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Electronic structure of cadmium-telluride–zinc-telluride strained-layer superlattices under pressure

B. Gil, D. J. Dunstan,* J. Calatayud, and H. Mathieu
Groupe d'Etudes des Semiconducteurs, Université des Sciences et Techniques du Languedoc,
place Eugène Bataillon, 34060 Montpellier CEDEX, France

J. P. Faurie
Department of Physics, University of Illinois at Chicago, Chicago, Illinois 60680

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The pressure dependence of the low-temperature photoluminescence of CdTe/ZnTe strained-layer superlattices is reported, up to the phase transition of the structure at about 6 GPa. The superlattices can be simultaneously type I for heavy holes and type II for light holes. A theoretical fit to the pressure dependence of the type-I and type-II luminescence lines confirms a number of bulk and superlattice parameters. In particular, the results are consistent with a treatment of the band structure in the framework of the envelope-function approach. The ground valence-band state is found to be the first light-hole valence subband. The valence-band offset has been fitted to be pressure dependent; we found $75+4.5P$ meV. Under pressure, a type-I–type-II transition is observed, due to a crossover in the valence band of the superlattice.

I. INTRODUCTION

II-VI compound superlattices and quantum wells, while less studied than the well-known III-V compound structures, are a rapidly growing field of semiconductor research.[1-5] They offer the possibility of a direct band gap, anywhere from metal to the blue region of the spectrum. In the CdTe/ZnTe case, furthermore, the non-lattice-matched layers can give strain effects in the valence band larger than those due to quantum confinement, so that a given superlattice can be simultaneously type I for heavy-hole excitons and type II for light-hole excitons (type-I H and type-II L hereafter). To predict the electronic structure of these new artificial materials, it is necessary to know the revelant bulk parameters—the hydrostatic and uniaxial pressure coefficients and the elastic constants—and heterojunction parameters such as the division of the band-gap offset between conduction and valence bands, as well as structural parameters such as the strains in the layers. A fit to the hydrostatic pressure dependence of the electronic levels can provide an excellent test of both the theory and of the parameter values.

In this paper, we report a study by photoluminescence (PL) at 2 K under high hydrostatic pressure in a diamond-anvil cell (DAC) of two CdTe/ZnTe strained-layer superlattices (SL's). One of the samples was grown with the CdTe layers thinner than the ZnTe, while in the other the CdTe layers were thicker than the ZnTe. Both type-I and type-II transitions give rise to photoluminescence; the pressure dependence of the emission energies are different for the type-I H and the type-II L transitions. This allows an unambiguous identification of the nature of the confined hole state involved in each emission band and gives valuable information on the band offset. From the pressure dependence of the luminescence peaks, the ground valence-band state is identified to be the first light-hole valence subband, in contrast with a previous idea we earlier developed in Ref. 4, using approximate bulk parameter values. A theoretical fit to the data is consistent with the most recent bulk parameter values; in particular, with the 65±2 meV/GPa pressure coefficient of the direct band gap in CdTe measured by us recently.[6] We report the first observation of a type-I–type-II transition due to the crossover in the valence band of a superlattice.

II. EXPERIMENTAL METHODS

Details of the sample design and growth have been reported elsewhere;[2] we studied samples 1 and 2 (206-40 and 120-17, respectively, of that paper). Both these samples were carefully grown on a GaAs substrate in such a way that, after x-ray diffraction investigations, they may be thought to be "free-standing" SLS's (Ref. 7) with fully relaxed buffer layers, and to have the entire lattice mismatch (6.4%) between CdTe and ZnTe taken up by a compressive biaxial strain in CdTe layers and a balancing tensile biaxial strain in the ZnTe layers.

The samples were thinned to ~30 μm by mechanically polishing the substrate and then cleaved to ~80 μm square for loading in the miniature cryogenic diamond-anvil cell.[8] Note that, after sample preparation, the II-VI epilayer is still about 1 order of magnitude thinner than the remaining thickness of the GaAs substrate; also the PL was not affected by the sample preparation. Argon was used as the pressure-transmitting medium and ruby as the pressure gauge. The DAC was inserted in a helium bath cryostat for the PL measurements at 2 K. All pressure changes were made at low temperature.

