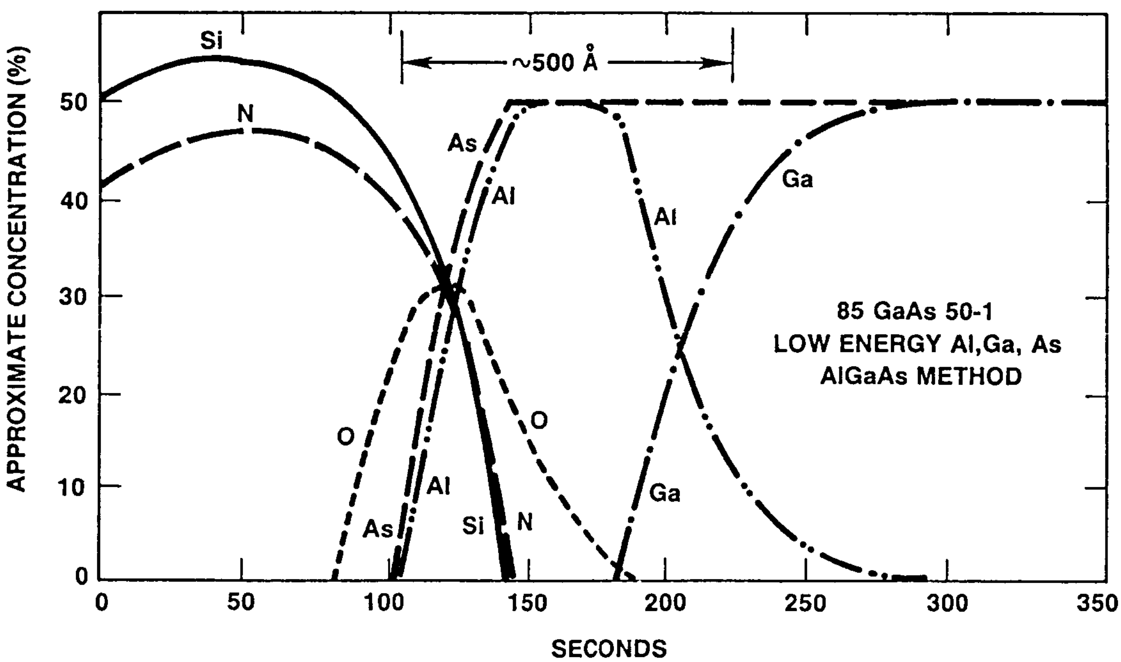


Figure 6. Depth Concentration Profiles Through Heteroface Region of GaAs Cell with 500 Å $Al_{.85}Ga_{.15}As$ Window.