AIP Applied Physics Letters

Hole confinement effects on multiple Si δ doping in GaAs

S. M. Shibli, L. M. R. Scolfaro, J. R. Leite, C. A. C. Mendonça, F. Plentz, and E. A. Meneses

Citation: Applied Physics Letters **60**, 2895 (1992); doi: 10.1063/1.106811
View online: http://dx.doi.org/10.1063/1.106811
View Table of Contents: http://scitation.aip.org/content/aip/journal/apl/60/23?ver=pdfcov
Published by the AIP Publishing

Hole confinement effects on multiple Si δ doping in GaAs

S. M. Shibli, L. M. R. Scolfaro, and J. R. Leite
Instituto de Física, Universidade de São Paulo, Caixa Postal 20516, 01498 São Paulo, S. P., Brazil

C. A. C. Mendonça, F. Plentz, and E. A. Meneses
Instituto de Física, Universidade Estadual de Campinas, Caixa Postal 6165, 13081 Campinas, S. P., Brazil

(Received 21 January 1992; accepted for publication 23 March 1992)

The observation of quantum-confined optical transitions in multiple δ doping in GaAs, grown by molecular beam epitaxy, is reported. Doping efficiency and carrier confinement are investigated by Hall and photoluminescence measurements. Hall measurement results for multiple δ-doped samples show a dramatic enhancement of carrier concentrations compared to the uniform doping case. From photoluminescence spectra we observed that the cutoff energy is significantly affected by the spacing between the dopant sheets. The strong localization of confined photoexcited holes in the spacing layers of these structures plays a fundamental role in the interpretation of the optical data.

Structures containing single and multiple δ-doped layers have been intensively investigated in compound semiconductors from both, experimental[1–10] and theoretical[10,11] points of view. Photoluminescence (PL) has been widely used to investigate periodically Si δ-doped GaAs[9] and AlGaAs[12] and doping superlattices.[13] Transitions below band gap have been observed and, in the first two cases, attributed to the recombination of electrons, confined by the conduction band potentials due to the δ layers, with holes on the top of the valence band, in the spacing layers. In the case of doping superlattices, such transitions were assigned to interband recombination of both confined electrons and holes. On the other hand, transitions above GaAs band edge have also been observed and have been explained in terms of the rise of Fermi energy due to the increase of the electron concentration in heavily doped samples, with the confinement of holes being practically neglected.[9]

In this letter, we report that the multiple δ-doping technique yields effective photogenerated hole confining structures. A systematic study of carriers confinement as a function of the layer spacing d_s is carried out on Si multiple delta-doped ($M\delta$-D) GaAs layers. The PL spectra of $M\delta$-D structures indicate an increase in carriers confinement as d_s decreases. From Hall measurements we have investigated the dependence of doping efficiency in these structures, and compared the results to a corresponding uniformly doped sample.

The GaAs samples were grown on (100) GaAs undoped semi-insulating substrates, in our laboratory, by using a Varian Gen II molecular beam epitaxy system. The substrate temperature was 540 °C to reduce Si diffusion and segregation.[1] A growth rate of 1.5 μ/h was obtained from reflection high-energy electron diffraction (RHEED) oscillations. $M\delta$ doping was performed by (a) interrupting growth, (b) opening the Si source to deposit the dopant, while keeping the As shutter open, and (c) closing the Si source and resuming the growth. The resulting structures consist of 100 δ layers with the layer spacing varying from 40 to 220 Å. A GaAs sample with uniform (conventional) doping was also grown for comparison. In all samples, an undoped GaAs buffer layer was grown before doping.

The samples were electrically characterized by Hall measurements at 300 K using the van der Pauw technique. The low temperature PL measurements were performed with the samples immersed in superfluid He (2 K). As excitation source we used the 580-nm line of a Spectra Physics ring dye laser pumped by an Argon ion laser. The excitation power density was 0.8 W/cm^2. The emission of the samples were analyzed with a 0.75 m double monochromator (Spex) and detected by an RCA-GaAs Peltier cooled photomultiplier and a photoncounting system.

The Hall measurements results displayed in Table I show a remarkable enhancement of electrical activity in the $M\delta$-D samples compared to the conventional doping case, as expected.

