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OBSERVATION OF TWO-DIMENSIONAL ELECTRON GAS IN LPE-GROWN GaInAs-InP HETEROSTRUCTURES

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A series of GaInAs/InP heterostructures was grown by liquid phase epitaxy. The heterostructures were characterized by magnetotransport measurements carried out down to 1.8 K and up 10 T. The results demonstrate the existence of the high-mobility two-dimensional electron gas in the narrow-gap GaInAs as well as the presence of residual conductance through the InP buffer layer.

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1. Introduction

High-quality lattice-matched $Ga_{0.47}In_{0.53}As/InP$ heterostructures were grown by molecular beam epitaxy (MBE) [1], low-pressure metal-organic chemical vapor deposition (LP MOCVD) [2], atmospheric pressure MOCVD [3], and chloride CVD [4]. It has recently been demonstrated that GaInAs/InP heterostructures with two-dimensional electron gas can also be obtained by means of the liquid phase epitaxy (LPE) [5–7].

In this paper we present an LPE technique employed to grow a series of $Ga_{0.47}In_{0.53}As/InP$ heterostructures as well as we discuss results of their characterization by means of magnetotransport measurements. The heterostructures were grown on the InP:Fe semi-insulating substrate and consisted of two epilayers: n-type InP and GaInAs.

2. Growing method

We have employed an LPE system with horizontal sliding boat. In order to obtain high purity InP and GaInAs layers a small amount of Yb was added to the indium solution. This method is known to result in gettering of donors [8, 9] and, therefore, it eliminates the necessity of the long-term baking of the solution. Indium of 6N initial purity was baked at 700°C for 2 hours and then policrystalline InAs, GaAs, and InP as well as Yb were added to the melt. The solutions obtained in this way were annealed for 4 hours at 650°C. As a next step semi-insulating InP:Fe substrate was placed in the boat and covered by GaAs wafer to prevent the dissociation of InP surface. The crystallization process was started at 630°C with 0.4°C/min cooling rate. At 625°C the substrate was etched *in situ* for 6 s in a pure indium liquid and then growth of the buffer InP layer was initiated. At 595°C cooling was stopped and crystallization of GaInAs by the step-cooling method began. As shown in Table we carried out three types of crystallization processes which differed by the electron concentrations in buffer layer and epilayer thicknesses.

TABLE

Heterostructure parameters.

Structure number	Buffer layer		GaInAs layer		Lattice mismatch	2D electron concentration/ /mobility
	thick. (μm)	concentr. n-type (cm^{-3})	thick. (μm)	concentr. (cm^{-3})	$\Delta a/a$	$n_{SdH}(cm^{-2})$ μ(cm/Vs)
MG 65	1.0	10^{17}	1.2	$\sim 10^{15}$ (n-type)	$< 5\times10^{-4}$	6.5×10^{11} 10^5
MG 74	0.5	10^{16}	2.0	$\sim 10^{15}$ (p-type)	$< 5\times10^{-4}$	3.1×10^{11} 5×10^4
MG 95	0.5	10^{15}	2.5	$\sim 10^{15}$ (p-type)	2.4×10^{-3}	2.9×10^{11} 2×10^4

3. Results

The obtained heterostructures were characterized by three kinds of probes: (i) room temperature Hall effect measurements giving estimates of the net impurity concentrations in the epilayers, (ii) X-ray determination of the lattice constant which provides information on the lattice mismatch, i.e. on the $Ga_{1-x}In_xAs$ alloy composition; (iii) low-temperature magnetotransport studies which allows one to characterize heterostructures via analysis of the Shubnikov–de Haas resistance oscillations. Some results of the studies are displayed in Table.

The samples for quantum transport measurements were prepared by a standard photolithography in the form of Hall bridges. Indium metal was alloyed into GaInAs to make ohmic contacts. As shown in Fig. 1 the studied heterostructures exhibit pronounced Shubnikov–de Hass oscillations which begin below 1 T, proving a good quality of the material. The period of the oscillations varies as $\cos\Theta$,

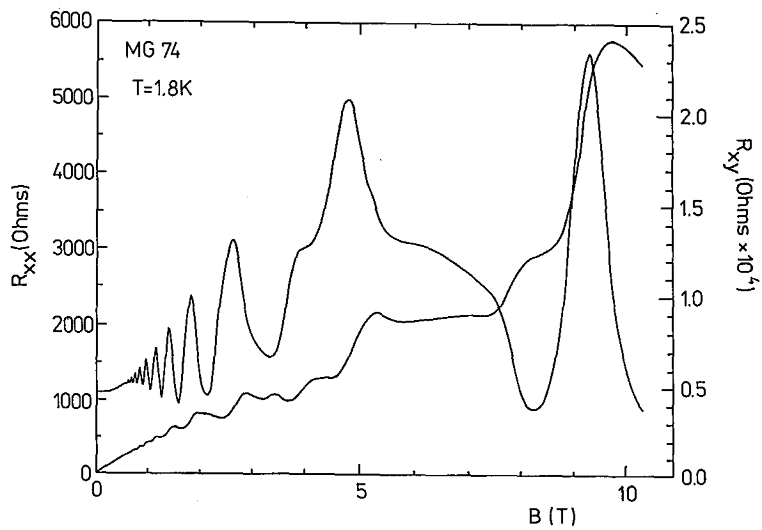

Fig. 1. Diagonal and Hall resistance (thicker trace) as a function of the magnetic field at 1.8 K for a MG 74 GaInAs-InP heterostructure. See Table for sample characterization.

where Θ is the angle between the direction of the magnetic field and normal to the GaInAs/InP interface. This, together with the appearance of characteristic plateaux in the Hall resistance, demonstrates the formation of two-dimensional electron gas in the narrow-gap GaInAs epilayer. According to the data summarized in Table the density of this electron gas increases with the net donor concentration in the InP buffer layer, which in turn decreases when the amount of Yb present during InP growth increases. From the electron concentration and the heterostructure conductivity we evaluated electron mobility depicted in the last column of Table.

However, the values obtained in this way constitute an upper-limit estimate only because of the presence of the conducting InP layer. This layer is responsible presumably for some current leakage and the associated sublinear dependence of the Hall resistance on the magnetic field. Furthermore, a contribution from an additional conductivity channel is seen in the spectrum of Shubnikov-de Hass oscillations. As shown in Fig. 2 the Fourier transform of the oscillations contains an additional maximum, whose position does not depend on the field direction. The electron concentration estimated from this maximum, $n = 1.2 \times 10^{17}\text{cm}^{-3}$, agrees with that deduced from the Hall data for InP epilayers obtained under the same growth conditions.

In summary, the developed LPE method gives heterostructures with the two-dimensional electron gas. The value of electron mobility and magnitude of the Shubnikov–de Haas oscillations point to a good quality of the epilayers and of the interface. However, a further work is needed to eliminate uncontrolled leakage of the current.

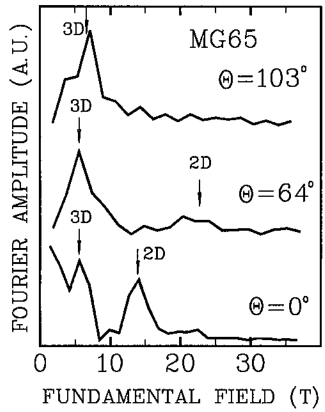

Fig. 2. Fourier transform of the Shubnikov–de Haas oscillations for MG 65 heterostructure for various angles between normal to the interface plane and magnetic field showing the simultaneous presence of the both two- and three-dimensional electron gases.

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