GROWN-IN DEFECTS AND DEFECTS PRODUCED BY 1-MeV ELECTRON IRRADIATION IN $Al_{0.3}Ga_{0.7}As$ P-N JUNCTION SOLAR CELLS*

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EXTENDED ABSTRACT

Studies of grown-in defects and defects produced by the one-MeV electron irradiation in $Al_{0.3}Ga_{0.7}As$ p-n junction solar cells fabricated by liquid phase epitaxial (LPE) technique have been made for the unirradiated and one-MeV electron irradiated (with electron fluence of 10^{14}, 10^{15}, and 10^{16} e/cm^2) samples, using DLTS and C-V methods. Defect and recombination parameters such as energy level, defect density, carrier capture cross sections and lifetimes were determined for various growth, annealing, and irradiation conditions. The results obtained from this study are discussed as follows: $Al_xGa_{1-x}As$ p-n junction solar cells (area 1 mm^2) grown by LPE technique were fabricated by S. Bedair at the Research Triangle Institute in conjunction with their $Al_xGa_{1-x}As$ cascade p-n junction solar cell program supported by the Air Force Aeropropulsion Lab. Fig. 1 shows the four different solar cell structures which have been fabricated for our DLTS, C-V, and I-V measurements. Fig. 1 (b) is the cell's structure used in our study of deep-level defects produced by the one-MeV electron irradiation. This structure is identical to the top cell of the cascade solar cell, reported by Bedair et al[1]. Fig. 2 shows the DLTS scans of the electron trap (E_c-0.31 eV) for three $Al_xGa_{1-x}As$ p-n junction solar cells shown in Fig. 1 (a) through 1 (c). From our DLTS data, it is found that the Ge-doped $Al_xGa_{1-x}As$ p-n junction solar cells usually have lower defect density than that of the Be-diffused p-n junction solar cells shown in Fig. 1 (a) and Fig. 1 (b). This is also the case for the hole trap shown in Fig. 3, where one hole trap with energy of E_v+0.18 eV was detected in both the Ge-doped and Be-diffused $Al_{0.3}Ga_{0.7}As$ p-n junction cells. Another interesting study is to investigate the effect of low temperature thermal annealing on the defect density in the $Al_{0.3}Ga_{0.7}As$ solar cell. Fig. 4 shows the DLTS scans of electron trap vs. annealing time (2 and 5 hrs. at 300°C). The results showed that the electron trap density was indeed decreased with increasing annealing time. Table 1 summarizes the defect parameters deduced from the DLTS and C-V data for the unirradiated $Al_{0.3}Ga_{0.7}As$ and GaAs solar cells shown in Fig. 1 for different annealing times. Table 2 summarizes the defect parameters for the unannealed and annealed $Al_{0.3}Ga_{0.7}As$ and GaAs solar cells shown in Fig. 4. To study the effect of one-MeV electron irradiation on the defects in the $Al_xGa_{1-x}As$ p-n junction solar cells grown by the LPE technique, we performed (done at the Air Force Aeronautical Lab.) the one-MeV electron irradiation on the $Al_{0.3}Ga_{0.7}As$ p-n junction solar cells shown in Fig. 1 (b) for electron fluence of 10^{14}, 10^{15}, and 10^{16} e/cm^2. The results are shown in Fig. 5 and Fig. 6. Fig. 5 shows the DLTS scan of electron traps for the one-MeV electron irradiated $Al_{0.3}Ga_{0.7}As$ solar cells as a function of electron fluence. Note that three electron traps with energies of E_c-0.12, 0.20, and 0.31 eV were observed in the one-MeV electron irradiated $Al_{0.3}Ga_{0.7}As$ cells; the dominant electron trap was due to E_c-0.31 eV. The density of this E_c-0.31 eV trap was found to increase with increasing electron fluence, while the other two shallower

