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GaAlAs ALLOY/PSEUDOALLOY TYPE II STRUCTURES

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The existence of type-II structures made from the combination of $Ga_{1-x}Al_xAs$ alloy and a short period GaAs/AlAs type-I superlattice is presented. Such three material structures are of type-II having at the same time electrons and holes of Γ-symmetry. This contrasts with the usual situation in type-II two material GaAs/AlAs structure where the ground state of electrons is of X-symmetry. The mechanism allowing creation of three material type-II structures is based on the difference of effective masses of electrons and holes. It should be valid for all similar semiconductor systems. Experimental results of photoluminescence and photoluminescence excitation studies of such structures made by Molecular Beam Epitaxy are presented. We determine the mutual positions of the electron and hole ground levels in the alloy and pseudoalloy and confirm that the studied structure is of type-II.

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In GaAs/AlAs type-II superlattices (SL's) electrons and holes are spatially separated, being predominantly localized in the AlAs and GaAs layers, respectively. This contrasts with a type-I SL's where both carriers are confined in GaAs layers. The mechanism leading to the spatial separation of electrons and holes is now well understood [1–3]. For GaAs widths less than 35 Å and, average Al contents in SL greater than 0.4, the lowest GaAs related Γ-level lies at higher energy than that of X-state confined in AlAs [3]. Thus, ground states of electrons and holes are spatially separated. Such a separation is inherently associated with the fact that electrons in their ground state have X-symmetry (while the ground state of holes is of Γ-symmetry). Thus type-II SL obtained from two different materials (e.g. GaAs and AlAs) are "indirect" in real space but also in k-space. Other combinations of GaAlAs alloys can be used to obtain a type-II SL but, in the framework

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of two material systems, it is necessary to keep in mind that the potentials felt by electrons and holes should have minima in different materials and, hence, should be of different symmetry.

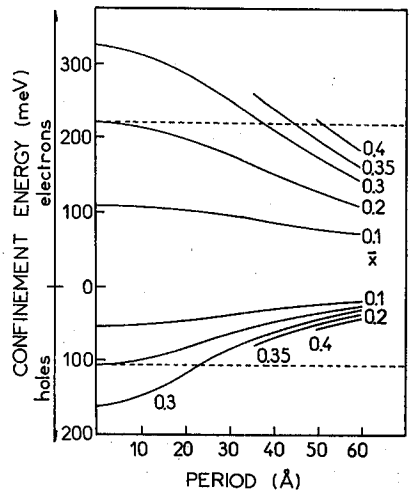

Fig. 1. Variation of electron and hole confinement energies as a function of the period P of GaAs/AlAs superlattices, for various mean aluminum contents x (solid lines). Dashed lines marks the relative position of conduction and valence bands for $Ga_{0.8}Al_{0.2}As$ alloy. As an example, type–II structures can be obtained from a combination of such an alloy and GaAs/AlAs superlattices determined by $P = 50$ Å and $x = 0.4$ or $P = 40$ Å and $x = 0.35$.

However, considering three component GaAs/GaAlAs/AlAs system it is possible to obtain type-II structures having ground states of electrons and holes both of Γ-symmetry (and so being "direct" in k-space). They can be made from $Ga_{1-x}Al_xAs$ alloy and short period GaAs/AlAs type-I SL (hereafter referred to as pseudoalloy).

The mechanism allowing such a possibility is due to the different effective masses of electrons and holes (in GaAs and in AlAs). In Fig. 1 the variations of confinement energies of electrons and holes as a function of the pseudoalloy period is plotted for several mean aluminum contents (as calculated using a transfer matrix technique). Only the cases where both electron and hole ground states are of Γ-symmetry are considered. In GaAs, due to much lighter mass of Γ-electrons than that of holes, the confinement electron energy rises faster than the hole energy. On the other hand, in AlAs, Γ-electrons, due to their lighter effective mass, tunnel easier than holes. This leads to a faster saturation of the 1-st electron miniband energy than that of the 1-st hole miniband while the period of pseudoalloy is decreased. Both energies converge towards the values of respective band energies of GaAlAs alloy with the same mean Al content as pseudoalloy. As a result, the variation of electron confinement energy does not scale to the variation of hole

confinement energy.

