Influence of ordered and random part on properties of InGaP alloy grown by MOVPE.

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MOVPE grown InGaP epitaxial layers order spontaneously in CuPt(B)−like structures consisting of alternating Ga− and In−rich planes along the (−111) and (1−11) directions. On exactly oriented GaAs substrates the both variants are equally distributed in platelike domains. Complete ordering is usually not achieved. Recent studies have shown that ordering has a marked influence on the reduction of band energy as well as on the splitting of the valence band, which results in the anisotropy of optical and electrical properties of the ternary. Strain produced by lattice mismatch between an InGaP layer and GaAs substrate can also lead to the valence band splitting and to an increase (if compressive) or decrease (if tensile) of the band−gap energy. It is quite surprisingly, that role of the random part of epitaxial layer and their influence on optical and electrical properties of alloy was not so carefully studied as in case of ordered domains. Probably it follows from fact that photoluminescence spectra of partially ordered InGaP epitaxial layers are fully ruled by ordered material and no signal from random part is to observe. On the other hand, spectral ellipsometry allows to show not only optical anisotropy in partially ordered samples but also to reveal signal from random part of the epitaxial layer.

In our contribution we will show that the band gap energy of InGaP follows closely the compositional dependence proposed by Wei and Zunger [1]. The Eg value measured in tensile strained epitaxial layers is significantly lower compared with the one that follows from the generally used parabolic interpolation between the Eg of InP and GaP. The additional transition caused by the random part of the InGaP alloy E_0 (random) lies at higher energy depending on the composition of the ternary. A difference between band gap of ordered and random part varies with composition of ternary and its value lies in interval between 20 − 65 meV.

It was previously suggested that the higher band gap associated with the boundaries between domains could act as a barrier and spatially separate the carriers [2]. We studied dependence of both band gap values on the InP mole fraction for two sets of InGaP samples grown at 640 ^{o} C and 20 mbar reactor pressure. At this temperature a massive evolution of the ordering effect can usually be achieved. Also, the reactor pressure of 20 mbar is, to our experience, the most appropriate as it allows for the best control of ordering as well as the highest reproducibility of its development. The growth conditions for each growth run were maintained the same, except for the In/Ga ratio in order to prepare a set of samples with nearly the same degree of order but with various tensile or compressive strain induced by different lattice mismatch. The source materials were trimethylgallium (TMGa), trimethylindium (TMIn), arsine (AsH_3), and phosphine (PH_3). All epitaxial layers were grown on semiinsulating exactly (001)−oriented GaAs substrates. This procedure led to the obtention of InGaP samples where the InP mole fraction ranged from x=0.35 to x=0.565, i.e., in a similar interval for which Wei and Zunger's calculations were made. The ternary composition of epitaxial layers was determined using X−ray diffraction data along with Vegaard's law.

Optical measurements were performed using a rotating polarizer ellipsometer with a 1.4 − 5.1 eV spectral energy range. Spectra were taken at room temperature after removing surface oxide layers by etching in a solution of 5% hydrofluoric acid in deionized water. During the measurement, samples were kept under a dry N_2 flux to prevent oxidation. The experimental energy step in the fundamental band gap region analysed was generally 5 meV, but we used finer steps of 2 meV to resolve the lowest−energy sharp features. For each sample, two different orientations were measured that approximately gave the two different components of the dielectric tensor.

While the band gap of ordered part of samples follows closely the compositional dependence proposed in theory, the random part shows a different dependence with maximum close to composition lattice matched to GaAs substrate at the growth temperature (see Fig.1). Random band gap energy value obtained for exactly lattice

matched sample is in very good agreement with E_g value of 1.910 eV published for completely disordered InGaP in [3]. At all other samples, the band gap energy behaves on another maner as the ordered part band gap energy value. For samples with lower value of x the random part bandgap energy is lower as it follws from theory, for samples with higher value of x it is on the contrary.

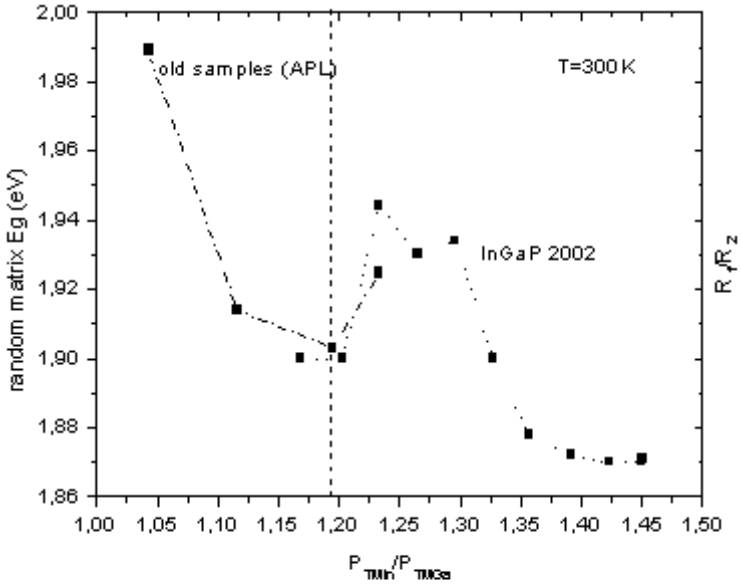

Fig. 1 Dependence of band gap energy of random part of the InGaP alloy on the p_{TMIn}/p_{TMGa} ratio

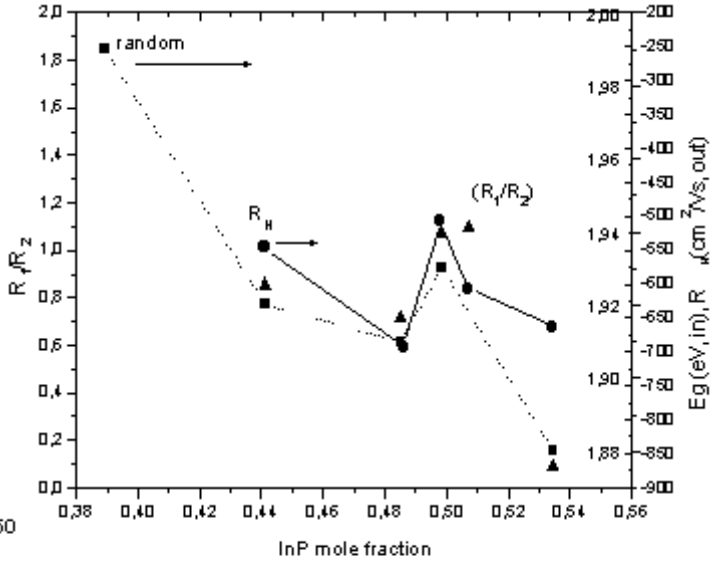

Fig. 2. Electrical parameters Hall constant R_H and R_1/R_2 ratio and band gap energy of random part of as a function InGaP composition.

Electrical parameters were measured using van der Pauw configuration. Fig. 2 shows a dependence of Hall constant and ratio of resistances R_1 (measured in the [0−11] direction) and R_2 (measured in the [011] direction) in dependence on the ternary composition. Obtained results have shown that the both electrical parameters ((i) Hall constant and (ii) ratio R_1/R_2 behave in relation to alloy composition similar as the band gap of random part of the epitaxial layer. Consequently, an electrical transport in such complicated structure is influenced by both materials. This influence of various band gaps on electrical properties may be realised either due to type II junction band offset between ordered and random part or due to creation of quantum wells in ordered domains close to interfaces between ordered and random alloy. In both cases the random matrix acts as barrier and supplies carriers.

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