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Persistent photoconductivity in AlGaAs–GaAs heterostructures

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Persistent photoconductivity (PPC) is studied in modulation doped AlGaAs–GaAs heterostructures in the conductivity parallel to the heterojunctions. The results indicate that the macroscopic fields of the heterojunction and traps primarily in the GaAs rather than AlGaAs are responsible for the phenomenon. PPC is also reported in n^+ GaAs–undoped AlGaAs–n^+ GaAs heterostructures for current perpendicular to the heterojunctions.

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Since the observation of high electron mobility in selectively doped GaAs–AlGaAs heterostructures, the phenomenon of persistent photoconductivity (PPC) at low temperature has been extensively studied by several workers.[1–6] PPC differs from ordinary photoconductivity in that the time constant for its decay is exceedingly long—10^5 s or even longer. It is a phenomenon that has been observed in almost every semiconductor including GaAs and Si. However, the mechanism for it has not been clear.

In an earlier paper the spectral dependence of the PPC in selectively doped GaAs–AlGaAs was reported.[5] It was concluded that trapping centers other than the D–X centers in AlGaAs are responsible for the PPC and that macroscopic fields associated with the heterojunctions are involved in the process. In this paper we report further measurements of PPC on several heterostructures with different undoped AlGaAs spacer thicknesses, with different Al concentrations, and grown in two different apparatuses. The main features of the results do not depend either on which apparatus the sample was grown in or on the Al mole fraction. From this we conclude that traps in the GaAs are mainly responsible for the PPC.

We have also studied photoconductivity in three layer structures consisting of n^+ GaAs– undoped $Al_xGa_{1-x}As$–n^+ GaAs. In these samples the current flow is perpendicular to the heterojunctions. The AlGaAs was grown under two sets of conditions: (1) at a substrate temperature of 700 °C and growth rate of 1 μm/h (these conditions are what is typically used by most workers), (2) at a slow (0.15 μm/h) growth rate at 600 °C substrate temperature. We find that PPC is observed only in samples of type (2) despite the fact that this material appears very good by other measurements.[7]

The photoconductance in modulation doped heterostructures was measured at 77 K as described in Ref. 5. The samples were grown in either of two MBE apparatuses, both Riber systems, one at IBM, Yorktown, the other at the University of Illinois, Urbana. The samples used in Ref. 5 were grown in a third system, a homemade one at Yorktown. The samples studied together with some relevant data about them are listed in Table I. The striking feature of all the results is the onset of photoconductivity at about 0.8 eV as the photon energy is swept from low to high energy. This is true of samples grown in all three systems. The Al concentration in these samples is 0 (pure GaAs), 0.3, 0.35, and 0.8. A second increase in the rate of change in photoconductance with time is observed at 1.5 eV (E_g for GaAs). The GaAs sample showed no structure at higher energies. However, the AlGaAs samples all showed a further increase in rate at higher photon energies (2.0 eV for all samples except for 1100 which showed the increase at 2.5 eV). This last increase is close to the gap of AlGaAs of the appropriate sample. In most of the samples (see Table I and Ref. 5), the PPC could be partially quenched if the sample was irradiated with long-wavelength light after exposure to photon energies greater than 1.5 eV.

The fact that the onset of PPC is observed in all the samples at 0.8 eV independent of Al concentration, including the GaAs sample with no AlGaAs layer, strongly suggests that the traps are in the GaAs. The additional increase observed at 1.5 eV, the energy gap of GaAs lends support to this suggestion. The final increase in conductance at the en-

TABLE I. Modulation doped heterostructures in which PPC was observed at 77 K parallel to the heterostructures. The magnitude of this is given by the value of the conductance G after illumination with light greater than 1.5 eV. The quenching was found by illuminating the sample with ~ 1 eV light after it had been exposed to > 1.5 eV light; the value is the drop in conductance. Samples labeled NH were grown in Yorktown. Those with just a number were grown at the University of Illinois.