electron traps showed less dependence on the electron fluence. In contrast to the GaAs p-n junction cells, no mid-gap deep-level traps were detected in the $Al_{0.3}Ga_{0.7}$-As p-n junction solar cells. Fig. 6 shows the DLTS scans of hole trap for the same cells shown in Fig. 5; only one hole trap with energy of E_V+0.18 eV was observed in these cells, and the density was found to vary from 2.75×10^{15} (for $\phi_e = 10^{14}$ e/cm^2) to 5.93×10^{15} cm^{-3} (at $\phi_e = 10^{16}$ e/cm^2). Again, no mid-gap hole trap or new hole trap was observed in these electron -irradiated $Al_xGa_{1-x}As$ p-n junction solar cells. Table 3 summarizes the defect parameters deduced from the DLTS data for the electron traps shown in Fig. 5. From the results of this study, it is concluded that: (1) for the unirradiated $Al_{0.3}Ga_{0.7}As$ p-n junction cells, the dominant electron trap is due to E_c-0.31 eV and the dominant hole trap is due to E_V+0.18 eV; thermal annealing will effectively reduce the density of both electron and hole traps, (2) Ge-doped $Al_{0.3}$-$Ga_{0.7}As$ p-n junction cells contain lower defect density than the Be-diffused cells, (3) one-MeV electron irradiation in the $Al_{0.3}Ga_{0.7}As$ p-n junction cells produces only one hole trap (i.e., E_v+0.18 eV) and three electron traps (E_c-0.12, 0.20, and 0.31 eV); no mid-gap deep level defects were observed, (4) defect density does increase with increasing electron fluence, and (5) the DLTS data showed that $Al_{0.3}$-$Ga_{0.7}As$ p-n junction solar cells may have more radiation tolerance than that of GaAs p-n junction solar cells reported in our previous paper[2].

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(1) S. M. Bedair, M. Lamorte, and J. Hauser, Appl. Phys. Lett., vol. 34, p. 38 (1979).

(2) In the same proceeding of this workshop.

Table 1. Measured and Calculated Defect Parameters in n-$Al_{0.3}Ga_{0.7}As$ and n-GaAs LPE Layers.

Sample No.	Trap Density (cm^{-3})		Energy Level (eV)		Capture Cross Section (cm^2)		Carrier Lifetime (μs)		Physical Origin	
	Electron	Hole	Electron	Hole	σ_n	σ_p	τ_n	τ_p	Electron	Hole
Y-015B	6.63×10^{12}	6×10^{12}	$E_c-0.31$	$E_v+0.18$	3.37×10^{-13}	-	0.015	-	V_{Ga}	-
Y-015C	5.99×10^{11}	-	$E_c-0.31$	-	4.23×10^{-13}	-	0.13	-	V_{Ga}	-
L-119D	9.34×10^{10}	-	$E_c-0.31$	$E_v+0.18$	4.49×10^{-13}	-	0.79	-	V_{Ga}	-
L-138D	7.1×10^{10}	5.46×10^{10}	$E_c-0.42$	$E_v+0.40$	1.29×10^{-12}	-	0.35	-	-	A
	1.71×10^{11}	4.1×10^{11}	$E_c-0.60$	$E_v+0.71$	1.25×10^{-12}	-	0.23	-	-	B

Table 2. Defect Parameters for the Unannealed and the Annealed $Al_{0.3}Ga_{0.7}AS$ and GaAs LPE Layers.

Sample No.	Annealing Condition	Electron Trap		Hole Trap		N_B (cm^{-3})
		E_c-E_t (eV)	N_t (cm^{-3})	E_v+E_t (eV)	N_t (cm^{-3})	
Y-015C	Unannealed	0.31	6.0×10^{11}	0.18	$<10^{10}$	2.6×10^{16}
Y-015C	300°C,2 hrs	0.31	4.4×10^{11}	0.18	$<10^{10}$	5.7×10^{16}
Y-015C	300°C,5 hrs	0.31	3.6×10^{11}	0.18	$<10^{10}$	3.5×10^{16}
L-138D	Unannealed	0.42	7.1×10^{11}	0.40	5.5×10^{10}	2.8×10^{15}
		0.60	1.7×10^{11}	0.71	4.1×10^{11}	3.6×10^{15}
L-138D	300°C,2 hrs	0.42	1.2×10^{10}	0.40	2.7×10^{10}	2.1×10^{15}
		0.60	4.7×10^{10}	0.71	2.4×10^{10}	2.4×10^{15}
L-138D	300°C,5 hrs	0.42	1.0×10^{9}	0.40	1.3×10^{10}	2.5×10^{15}
		0.60	6.6×10^{9}	0.71	1.5×10^{10}	2.4×10^{15}

Table 3. Electron Traps in One-MeV Electron Irradiated $Al_{0.3}Ga_{0.7}As$ P-N Junction Solar Cells

