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Origin of Persistent Photoconductivity in n-InP/GaInAs Two Dimensional Electron Gas

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Persistent photoconductivity exists at low temperature in two dimensional electron gas (2DEG) at the heterojunction interface.[1,2] In n-AlGaAs/GaAs 2DEG, this persistent photoconductivity originates both at the DX-center in the AlGaAs and from electron-hole separation.[1] However, in n-InP/GaInAs 2DEG, it has been pointed out that only the electron-hole separation is responsible to its persistent photoconductivity because of the lack of a DX-center-like-deep-level in n-InP.[3] In this paper, the photo-conductivity of n-InP/GaInAs 2DEG having different structures is studied, in order to clarify the detailed mechanism of the persistent photoconductivity.

Three different structures consisting of n-InP and $Ga_{0.47}In_{0.53}As$ layers were fabricated on a (001)-oriented Fe-doped semi-insulating InP substrate by low-pressure metal organic chemical vapor deposition. Table I gives the layer thicknesses and electronic properties of each sample investigated in this study. No.514 contained only a three-dimensional electron gas (3DEG) only. No.118 contained 2DEG in the 0th and 1st subbands and 3DEG. No.810 contained only 2DEG in the 0th subband because the layer thickness of 0.4μm is equal to the depletion layer thickness. Persistent photoconductivity, which has a long relaxation time, is observed only in τ_{2D-0} of No.810 (Table I). The photocurrent decays and its relaxation times for all samples after irradiation of light pulses are shown in Fig.1. Only in No.810, the current decrease is observed by the light pulse irradiation. This decrease is due to the decrease in mobility resulting from the parallel conduction of the photo-excited electrons in the 1st subband and GaInAs layer (Table I). Thus this relaxation time is the time constant of the photo-excited electron decrease in the 1st subband.

The decrease in photocurrent is determined not by the non-radiative transition but by the radiative transition of electrons. This is because the former cannot explain the existence of persistent photoconductivity. The radiative transition rate from the conduction band to the acceptor state was formulated by performing the the integral of the electron wave-function and the hole wave-function trapped in the acceptor. The calculated relaxation time of the radiative transition is given in Table II. The radiative transition of electron-acceptor clearly explains the τ_{3D} value. The calculated τ_{2D-0} is 5 hours large enough to cause the persistent photoconductivity.

Table I. Sheet electron concentration, electron mobility and thickness of each layer in n-InP/GaInAs heterojunction and bulk GaInAs layer at liquid helium temperature. The electron concentration of No.514 is estimated to be 4×10^{15} cm^{-3} considering the depletion layer. Hall(d) and Hall(a.ir) indicate the Hall measurement in the dark and after irradiation, respectively.

		2DEG,0th	2DEG,1st	GaInAs	n-InP	Hall(d)	Hall(a.ir)
No.514	n_s, cm^{-2}	----	----	8.0×10^{11}	----	8.0×10^{11}	same
	μ, cm^2/Vs	----	----	5,000	----	5,000	same
	t, μm	----	----	3.5	0	----	----
No.118	n_s, cm^{-2}	5.8×10^{11}	2.2×10^{11}	4.4×10^{11}	----	7.4×10^{11}	same
	μ, cm^2/Vs	44,000	20,000	5,000	----	40,000	same
	t, μm	----	----	1.5	0.13	----	----
No.810	n_s, cm^{-2}	5.3×10^{11}	0	0	----	5.3×10^{11}	5.6×10^{11}
	μ, cm^2/Vs	75,000	----	----	----	75,000	76,000
	t, μm	----	----	0.4	0.07	----	----

Since the calculated lifetime values clearly explain the experimental results, it can be concluded that the persistent photoconductivity in n-InP/GaInAs system is originated only from the electron-hole separation and that the main recombination process is radiative process from the conduction band to the acceptor level. The persistent photo-conductivity in n-InP/GaInAs 2DEG will be suppressed by the enlargement of electron distribution region due to the large electron-hole separation.