III. EXPERIMENTAL RESULTS

Sample 1 is a superlattice made of 200 periods of 8 CdTe and 11 ZnTe monolayers; it shows two emission bands (Fig. 1) which are identified in Sec. IV of this paper as a type-I H $e(1)$-HH(1) transition in the CdTe layers and a type-II L spatially indirect $e(1)$-LH(1) transition between the CdTe and ZnTe layers. The high-energy type-I H transition is always very weak relative to the type-II L one at lower energy (Fig. 1). Figure 2 shows the type-I H emission band and its shift relative to the type-II L band at lower energy. In Fig. 3, the peak positions of the two bands are plotted against hydrostatic pressure for various pressures. They display different pressure coefficients of 54 meV/GPa for the type-II L transition compared with 75 meV/GPa for the type-I H transition. These values differ significantly from the bulk CdTe and ZnTe direct-band-gap pressure coefficients of 65 meV/GPa (Ref. 6) and ~109 meV/GPa, respectively (see Refs. 9 and 10 and the discussion in Sec. IV of this paper).

As can be seen in Fig. 1, the photoluminescence intensity of the main peak was observed with no significant change in intensity up to 6.2 GPa. For pressures higher than 3.5 GPa, we could no longer determine the energy position of the type-I H transition. At 6.3 GPa, both bands were quenched completely, presumably due to a phase transition to a more compact structure.[11]

In sample 2, the CdTe layers are 7 monolayers thick and the ZnTe 6 monolayers. Although at ambient pressure a type-I H transition could be observed, it was too weak to detect in our DAC. However, the type-II L direct transition could be easily followed as shown in Fig. 4 up to 4.86 GPa and its pressure dependence is found to be 53.5 meV/GPa. At 5.6 GPa the luminescence intensity drastically collapsed, and the emission band became much broader, with the appearance of a wide low-energy wing. A further increase of pressure quenched the luminescence completely and we conclude that the same phase transition occurs as in sample 1, but at a slightly

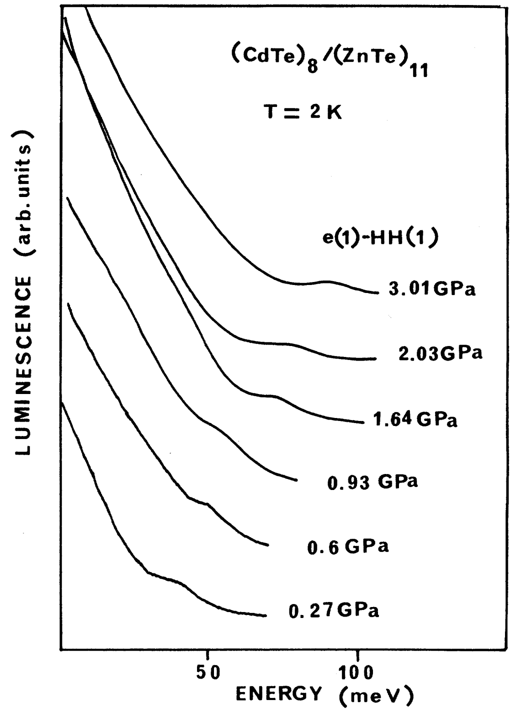


FIG. 2. Shift of the $e(1)$-HH(1) high-energy transition relative to the position of $e(1)$-LH(1) for various pressures in the case of sample 1 [(CdTe)$_8$/(ZnTe)$_{11}$].