Electron Fluence (e/cm^2)	N_B (cm^{-3})	E_T (ev)	N_T (cm^{-3})	σ_n (cm^2)	τ_n (ns)
0	1.14×10^{17}	$E_c-0.12$	1.6×10^{14}	-	-
		$E_c-0.20$	2.2×10^{14}	2.63×10^{-15}	172.8
		$E_c-0.31$	1.04×10^{14}	1.64×10^{-13}	5.86
10^{14}	1.03×10^{17}	$E_c-0.12$	2.1×10^{15}	-	
		$E_c-0.20$	4.3×10^{15}	2.63×10^{-15}	8.84
		$E_c-0.31$	7.8×10^{15}	1.64×10^{-13}	0.078
10^{15}	1.26×10^{17}	$E_c-0.12$	1.9×10^{15}	-	
		$E_c-0.20$	6.5×10^{15}	2.63×10^{-15}	5.85
		$E_c-0.31$	1.11×10^{16}	1.64×10^{-13}	0.055
10^{16}	1.16×10^{17}	$E_c-0.12$	2.2×10^{15}	-	
		$E_c-0.20$	3.9×10^{15}	2.63×10^{-15}	9.75
		$E_c-0.31$	1.8×10^{16}	1.64×10^{-13}	0.034

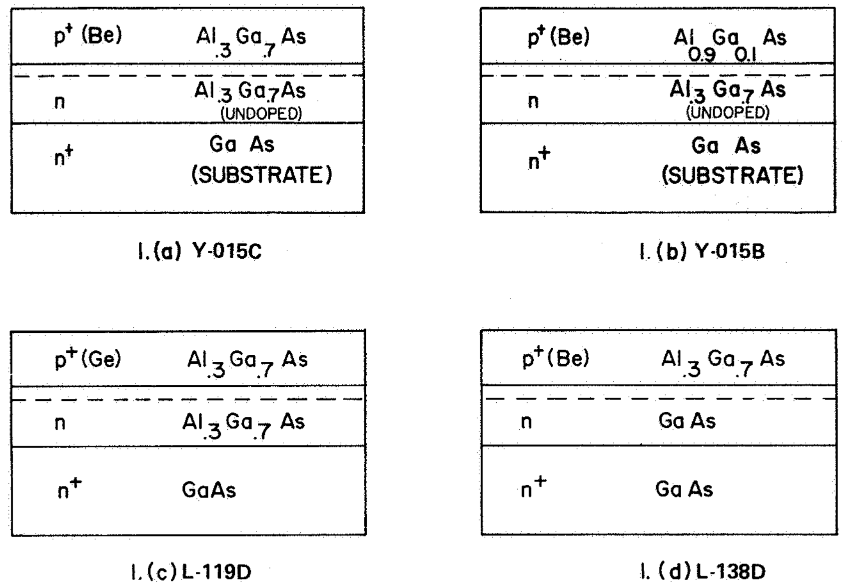

Fig. 1 Structure of $Al_xGa_{1-x}As$ p-n junction solar cells for DLTS and C-V study.

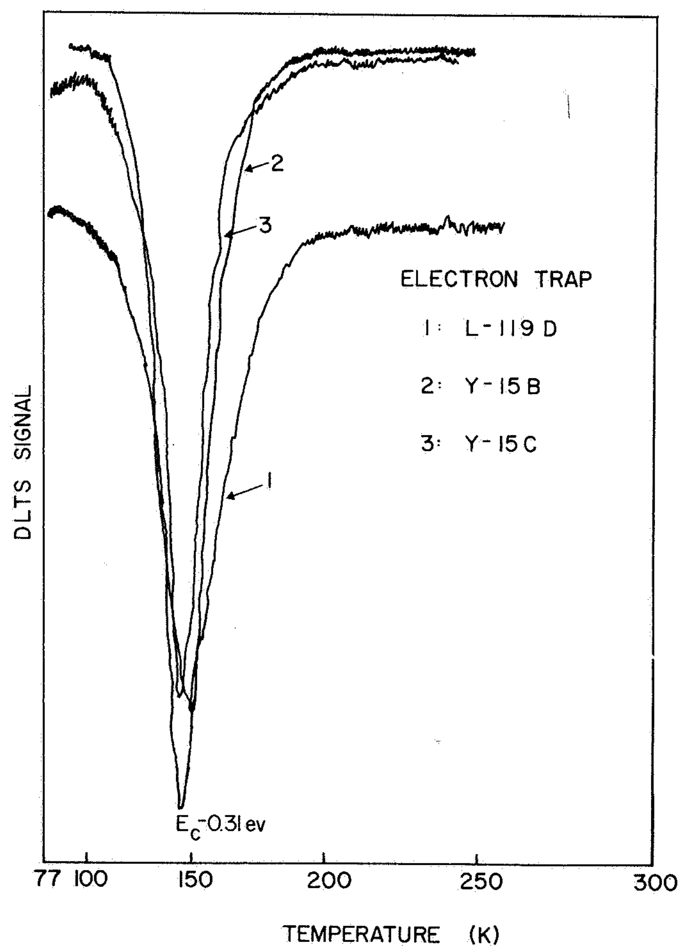

Fig.2 DLTS scans of electron traps in Be-diffused and Ge-doped $Al_{0.3}Ga_{0.7}As$ p-n junction solar cells grown by LPE technique.

