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ASSESSMENT OF A MULTIPLE QUANTUM WELL AND A SUPERLATTICE STRUCTURE BY SPECTROSCOPIC ELLIPSOMETRY, ELECTROREFLECTANCE AND PHOTOREFLECTANCE MODULATION SPECTROSCOPY

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Résumé Utilisant l'ellipsométrie spectroscopique, l'électro-réflexion et la photoréflexion, nous avons analysé une structure multicouche GaAlAs/GaAs. L'échantillon présente un gradient d'épaisseur parallèlement au diamètre de la plaquette. Grâce à cette non-uniformité, nous avons pu observer l'évolution continue entre une structure type puits quantiques multiples et type super-réseau.

Abstract A GaAlAs/GaAs multiple quantum well structure exhibiting a thickness gradient over the wafer surface has been analyzed using spectroscopic ellipsometry, electroreflectance and photoreflectance. Due to the sample non uniformity, we have been able to observe the continuous transition from multiple quantum well regime to superlattice regime.

Introduction A GaAlAs/GaAs multiple quantum well (MQW) structure grown by organometallic chemical vapor phase epitaxy has been analyzed using spectroscopic ellipsometry (SE), electroreflectance (ER) and photoreflectance (PR). The sample, consisting of 25 periods of GaAlAs and GaAs layers (Figure 1), has been grown on half of a two inches n⁺ doped GaAs substrate. The growth conditions have been set so that the sample exhibits a thickness gradient along the diameter of the wafer, while the GaAlAs/GaAs interfaces are still sharp within one monolayer. The purpose of our study is to use this thickness non uniformity to observe the evolution of the spectra vs quantum well and GaAlAs barrier thicknesses. As the barrier thickness decreases the sample should allow for the observation of the coupling between quantum wells.

Ellipsometry The sample has been first analyzed using high laterally resolved ellipsometry. This technique determines the ratio between the reflection coefficient of light polarized parallel (r_p) and perpendicular (r_s) to the plane of incidence. The actually measured parameters are $\tan(\psi)$ and $\cos(\Delta)$ which are related to ρ by :

$$\rho = r_p/r_s = \tan(\psi) \exp(i\Delta)$$

The sample has been scanned in energy from 1.4 eV to 4 eV and in position over a 46 mm line. Figure 2 shows one typical experimental spectrum. We have used such spectra for both analyzing the multilayer structure of the sample (thicknesses, Al composition and interface quality) and measuring the energy position of various excitonic features of the MQW. As observed on Figure 2, experimental spectra exhibit two regions of interest :

- at low energies ($E < 2.3$ eV) interferences due to the total thickness of the MQW are observed.
- at high energies ($2.8 < E < 3$ eV) the absorption of both GaAs and GaAlAs is high and only a few layers close to the surface contribute to

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optical spectra (1). Multilayer modelling of this part of the spectra allows for the determination of the Al concentration, the localisation energy of the E_1 transition and the thicknesses of the top layers (2). In particular, we found the ratio d_2/d_3 to be 1.025 and the Al concentration 64 %. These two parameters do not vary over the wafer. The variation of the quantum well thickness vs the position X is reported on Figure 1.

The excitonic transitions associated with each sub-band are responsible for sharp structures which in SE spectra appear as perturbations of the low energy interference patterns. We have determined the energy of these transitions considering the first derivative of the effective dielectric function (3).

Figure 3 summarizes our results. The first three heavy hole-electron transitions (labeled 1,2 and 3) are observed when the quantum well thickness is large enough. For a barrier width of 30Å, the electron and the hole wave functions overlap and the levels 1 and 1' (i.e. light hole-electron transition) split to form a sub-band. The lowest energy levels correspond to a symmetric wave function (1_s and $1'_s$) and the highest energy level (i.e. the upper edge of the sub-band) to the anti-symmetric wave function (1_a and $1'_a$). The theoretical curves on figure 3 have been calculated using the classical Kronig-Penney model (3). A good agreement between our experimental data and the model is found for a 60 % conduction band offset.

Photoreflectance and electrophotoreflectance

ER and PR have been proven to be very useful for the study of QW structures (2,4). In PR the modulation is provided by a chopped beam (HeNe 1mW laser) while in ER the electric field in the structure is modulated via a transparent electrode. One of the advantages of PR over ER is that it is contactless. On the other hand, in PR, complicated modulation mechanisms are associated with carrier injection and are still not completely understood.

Figure 4 shows two typical PR spectra : the top spectrum corresponds to the MQW part of the sample ($d_2 = 77\text{\AA}$) while the bottom one has been recorded on the superlattice region. The arrows indicate the transitions already observed and assigned in SE (see Fig. 3). The agreement between SE and PR is very good. However, more and better resolved structures can be seen on PR spectra. The structures at 1.42 eV can be associated to GaAs (both cladding layer and substrate). The other lines correspond to excitonic transitions and clearly shift with position on the sample (i.e. with the quantum well and barrier thickness). The strong line at 1.96 eV is the scattered HeNe light. On the bottom GaAs line, Franz-Keldysh oscillations (FKO) indicate a strong built-in electric field. This complicates the lineshape analysis and makes the classical "third derivative" curve fitting inadequate (5).

Figure 5 shows ER spectra recorded at the same positions as previous PR spectra. The electric field was modulated by varying the voltage between -25 and 0V. A -25 V bias corresponds to low electric field whereas a strong built-in electric field is present at zero bias (see above). The spectrum obtained for $d_2 = 77\text{\AA}$ (Fig. 5a) compares well with the PR one and the SE data. However, ER spectra have been recorded up to 3.2 eV allowing for the observation of Ga_{0.36}Al_{0.64}As E_0 structure as well as the E_1 transition of the QW. The second spectrum ($d_2 = 18.7\text{\AA}$) exhibits some differences with PR. The origin of these discrepancies can only be understood by comparing spectra obtained at different positions and by varying the static component of the electric field in the structure (i.e. changing the offset in the applied voltage). Corresponding results will be published elsewhere.

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Figure1: Schematic representation of the sample (a) and the quantum well thickness d_2 vs position X along the strongest thickness gradient line, as deduced from SE analysis (b).

Figure2: One example of measured SE spectra. Dotted lines represent a multilayer model fit of the interference patterns at low energy (1.2 - 2.2 eV). Weak structures, superimposed to interference regime are due to the optical transitions in the MQW. The E_1 and $E_1+\Delta_1$ structures of GaAs and Ga_{0.36}Al_{0.64}As are observed at higher energies.

Figure3: Energy of the optical transitions as a function of the quantum well thickness d_2 for 60% (full line) and 85% (dashed line) conduction band offset. Dots indicate experimentally measured structures.

Figure 4 : Photoreflectance spectra recorded at positions where the well thickness is 77 Å (a) and 19 Å (b). Arrows indicate transitions determined by spectroscopic ellipsometry. Note the clear Franz Keldysh oscillations (FKO) near the GaAs structure on curve b.

Figure 5 : Electroreflectance spectra recorded at positions where the well thickness is 77 Å (a) and 19 Å (b). As in Figure 4, arrows indicate transitions determined by SE. In the insets, the $\Delta R/R$ signal is multiplied by an energy-dependent term in order to enhance high energy structures without introducing discontinuities in the spectra.