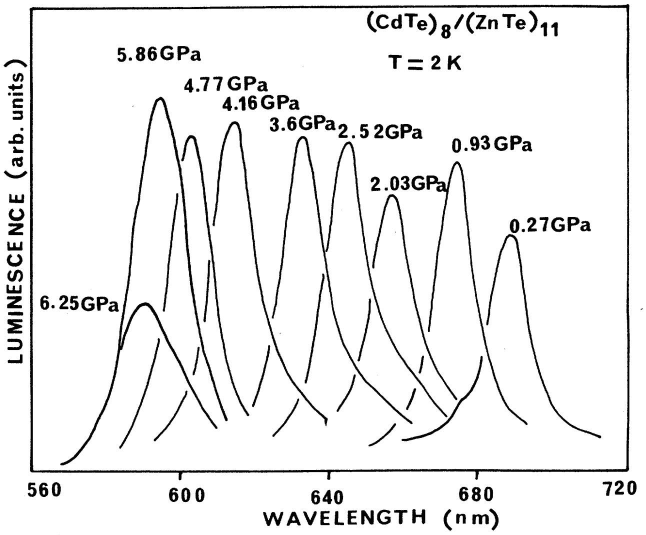


FIG. 1. Shift of the luminescence peak $e(1)$-LH(1) of sample 1 [(CdTe)$_8$/(ZnTe)$_{11}$] as a function of pressure. The high-energy peak $e(1)$-HH(1) is shown on the 0.27-GPa spectrum only. Note the quenching of the photoluminescence at 6.25 GPa.

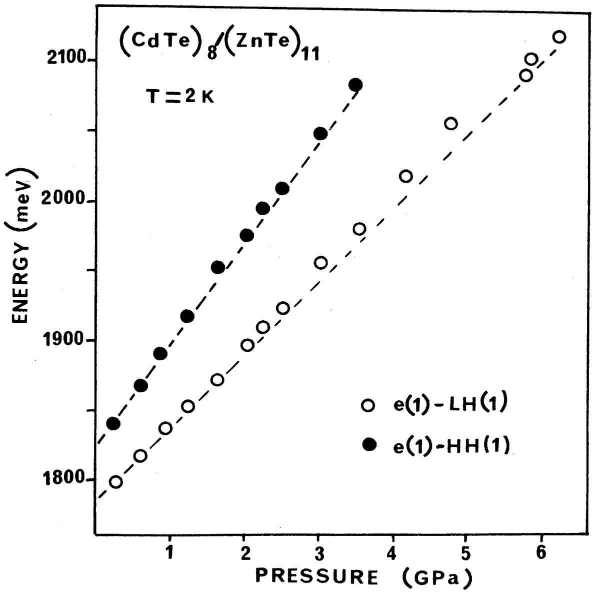


FIG. 3. Transition energy as a function of the pressure for sample 1 [(CdTe)$_8$/(ZnTe)$_{11}$]. Open circles, $e(1)$-LH(1) transition; solid circles, $e(1)$-HH(1). Dashed lines correspond to the theoretical calculation of Sec. IV.

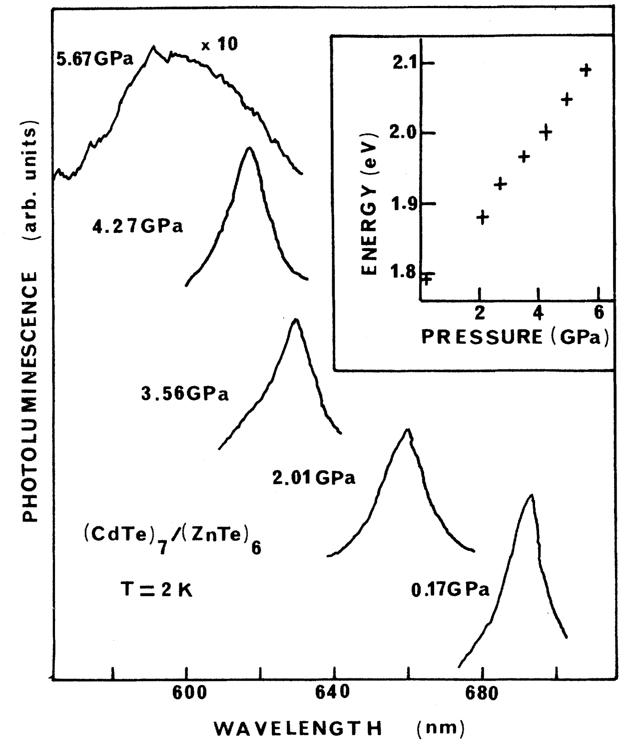


FIG. 4. Luminescence spectra from sample 2 [$(CdTe)_7/(ZnTe)_6$] at various pressures. Note the drastic influence of the phase transition in the 5.67-GPa spectrum. The inset shows the pressure dependence of the luminescence peak energy.

lower pressure (~5.7 GPa instead of ~6.3 GPa).

