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AlGaAs/InGaP interfaces in structures prepared by MOVPE

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ABSTRACT

$Al_{0.3}Ga_{0.7}As/In_{1-x}Ga_xP$ structures were prepared by low-pressure MOVPE. Lattice matched and strained ones with top $In_{1-x}Ga_xP$ layers as well as reverse ones with top $Al_{0.3}Ga_{0.7}As$ layers were examined. The structures were studied by photoluminescence, X-ray and atomic force microscope (AFM) methods. An additional photoluminescence peak from the $Al_{0.3}Ga_{0.7}As/In_{1-x}Ga_xP$ interface was observed in our samples and it was attributed to a type-II band offset. A conduction band offset of 0.121 eV was measured in the $Al_{0.3}Ga_{0.7}As/In_{0.485}Ga_{0.515}P$ lattice-matched structure and a linear dependence of the conduction band offset on $In_{1-x}Ga_xP$ composition, with a zero offset in the $Al_{0.3}Ga_{0.7}As/In_{0.315}Ga_{0.685}P$ structure, was determined. The valence band discontinuity had a nearly constant value of 0.152 eV.

1. Introduction

AlGaAs/GaAs has become the most favoured III–V semiconductor system as a material basis for a variety of electronic devices, because it possesses some favourable physical properties. Most favourably, $Al_xGa_{1-x}As$ is nearly lattice matched to GaAs in the whole range of compositions. As a consequence, the formation of strain-induced defects during its growth is suppressed. However, $Al_xGa_{1-x}As$ also has some disadvantages. It suffers from a high reactivity of Al with oxygen, and the reactivity is proportional to the Al content. Moreover, $Al_xGa_{1-x}As$ with $x\sim0.3$ (most useful compositions) exhibits high densities of deep levels and surface states [1–3], which is critical especially in sub-micrometer devices.

$In_{0.485}Ga_{0.515}P$/GaAs is a promising alternative to the AlGaAs/GaAs system. $In_{0.485}Ga_{0.515}P$ (hereafter InGaP) is chemically more stable than AlGaAs. It has a lower density of surface states [4], and it exhibits a good etching selectivity with respect to GaAs. However, unlike AlGaAs, $In_xGa_{1-x}P$ is lattice matched to GaAs only at the $In_{0.485}Ga_{0.515}P$ composition. Although $In_{0.485}Ga_{0.515}P$/GaAs is an attractive system, it has not met the expectations due to problems linked with the ordering effect [5] and due to problems linked with the complexity of the InGaP/GaAs interface. The former is caused by the self-organisation of Ga and In atoms at the grown surface and the latter by an As/P exchange process [6,7]. The former effect leads to the formation of ordered domains and to a reduction of the band gap and the latter lowers the quality of the InGaP/GaAs interface, which is always worse than the quality of the AlGaAs/GaAs interface despite growth optimisation efforts [16,17].

The advantages of AlGaAs/GaAs and InGaP/GaAs systems can be combined in a GaAs/AlGaAs/InGaP structure. One can expect a standard AlGaAs/GaAs structure with a high-mobility two-dimensional electron gas can become more stable if it is capped with an InGaP layer. The InGaP layer can also serve as an etch-stop layer. Such a combined structure can be exploited in devices with improved performance.

To incorporate InGaP layers successfully into the AlGaAs/GaAs system, one needs to know well the AlGaAs/InGaP interface, including the band offset and other important characteristics. In the past, $GaAs/Al_xGa_{1-x}As$/InGaP structures were used for the preparation of HBTs with improved electrical parameters [8,9]. The band offset of the $Al_xGa_{1-x}As/In_{0.5}Ga_{0.5}P$ system was studied only with samples prepared by liquid phase epitaxy (LPE) [10,11]. This paper reports on the low-pressure MOVPE preparation and study of $Al_{0.3}Ga_{0.7}As/In_{1-x}Ga_xP$ structures. Contrary to LPE, the

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MOVPE allows for a better control of the formation of the AlGaAs/InGaP interface by varying growth conditions.

2. Experiment and results

The $Al_{0.3}Ga_{0.7}As/In_{1-x}Ga_xP$ structures were prepared by a conventional low-pressure MOVPE process in Aixtron AIX 200 equipment. Trimethyl-gallium, trimethyl-indium, trimethyl-aluminium, arsine and phosphine were used as the precursors. The carrier gas was purified hydrogen. The growth rates of AlGaAs and InGaP were 0.23 and 0.33 nm/s, respectively. Semi-insulating GaAs (0 0 1)$\pm$0.25° oriented substrates were used in all experiments. As the optimal growth temperatures for AlGaAs and InGaP are different, the AlGaAs was grown at 700 °C and the InGaP at 560 °C. InGaP is grown at such a low temperature to reduce ordering and suppress inter-diffusion at the interface [12,13,23].

The structures were characterized with photoluminescence (PL) at 6 K: samples were placed in an optical cryostat and cooled by flowing He vapour. The cryostat allowed for setting the temperature in a 4.2–300 K range with a precision of $\pm$0.1 K. The samples were pumped with radiation at a wavelength of 488 nm from an Argon ion laser. The laser beam was focused on the samples, and approximately 1 W/cm^2 of maximum power density was used. The pumping power was regulated using a set of neutral density filters. PL radiation from the samples was focused onto a monochromator and detected at the output by a silicon photodetector.