Sample No.	$X = \%$ Al	Spacer thickness Å	Threshold eV	Magnitude (G light/G dark)	Quenching (%)
720	0 (GaAs)	···	0.8	1.64	0
1039	0.3	30	0.8	1.23	5
1050	0.3	30	0.85	1.12	0
1128	0.3	200	0.80	1.19	0
NH43	0.3	200	0.80	4.4	6
NH45	0.3	200	0.85	3.6	16
1000	0.35	60	0.8	1.7	7
1100	0.8	75	0.75	2.3	74

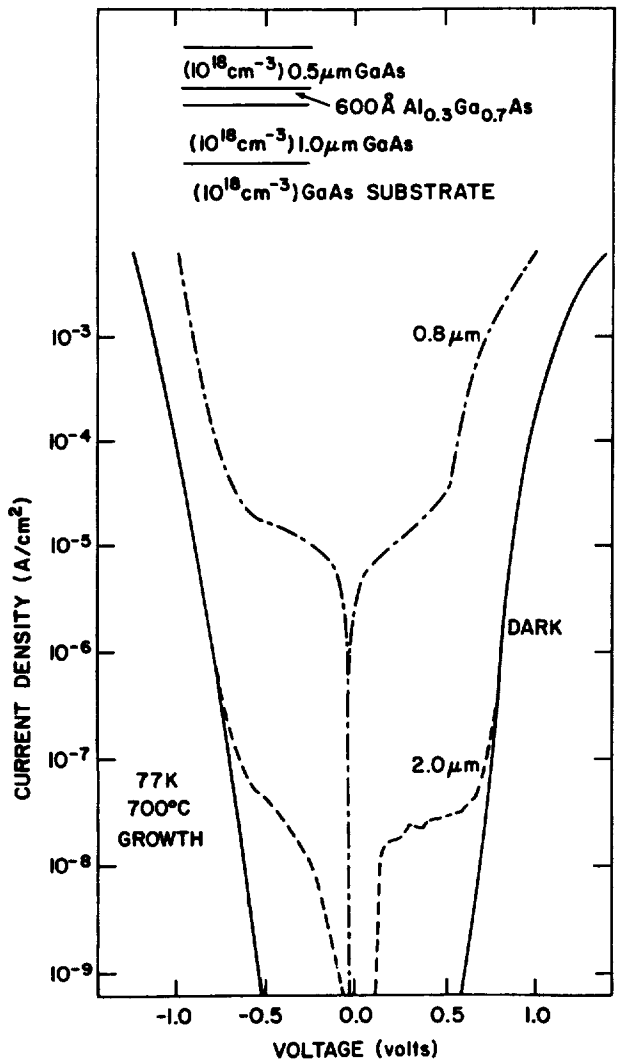

FIG. 1. Current density vs voltage perpendicular to the heterojunction at 77 K in the dark and light for a typical sample grown at 700 °C at a rate of 3 Å/s. No persistent effect observed.