Reduction of the pressure to below the phase-transition pressure does not restore the photoluminescence; this is not surprising since passage through the phase transition is likely to create sufficient defects—vacancies, dislocations, etc.—to quench the photoluminescence completely.

IV. DATA ANALYSIS

The influence of hydrostatic pressure on quantum wells and superlattices is now quite well understood theoretically in the case of the most intensively studied III-V systems such as GaAs-(Ga,Al)As or $Ga_{1-y}In_yAs$-InP. Experimentally, the pressure coefficients of the quantized states are found to decrease with confinement energy, both in quantum wells[12–15] and in superlattices.[16,17] The central result obtained from various theoretical approaches to this problem is the influence of the carrier effective masses due to the Γ_8^v-Γ_6^c band gap widening under pressure.[18,19] However, other effects of hydrostatic pressure have also to be taken into account, including the influence of differences between the bulk material pressure coefficients of the barriers and of the wells, to improve the agreement between theory and experiment.[15,18,19] In GaAs-$Ga_{1-x}Al_xAs$ superlatticess near the Γ-X crossing where symmetry considerations predict a coupling between zone-center and folded-zone-boundary conduction subbands, this coupling has to be included in the theory.[20] However, the satellite conduction states in both CdTe and ZnTe are very high in energy relative to the Γ point in the conduction band and this simplifies the problem since their contribution to the conduction wave function of our superlattices can be ignored with an extremely good approximation. On the other hand, a pressure dependence of the band offset ratio has been recently proposed to interpret data collected from $Ga_yIn_{1-y}As$-InP quantum wells[15] and GaAs/AlAs superlattices[17] and we have allowed such a dependence in the fits reported here.

However, in structures such as those we are concerned with here, before proceeding to a calculation of the quantized energy states, it is necessary to consider the hydrostatic and uniaxial strains in the various layers of the samples; this is the subject of the following sections.

A. Influence of the lattice matching and built-in strains in SLS's

While bulk CdTe and ZnTe are not lattice matched, a homomorphism occurs between CdTe and ZnTe layers during the growth of the relaxed (free-standing) superlattices.[2] The new in-plane lattice constant can be calculated as a function of the CdTe and ZnTe elastic constants $(S_{ij})_\alpha$ and lattice parameters a_α and thicknesses expressed in number of monolayers n_α:[4]

$$\langle a \rangle = \frac{\sum_\alpha n_\alpha/(S_{11}+S_{12})_\alpha}{\sum_\alpha n_\alpha[(S_{11}+S_{12})_\alpha/a_\alpha]^{-1}} .$$

Such in-plane lattice matching provokes a lowering of layer symmetry from cubic to tetragonal when growth is along the [001] direction. In each layer a strain tensor can be defined:

$$(e)_\alpha = \frac{\langle a \rangle - a_\alpha}{a_\alpha} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -2(c_{12}/c_{11})_\alpha \end{bmatrix} ,$$

where C_{ij} are the compliance constants. From Hooke's law the magnitude of the built-in stress experienced by each layer is

$$X_\alpha = \frac{\langle a \rangle - a_\alpha}{a_\alpha}(c_{11}-c_{12})_\alpha .$$

$\langle a \rangle$ is intermediate between a_{CdTe} and a_{ZnTe}; in both these compounds, $C_{11}-C_{12}$ is a positive quantity, thus the sign of the built-in stress experienced by each material is different. In our SLS's, the CdTe layers experience a biaxial compression while the ZnTe layers are biaxially stretched. These built-in stresses modify the overlap of atomic wave functions, resulting in a change of the electronic levels in the layers which we calculate using the deformation potential approximation.[21] In each compound, the conduction levels are shifted at rates

$$\delta E_{c\alpha}(X_\alpha) = 2c_\alpha(S_{11}+2S_{12})_\alpha X_\alpha ,$$

where c_α is the conduction-band deformation potential. The situation is somewhat more complicated for valence-band states, where any lowering of cubic symmetry splits the Γ_8 manifold. For biaxial stress the valence-band energies are shifted by the amount

$$\delta E_{v\mathrm{HH}}(X_\alpha)=2a_{v\alpha}(S_{11}+2S_{12})X_\alpha+b_\alpha(S_{11}-S_{12})_\alpha X_\alpha$$

and

$$\delta E_{v\mathrm{LH}}(X_\alpha)=2a_{v\alpha}(S_{11}+2S_{12})X_\alpha-b_\alpha(S_{11}-S_{12})_\alpha X_\alpha$$