We prepared structures with top InGaP layers (InGaP-on-AlGaAs) at first. The basic structure (#803) was grown the following way: the AlGaAs layer was grown at 700 °C, and the temperature was then lowered to 560 °C during 360 s under an overpressure of arsine. Then arsine was switched off and the phosphine was switched on at the same time. Subsequently, the In and Ga precursors were switched into the reactor 5 s later. A photoluminescence spectrum of sample #803 is shown in Fig. 1. An additional peak at an energy of 1.77 eV was observed alongside the typical peaks present in single AlGaAs and InGaP layers. The energy is significantly lower than the band–band transitions of both materials and it can be consequence of a type-II band discontinuity at the interface, to a transition from the conduction band of InGaP to the valence band of AlGaAs. More precisely, the band line-up leads to the formation of shallow triangular quantum wells (QWs) at the GaAlAs/InGaP interface. It is schematically depicted in Fig. 2a (transition $E1_{InGaP}$–$HH1_{AlGaAs}$). Similar PL peaks were interpreted as a consequence of a type-II band discontinuity in LPE-grown AlGaAs/InGaP interfaces in [10,11]. A type-II band discontinuity results also from a comparison of the AlGaAs/GaAs and GaAs/InGaP band offsets, taking the transitivity principle [19] into account.

Because the interlayers (or clusters) spontaneously forming at the interface during the growth process can modify the PL spectra significantly, the structure of the interface must be analysed carefully in order to determine the band offset between the AlGaAs and InGaP properly. Especially, the formation of low band gap interlayers must be eliminated in the method.

We suppose that an As/P exchange mechanism plays a basic role in modifying the InGaP-on-AlGaAs and the AlGaAs-on-InGaP interfaces during the MOVPE growth. Such an As/P exchange was observed in the InGaP/GaAs interfaces [6,7] and also in other ones [14,15]. The thickness of a transition layer formed by the process varied with growth conditions. Values between 1 and 2 monolayers (ML) were typical for temperatures close to 560 °C [6,13]. An impact of the As/P exchange process on the InGaP-on-AlGaAs interface in sample #803 can be characterized by the formation of an AlGaP or AlGaPAs wide band gap interlayers. A time constant of 0.5 s can be extrapolated for the As/P exchange process at 560 °C from data published in [24]. Therefore, one can expect: (1) the formation of an AlGaP monolayer with top As atoms nearly completely exchanged with P atoms; and (2) the formation of an underlying graded AlGaPAs interlayer as a consequence of diffusion during the 5 s phosphine pre-flow. Fortunately, as both layers have wider band gaps compared with that of AlGaAs, the position of the PL peak from the interface should be determined by the band offset of AlGaAs and InGaP. We suppose that Fig. 2b depicts the real structure of the interface in sample #803 better than ideal interface according to Fig. 2a.

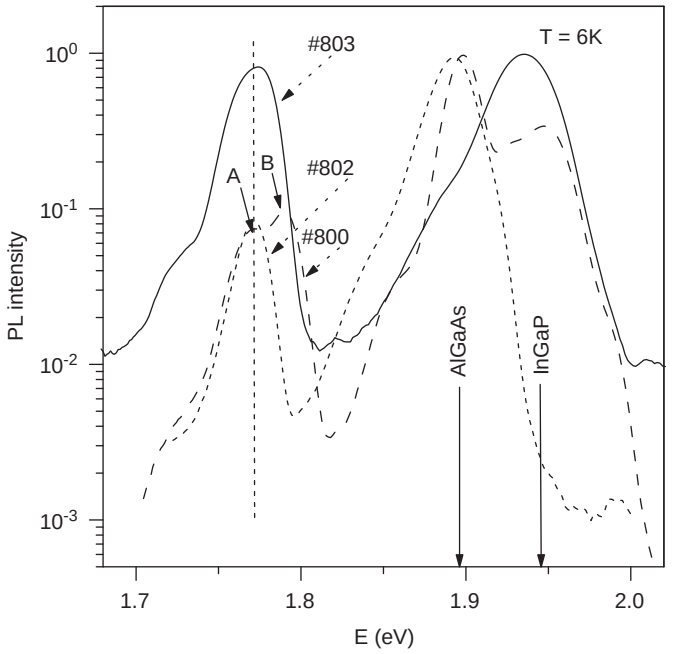

Fig. 1. PL spectra of the structures without a GaP interlayer (#803) and with GaP interlayers (#800, #802).

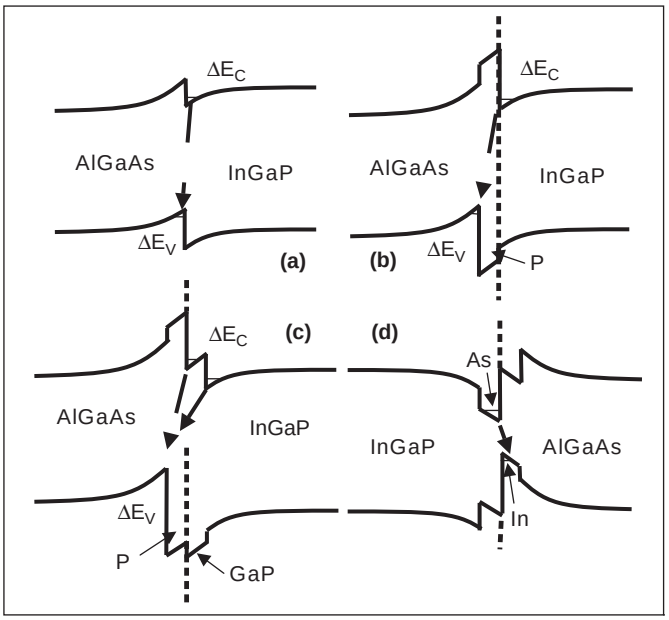

Fig. 2. Schematic band structures with various InGaP-on-AlGaAs interfaces. (**a**—ideal, **b**—with AlGaP interlayer, **c**—with AlGaP and GaP interlayers) and AlGaAs-on-InGaP one (**d**).