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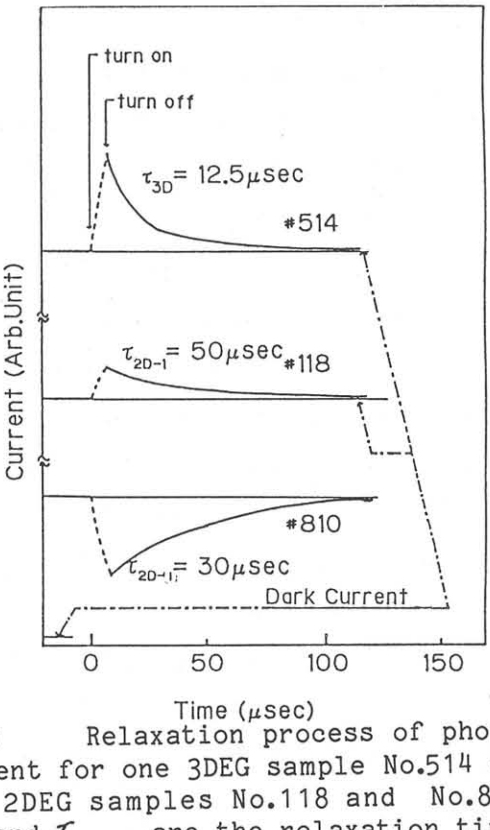

Fig.1 Relaxation process of photocurrent for one 3DEG sample No.514 and two 2DEG samples No.118 and No.810. τ_{3D} and τ_{2D-1} are the relaxation times determined in 3 DEG and in the 1st subband of 2 DEG, respectively. "Turn on" and "turn off" in the figure show the beginning and end of light pulse produced by a Xenon flash lamp.

Table II. Experimental and calculated relaxation times for each sample. τ_{2D-1} and τ_{2D-0} are calculated as shown in Fig.2 (a) and (b). "L" shown in the inset of Fig.2 (a) is obtained by equalizing the calculated τ_{2D-1} to the experimental value.

τ (μsec)	exp.	cal.	L (A)
τ_{3D}	12.5	25	---
τ_{2D-1}	30	30	550
τ_{2D-1}	50	50	590
τ_{2D-0}	>1 h.	5 h.	590

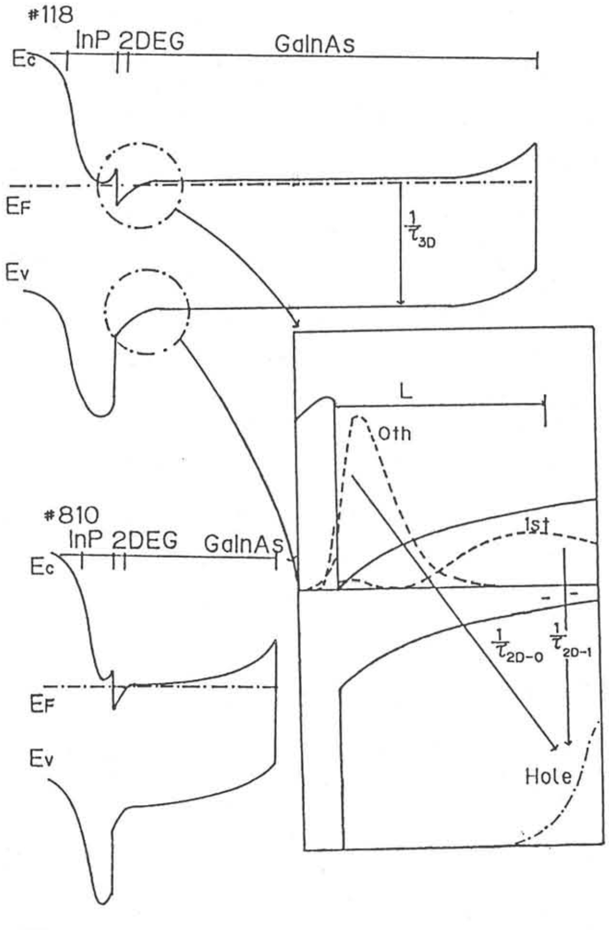

Fig.2 Schematic representations of conduction and valence band diagrams for two 2DEG samples, No.118 (a) and No.810 (b). Inset shows the details of the conduction and valence band diagrams for No.118. Dashed line shows the distribution of 2DEG calculated by the combination of the variational method and SdH measurement.[4] The dash-dotted line shows the distribution of holes trapped in the acceptor. The notations "-" and "L" indicate the ionized acceptor and its distance from the heterojunction. The notation "→" reperesents the radiative transition from the 0th and 1st subbands and 3DEG to the acceptor.