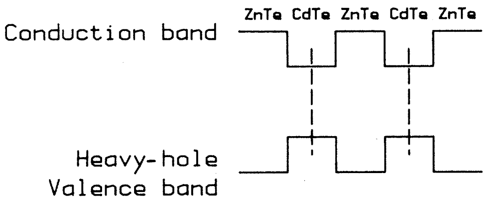
for $|\frac{3}{2},\frac{3}{2}\rangle$ heavy-hole and $|\frac{3}{2},\frac{1}{2}\rangle$ light-hole valence bands, respectively.

The influence of the built-in strains on the ordering of the electronic levels has been sketched in Fig. 5 in the special case of an initial zero value of the valence-band offset. Clearly two different situations can be obtained in that special case: a type-I superlattice for conduction-band (CB) to $|\frac{3}{2},\frac{3}{2}\rangle$ valence-band optical transitions and a type-II superlattice for the conduction-band to $|\frac{3}{2},\frac{1}{2}\rangle$ valence-band optical transitions. This situation can be different depending on the valence-band offset in the absence of stress as sketched in Fig. 1 of Ref. 4. The pressure dependence of the optical transition will enable us to identity them as a heavy-hole or light-hole exciton and as a type-I or type-II transition.

B. Distribution of the external strain in the samples

Our SLS's are grown on a GaAs(001)-oriented substrate. Since we are dealing with materials for which the bulk moduli are very different (75, 52, and 48 GPa for GaAs, CdTe, and ZnTe, respectively), the effective hydrostatic pressure experienced by each layer will be different and hydrostatic pressure will also give rise to uniaxial strains. The GaAs substrate is about 1 order of magnitude thicker than the SLS's. As a consequence, under pressure, *the GaAs substrate dominates the deformation in the plane of the SLS's unless misfit dislocations are created at the heterointerfaces.* The substrate effect on the strain tensor in the SLS can be easily quantified, if we use a simple model in which the GaAs substrate is infinitely thick. In GaAs, the components of the strain tensor are directly related to the external pressure; from elasticity theory

$$e_{xx}=e_{yy}=e_{zz}=(\sigma_{11}+2\sigma_{12})P\ ,$$



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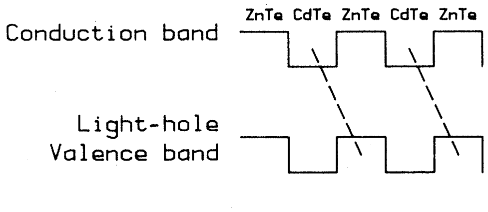

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FIG. 5. Distribution of the conduction- and valence-band confining potentials along the growth of the strained-layer superlattice. Biaxial stress effects due to lattice mismatch between bulk CdTe and ZnTe have been included. For clarity, the valence-band offset has been taken to zero before taking into account the built-in stresses.

where σ_{ij} are the GaAs elastic constants and P is the external pressure. Let us now consider a thin epilayer with elastic constants s_{ij}. Under pressure, its strain tensor is no longer isotropic since the in-plane deformation is the substrate one, while the e_{zz} component is now different:

$$e_{xx}=e_{yy}=(\sigma_{11}+2\sigma_{12})P=(s_{11}+s_{12})\Pi+s_{12}P$$

and

$$e_{zz}=2s_{12}\Pi+s_{11}P\ ,$$

where Π is the effective in-plane stress. The stress tensor can be decomposed into a pure hydrostatic component and a pure uniaxial (001)-oriented component:

$$\begin{bmatrix}\Pi & 0 & 0\\ 0 & \Pi & 0\\ 0 & 0 & P\end{bmatrix}=\langle P\rangle\begin{bmatrix}1 & 0 & 0\\ 0 & 1 & 0\\ 0 & 0 & 1\end{bmatrix}-\langle U\rangle\begin{bmatrix}1 & 0 & 0\\ 0 & 1 & 0\\ 0 & 0 & -2\end{bmatrix}$$

with $\langle P\rangle=(2\Pi+P)/3$ and $\langle U\rangle=(P-\Pi)/3$.