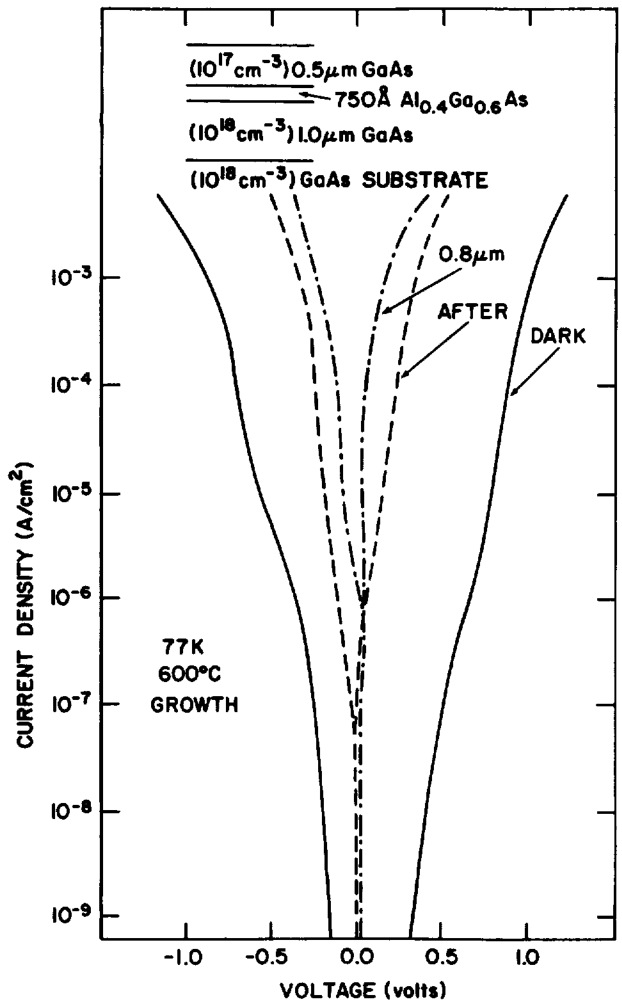

FIG. 2. Current density vs voltage perpendicular to the heterojunction at 77 K in the dark and light, for a typical sample grown at 600 °C at a rate of 0.3 Å/s. PPC is shown by conductivity after illumination labeled "after."

ergy gap of the AlGaAs indicate that it may also be involved. The fact that increases are seen at energy gaps suggests that macroscopic fields in the structure separate the electron-hole pairs and that the holes are subsequently trapped. The results of Klem *et al.*[6] suggest that states in the AlGaAs mainly give rise to this phenomenon while our results suggest states in the GaAs are primarily responsible.

The effect of light on the current–voltage characteristics of barrier heterostructures consisting of an undoped $Al_{0.3}Ga_{0.7}As$ layer sandwiched between n^+ GaAs layers was also studied. The samples were grown in the MBE apparatus at Yorktown, on n^+ 2×10^{18} cm^{-3} Si doped GaAs substrates. The samples were grown by two techniques: (1) The substrate temperature was 600 °C for the GaAs growth and was changed to 700 °C for the $Al_{0.3}Ga_{0.7}As$ portion of the growth. (2) The substrate was at 600 °C throughout the growth but the growth rates was reduced to 0.3 Å from the normal 3 Å per s.

Electrical contact was made to the top and bottom GaAs region by using standard AuGeNi alloyed contacts. The top contact covered only a small area allowing light to impinge on the sample.

Measurements of current voltage curves and the effect of light were made at 77 K with the sample immersed in liquid N_2. Light from a tungsten bulb was shown on the sample through a series of narrow band interference filters.

Figures 1 and 2 show the current voltage characteristics and the effect of light on them for a sample of each type. For the sample of type 1 in Fig. 1 no storage effect (PPC) was observed, i.e., when the light is turned off the curve returns to its dark characteristic. For wavelengths longer than 2.5 μ no response was observed. Between 2.3 and 0.95 μ the response is shown by the curve labeled 2 μ. At 0.8 μ a much stronger response is observed. A small photovoltaic effect—a light induced voltage of about 0.04 V—was observed.

In the samples grown at 600 °C shown in Fig. 2, a different type of effect was found. Again no effect was seen for excitation wavelengths longer than 2.5 μ. With shorter wavelengths, the effect of light is shown by the 0.8 μ curve in Fig. 2. The magnitude of the effect increased with decreasing wavelength, but the shape was essentially the same. The increase in conductivity was relatively slow with a time constant of a few seconds. When the light was turned off the current curve did not return to its original value in the dark but to the curve labeled "after." It remained at the curve for as long as it was observed—about 30 min. If the sample was warmed to room temperature and cooled again to 77 K, the *I–V* curve returned to the original dark one.

The persistent effect in the 600 °C samples is clearly caused by excitation from traps in the $Al_xGa_{1-x}As$. The photoconduction effect in the 700 °C could be either due to traps in the $Al_xGa_{1-x}As$ or the GaAs.

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