In Fig. 1 the PL spectra of four $M\delta$-doped and the corresponding uniformly doped samples are shown. An emission band above GaAs band-gap energy is observed for all samples. For those with the δ layers the linewidth of this band increases with decreasing layer spacing. The cutoff energy for each spectrum, defined as the termination point of the high energy tail of the emission band,[14] is indicated in Fig. 1. Its dependence on d_s is shown in Table I. It can be noticed that the cutoff energy shifts up to approximately 100 meV above GaAs band-gap energy. The structure observed around 1.49 eV, which does not show a significant shift with the variation of d_s, has been assigned to acceptor-related recombinations from the GaAs cap layer. Although this structure is not seen in the spectrum of the sample with $d_s = 100$ Å, probably due to an unintentional high doping level of the cap layer, the value of the cutoff energy is consistent with the trend shown in Fig. 1.

In our samples the $M\delta$-D structures present the characteristics of superlattices,[11] in which energy minibands are originated, with their widths depending on d_s. This effect is due to the strong coupling between adjacent δ layers which increases when d_s decreases. In this regime the minibands

TABLE I. Electrical and optical measurement results for the uniform and $M\delta$-doped samples. d_s is the layer spacing; n is the electron concentration; and $h\nu^{\text{cutoff}}$ is the cutoff energy from PL spectra.

d_s(Å)	$n(10^{18}\ \text{cm}^{-3})$	$h\nu^{\text{cutoff}}$(eV)
40	9.2	1.62
100	2.7	1.58
160	2.1	1.56
220	1.1	1.54
Uniform	0.8	1.53

are extended into the spacing layer and, therefore, the electronic density in this region must be taken into account when analyzing the PL spectra.

The analysis of the experimental results are based on the discussion above and on the schematic band diagram for two δ layers shown in Fig. 2. In the region between the two δ layers we have minibands for both electrons and holes, with those for the electrons occupied up to the Fermi level E_F. Due to low temperature and low excitation intensity, only the first valence miniband will be (partially) occupied by the photogenerated holes. In contrast to the case of an isolated δ layer, in the $M\delta$-D samples these holes will also be confined due to the valence band potential profile. We assigned the high energy band to the recombination between electrons in the conduction minibands and photoexcited holes at the first valence miniband. Then, the cutoff energy can be estimated by (see Fig. 2):

$$h\nu^{\text{cutoff}}=E_g^{\text{GaAs}}-V+E_F+E_h, \qquad (1)$$

where V is the depth of the effective potential, E_F is the Fermi energy for the electrons, and E_h is the confinement energy for the holes. Equation (1) indicates that both E_F and E_h can contribute to the rise of the cutoff energy. When the spacing between the δ layers is reduced these energies increase. The former due to the increase of electron density and the latter as a result of the strong confinement in the spacing layer. The broadening of the emission band, clearly seen in Fig. 1, is consistent with the increase miniband width due to the coupling between adjacent δ layers.

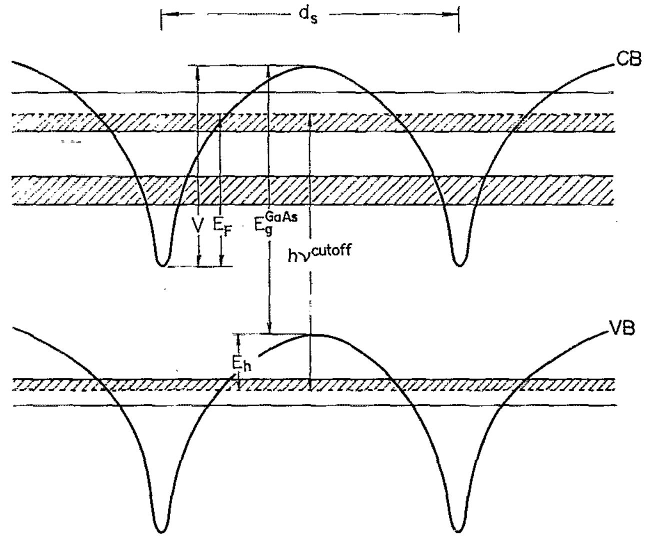

FIG. 2. Schematic band diagram for a structure with two δ layers showing the energies defined in Eq. (1). CB and VB refer to conduction and valence band edges, respectively.

