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MEASUREMENT OF ELECTRON AND HOLE MOBILITIES PERPENDICULAR TO THE INTERFACE OF GaAs/GaAlAs SUPERLATTICES

H. LE PERSON, C. MINOT, F. ALEXANDRE and J.F. PALMIER

Centre National d’Etudes des Télécommunications, 196 Avenue Henri Ravera, F-92220 Bagneux, France

Résumé : Il est rapporté une série de mesures de la mobilité des électrons et des trous, perpendiculaire aux plans des couches dans des superréseaux GaAs/GaAlAs ayant des épaisseurs de barrières de 24 Å et 67 Å. L’interprétation des résultats expérimentaux, obtenus par une technique de temps de vol, s’appuie sur un modèle utilisant l’équation de Poisson couplée aux équations de dérive-diffusion. Les valeurs sont en accord avec une conduction de type minibande dans le cas des faibles épaisseurs de barrières ; pour des grandes barrières, plusieurs mécanismes sont suggérés.

Abstract : We report on measurements of the electron and hole mobilities perpendicular to interfaces of GaAs/GaAlAs superlattices. The superlattices are in intrinsic region of nin or pin structures and have two values of barrier thickness, 24 Å and 67 Å. The experimental results are associated to a numerical simulation using Poisson and drift-diffusion equations. The obtained values, for a small barrier, are in agreement with a conduction by miniband and, for a large barrier (at mid electric field) several effects are involved.

I - INTRODUCTION : Initiated by Esaki and Tsu [1], the studies of the superlattice (SL) structures bring up a great interest by the fundamental concepts which they use, as well as the important applications which they suggest. In the case of perpendicular transport at low field, two theoretical approaches have been developed. A first is a Bloch’s theory [2] for type I regular SLs, the other, valid when the states are localized is a hopping theory [3].

Fig. 1 : Schematic view of the n/SL/n and p/SL/n structures

Fig. 2 : Experimental setup, sample mounted on the microstrip line.
II - EXPERIMENTS AND MODEL: The samples are grown by molecular beam epitaxy on (100) n⁺ GaAs laser quality substrates. The GaAs/Ga₁₋ₓAlₓAs undoped SL (x = 0.27 or 0.3) is deposited after a n⁺ GaAs buffer layer. The growth is terminated by a Ga₁₋ₓAlₓAs p' (Be) or n⁺ (Si) window layer (WL) followed by a p⁺ or n⁺ GaAs contact layer, respectively. The detailed structures - characterized by X rays, Auger and spectral photoconductivity measurements - of the two studied samples are indicated in Fig. 1. For the n⁺/SL/n⁺ structures (nSLS) the SL is embedded in two layers, gradual in Al concentration, which avoid a discontinuity between the SL's first conduction miniband and the conduction band of the contact layers. The ohmic contacts on either side of the wafer are achieved by an AuGeNi deposit. A technological process etches an optical window in the top GaAs layer and separates each device by a mesa. The typical device area is 5.10⁻⁵ cm² and the zero bias capacitances are 0.4 pF for the nSLS and 1.0 pF for the p⁺/SL/n⁺ structure (pSLS), this latter decreases to 0.43 pF at 20V reverse polarisation. This last point indicates that the electric field is not homogeneous in the SL at zero-bias. After cleavage of the processed sample each device is stuck on an alumina microstrip line of 12 GHz frequency bandwith (FB). The whole is mounted in a super high frequency (SHF) case and biased by a 18 GHz network Fig. 2. The photocurrent is measured by a 14 GHz sampling oscilloscope and averaged by a multi-channel analyser. The signal time constant (RC=40 ps) is determined by the FB measurement of each electronic component. A pyridine dye laser synchronously pumped by a frequency doubled CW Nd³⁺:YAG laser photoexcites the samples with 1-3 ps light pulses of 100 MHz repetition rate. The photon energy (1.75 eV) is a little below the WL and SL barrier bandgap (1.8 eV). The focused laser beam spot has a diameter of 14 μm on the device WL. The temporal photoresponses versus the applied voltage for the nSLS and pSLS are compared to those calculated by the simulation. The theoretical responses are convoluted by the RC Fig. 3 and 4.