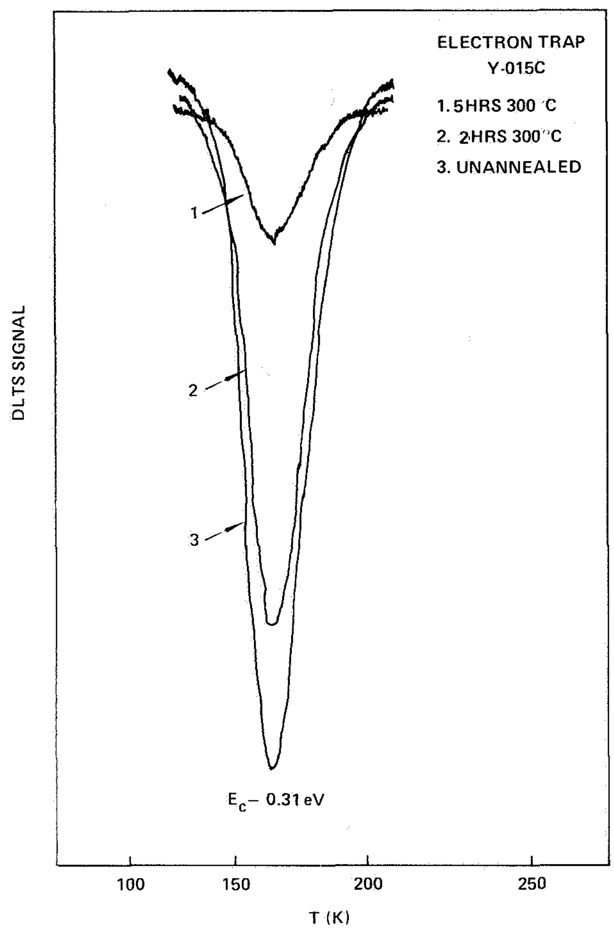

Fig. 3 DLTS scans of electron traps in $Al_{0.3}Ga_{0.7}As$ p-n junction solar cells annealed at 300 °C for 0, 2, and 5 hours.

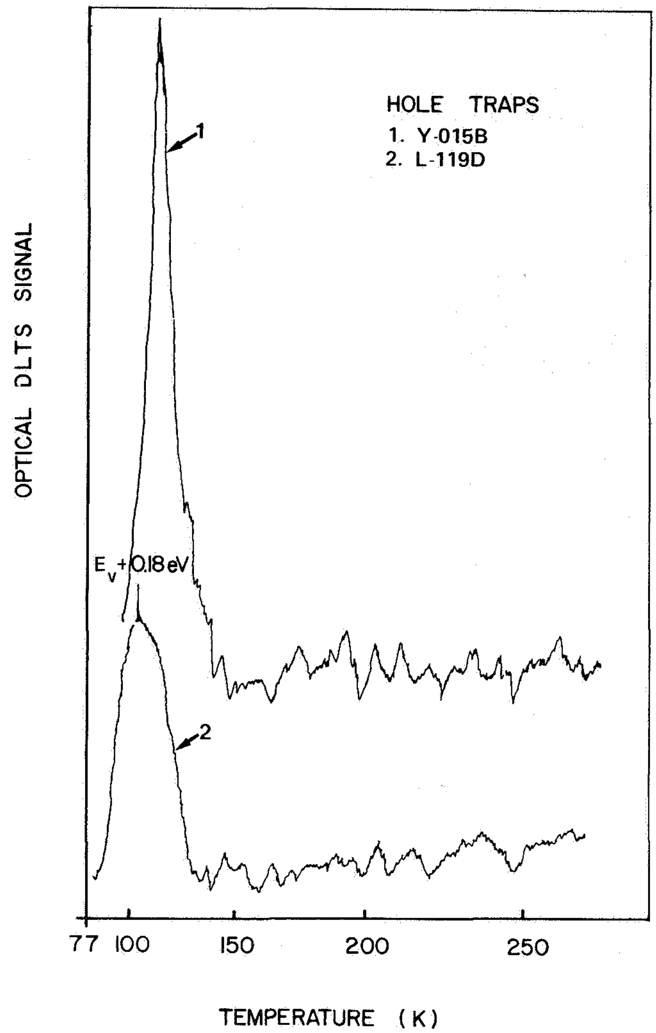

Fig. 4 Optical DLTS scans of hole trap in Be- and Ge-doped $Al_{0.3}Ga_{0.7}As$ p-n junction solar cells.