In conclusion, we find that besides the high electron density, the strong localization of confined photogenerated holes in the spacing layer is determinant to establish the origin of the transitions in the photoluminescence from $M\delta$-doped structures.

The authors (S.M.S.) and (C.A.C.M.) acknowledge the Conselho Nacional de Desenvolvimento Cientifico e Tecnologico (CNPq) Brazil, for financial support.

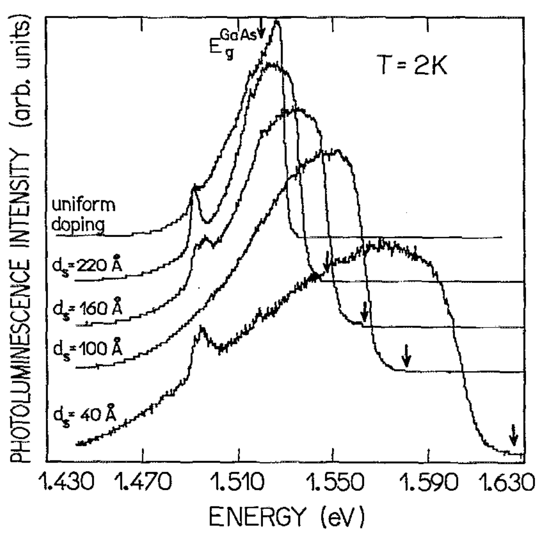

FIG. 1. Photoluminescence spectra of $M\delta$-doped GaAs structures with different values of d_s. The cutoff energies, $h\nu^{\text{cutoff}}$, are indicated by the arrows. The spectrum for the uniformly doped sample is also shown. The GaAs band gap, E_g^{GaAs}, is also indicated.

[1] E. F. Schubert, J. Vac. Sci. Technol. A **8**, 2980 (1990), and references therein.
[2] S. M. Shibli, M. C. Tamargo, J. L. de Miguel, B. J. Skromme, R. E. Nahory, and H. H. Farrell, J. Appl. Phys. **66**, 4295 (1989).
[3] S. M. Shibli, M. C. Tamargo, B. J. Skromme, S. A. Schwarz, C. L. Schwarz, R. E. Nahory, and R. J. Martin, J. Vac. Sci. Technol. B **8**, 187 (1990).
[4] M. Santos, T. Sajoto, A. M. Lanzilotto, A. Zrenner, and M. Shayegan, Surf. Sci. **228**, 225 (1990).
[5] G. Tempel, F. Muller, N. Shwarz, F. Koch, G. Weimann, H. P. Zeindl, and I. Eisele, Surf. Sci. **228**, 247 (1990).
[6] J. Wagner, M. Ramsteiner, W. Stolz, M. Hauser, and K. Ploog, Appl. Phys. Lett. **55**, 978 (1989).
[7] S. Yamada and T. Makimoto, Appl. Phys. Lett. **57**, 1022 (1990).
[8] L. M. R. Scolfaro, C. A. C. Mendonça, E. A. Meneses, J. M. V. Martins, and J. R. Leite, Int. J. Quant. Chem. S **24**, 447 (1990).
[9] A. C. Maciel, M. Tatham, J. F. Ryan, J. M. Worlock, R. E. Nahory, J. P. Harbison, and L. T. Florez, Surf. Sci. **228**, 251 (1990).
[10] J. C. Egues, J. C. Barbosa, A. C. Notari, P. Basmaji, L. Ioriatti, E. Ranz, and J. C. Portal, J. Appl. Phys. **70**, 3678 (1991).
[11] M. Degani, J. Appl. Phys. **70**, 4362 (1991).
[12] H. Mejri, A. Selmi, H. Maaref, and J. C. Bourgoin, J. Appl. Phys. **69**,4060 (1991).
[13] E. F. Schubert, Surf. Sci. **228**, 240 (1990).
[14] A. Dodabalapur, K. Sadra, and B. G. Streetman, J. Appl. Phys. **68**, 4119 (1990).