Fig. 3.a) Experimental photocurrent of the n/SL/n versus time at different applied voltages. Positive bias corresponds to + on the upper contact.
b) Current density (A/cm²) vs. time obtained by simulation. N₀ is the maximal photogenerated carrier density, in the SL, at the WL-SL interface, α is the SL absorption coefficient.

The model treats the SL like an effective medium having macroscopic parameters [4] which are: conduction and valence band positions, an effective mobility for the electrons and likewise for the holes. It assumes the existence of quasi instantaneously thermalised populations and solves numerically - by finite difference algorithms - Poissons and classical drift-diffusion equations in one dimension. The recombination rate is described by the sum of Shockley-Read and radiative term. The light generation term has a 3 ps FWHM lorentzian shape. We introduce a residual p- doping Na (10¹⁴ - 10¹⁵ cm⁻³), in the SL, confirmed by
Fig. 4: Photocurrent density of the p/SL/n versus time at different applied voltages, reverse bias. a) Experiment - b) Simulation.

a is the SL absorption coefficient : 0.78 $10^4$ cm$^{-1}$.

The heterojunctions are not taken into account.

The nSLS photocurrent (positive on the upper contact) is interpreted as the sum of different contributions [6, 7]:

- an electron current resulting from the time of flight of the primary charges created by the light. Its duration is $t_e = (1/a)(1/\mu_e E) = 40$ ps, where $E$ is the effective electric field, $\mu_e$ the electron mobility, $a$ the absorption coefficient ($a = 1.6 \times 10^4$ cm$^{-1}$).

- the holes, which have a weaker mobility, stay longer in the SL region and modify its neutrality. They give rise to an electron injection current which increases during the time necessary for the holes to go to the SL-GaAs interface, where they are locked by the valence band discontinuity (if the applied electric field is not too strong, $V$ applied $\leq 2.5$ to $3.0$ V). This electron current decays with a time constant that is the hole recombination time.

- a hole current, always very weak, of a duration equal to $t_e(\mu_h/\mu_e)$.

For negative polarisation, the phenomenon is roughly the same but the primary electron current is weaker because the charges are created near the ML-SL zone where the electric field is weak. The holes are trapped at the ML-SL interface. The electron injection current decreases with an effective time constant greater than for a positive bias.

III - RESULTS: The fit, between experimental results and the modeling, with the three adjustable parameters $\mu_e$, $\mu_h$ and Na, enables us to deduce the $\mu_e$, $\mu_h$ and Na values to $110 \pm 20$ cm$^2$V$^{-1}$s$^{-1}$, $12.5 \pm 2$ cm$^2$V$^{-1}$s$^{-1}$ and $1.5 \times 10^{15}$ cm$^{-3}$, respectively. The effective lifetime, used in the equations, is readily obtained from the measurements ($2.2 \times 10^{-9}$ s).

The pin structures, with a SL in intrinsic region, have been studied by Capasso and al. [8] for the couple AlInAs/GaInAs and Larsson and al. [9] for GaAs/GaAlAs.

The Na concentration ($2.5 \times 10^{15}$ cm$^{-3}$), for the pSLS, is measured by DLTS. The fit gives : $\mu_e = 10$ and $\mu_h = 15$ (for a SL of 53 A - Wells and 67 A - Barriers), with an electric field ($E$) of $4 \times 10^4$ Vcm$^{-1}$. At forward-bias ($E$ less than $10^4$ Vcm$^{-1}$) the total time response leads to a lower mobility value about $4$ cm$^2$V$^{-1}$s$^{-1}$.
IV - CONCLUSION: The agreement between experiment and simulation is good for both studied structures as long as the electric field is not too strong \((<4 \times 10^{-4} \text{ V cm}^{-1})\). The high mobility values, for the SL having small barrier \((24 \text{ Å})\), greater than those calculated in hopping conduction regime, are in favor to miniband conduction and agree with the previous results obtained in transistor structures [10]. The effective hole mobility integrates the contributions of the heavy and light holes which have very different mobilities in Bloch's regime. In the case of thick barriers \((67 \text{ Å})\), the carriers are more localized and we expect a conduction of phonon-assisted tunneling type (hopping). The measured mobility values for mid electric fields \((1 \text{ to } 4 \times 10^4 \text{ V cm}^{-1})\) indicate that other effects take place, such as hot carrier effects and thermoionic emission yielding a conduction above the barriers.

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