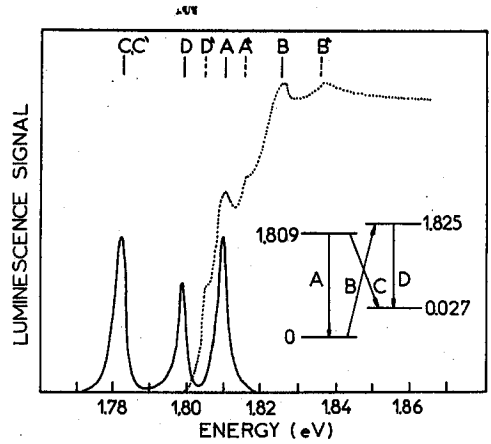

Fig. 2. Solid line: luminescence spectrum of our structure made from $Ga_{0.8}Al_{0.2}As$ alloy and GaAs/AlAs superlattice ($P = 50$ Å, $x = 0.4$). Dashed line: C – luminescence line excitation spectrum. Inset: Interpretation of the three luminescence lines and of the features of the excitation spectrum. The positions of ground levels of alloy and pseudoalloy with respect to the bottom of the valence band of alloy are determined on the basis of this interpretation. The structures denoted with prime corresponds to the second alloy/pseudoalloy interface having slightly different parameters (due to unavoidable cell temperature transient during the MBE growth).

On the other hand, the changes of both band energies of GaAlAs alloy are fairly proportional to the Al content.

Thus, it is possible to obtain the ordering of alloy and pseudoalloy ground states which is characteristic of type-II system. This requires the proper choice of three parameters: the Al content of GaAlAs alloy, the period of GaAs/AlAs pseudoalloy and the mean Al content of this pseudoalloy. As an example the combination of $Ga_{0.8}Al_{0.2}As$ alloy and GaAs/AlAs pseudoalloy of period of 50 Å and mean Al content of 0.4 can be considered.

Using Molecular Beam Epitaxy, the following sequence of undoped layers has been grown on GaAs Semi-Insulating substrate: 0.5 μm wide GaAs buffer layer, 400 Å $Ga_{0.7}Al_{0.3}As$, 500 Å $Ga_{0.8}Al_{0.2}As$, 11 periods of GaAs/AlAs superlattice with period 50 Å and Al content 0.4 (ended on both sides by an AlAs layer), 500 Å $Ga_{0.8}Al_{0.2}As$, 400 Å $Ga_{0.7}Al_{0.3}As$ and 100 Å undoped GaAs Cap layer. The $Ga_{0.7}Al_{0.3}As$ alloy creates a potential barrier in the structure for both electrons and holes. The structure was studied by photoluminescence and photoluminescence excitation spectroscopy, at 2 K, using a tunable DCM dye laser excitation and a GaAs cooled photomultiplier with photon-counting detection. Luminescence was excited with low power to avoid photocreated electric field which alters the relative position of the bands. The luminescence spectrum (see Fig. 2) contains three luminescence lines which can be interpreted (see inset in the Fig. 2) as a

transition within: $Ga_{0.8}Al_{0.2}As$ alloy (line A), GaAs/AlAs pseudoalloy (line D) and a cross recombination of electrons being in pseudoalloy and holes being in the alloy (line C). On this basis, it is possible to determine mutual positions of alloy and pseudoalloy bands. The excitation spectrum of luminescence line corresponding to the cross recombination (see Fig. 2) starts at the position of luminescence of pseudoalloy (line D – the lowest type-I transition energy in the system). Furthermore, it contains the structures corresponding to the carrier excitation within the alloy (lines A and A') and the cross excitation (lines B and B' – alloy valence band to the 1-st electron miniband of pseudoalloy). The energy of the B-transition is in agreement with the value expected from the energies of luminescence lines. All the measured values agree with the results of the effective mass model described above and confirms that type-II "direct in k-space" structures can be fabricated using GaAlAs systems. The difference of alloy and pseudoalloy level energies are much smaller than in two material GaAs/AlAs structures.

In conclusion, a new mechanism leading to the creation of type-II structures has been presented. It is based on the difference of effective masses of electrons and holes and should be valid for all semiconductor systems with a large difference of carrier masses.

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