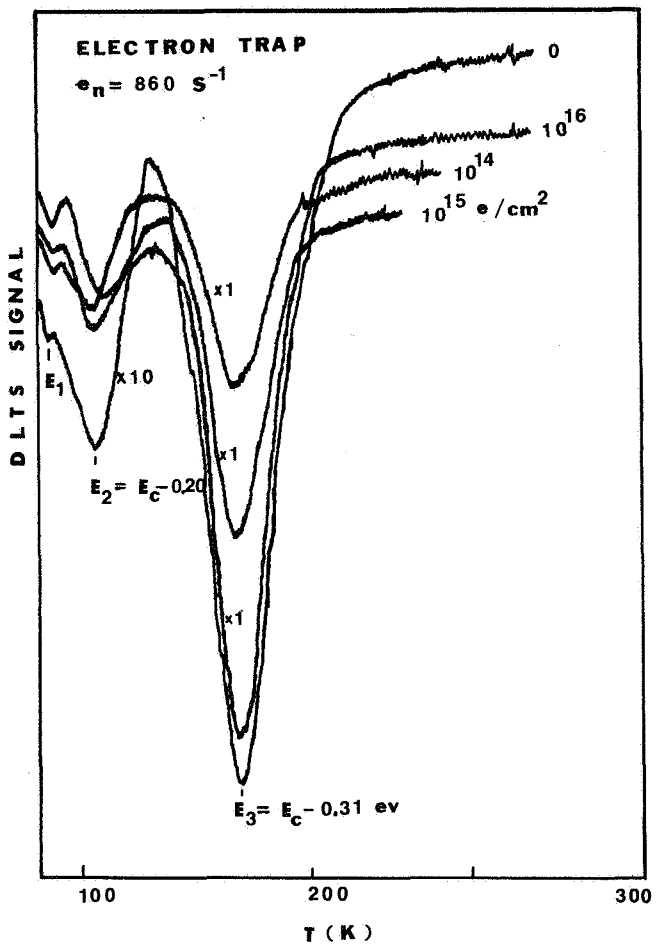

Fig.5 DLTS scans of electron traps in one-Mev electron irradiated $Al_{0.3}Ga_{0.7}As$ p-n junction solar cells for three electron fluences.

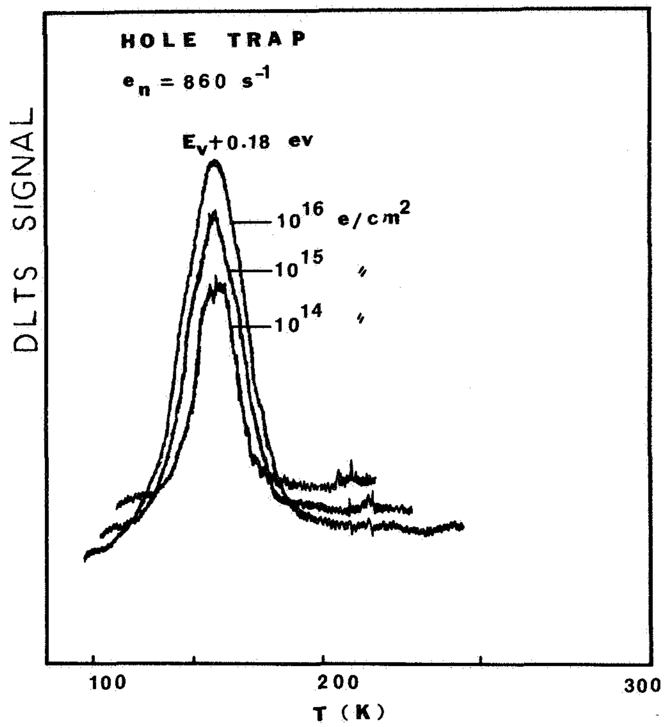

Fig. 6 DLTS scans of hole trap in one-Mev electron irradiated $Al_{0.3}Ga_{0.7}As$ p-n junction solar cells shown in Fig. 5.