Thus at, for example, 6 GPa external pressure, the infinite GaAs substrate is under 6 GPa hydrostatic stress with no uniaxial component, while the superlattice is under effective hydrostatic and uniaxial stresses which do not depend on the relative CdTe and ZnTe layer thicknesses. The individual CdTe layers are under 5.52 GPa hydrostatic and 160 MPa (001) shear uniaxial stress and the ZnTe under 5.88 GPa hydrostatic and 60 MPa shear uniaxial stress. These stress values in the II-VI layers are to be added directly to those built into a CdTe/ZnTe free-standing superlattice. In analogy with the quantities due to lattice-matching effects we just write

$$\delta E_{c\alpha}(P)=c_\alpha(S_{11}+2S_{12})_\alpha(2\Pi_\alpha+P)\ ,$$

$$\delta E_{\mathrm{HH}\alpha}(P)=a_{v\alpha}(S_{11}+2S_{12})_\alpha(2\Pi_\alpha+P)+b_\alpha(\Pi_\alpha-P)(S_{11}-S_{12})_\alpha\ ,$$

$$\delta E_{\mathrm{LH}\alpha}(P)=a_{v\alpha}(S_{11}+2S_{12})_\alpha(2\Pi_\alpha+P)+b_\alpha(\Pi_\alpha-P)(S_{11}-S_{12})_\alpha\ .$$

C. Electronic structure of the superlattices

To calculate the electronic structure of these SLS's we adopt the envelope-function approach developed by Bastard.[22] Limiting the calculation at the Brillouin-zone center we have to solve the Schrödinger equation:

$$\left[\nabla \frac{1}{m(z)} \nabla + V(z) - E\right] \Psi(z) = 0 \ .$$

Let $\Delta f_\alpha(P) = \delta f_\alpha(X_\alpha) + \delta f_\alpha(P)$ for any band f and material α of interest. The potential V is z dependent and for electrons is

$$V_e(z) = \begin{cases} E_{g0}^2 + \Delta E_{c2}(P) - \Delta E_v(P) & \text{in ZnTe layers} \\ E_{g0}^1 + \Delta E_{c1}(P) & \text{in CdTe layers,} \end{cases}$$

where the index 1 (2) refers to CdTe (ZnTe). We have

$$-V_{\rm HH}(z) = \begin{cases} \Delta E_{\rm HH2}(P) + \Delta E_v(P) & \text{for ZnTe layers} \\ \Delta E_{\rm HH1}(P) & \text{for CdTe layers} \end{cases}$$

for heavy-hole particles and

$$-V_{\rm LH}(z) = \begin{cases} \Delta E_{\rm LH2}(P) + \Delta E_v(P) & \text{for ZnTe layers} \\ \Delta E_{\rm LH1}(P) & \text{for CdTe layers} \end{cases}$$

when calculating light-hole states. Nonparabolicity has been also included in the calculation, following Ref. 22.

$\Delta E_v = E_{v2} - E_{v1}$ is the valence-band offset in the absence of built-in strains and is a fitting parameter which will be obtained from the pressure dependence of the optical transitions. It may be pressure dependent.

To proceed to a numerical calculation we used the material parameters obtained from the literature (Table I). The electron effective mass, the band gap, and the Luttinger parameters have been taken from the recent work of Neuman *et al.*,[23] who measured both CdTe and ZnTe. For the hydrostatic pressure dependence of CdTe we used our recently measured experimental shift of 65±2 meV/GPa.[6,24] The tetragonal shear deformation potential b of CdTe is more difficult to determine since there is a large scatter in the literature. First, we discuss results obtained from uniaxial stress. A reassessment of Thomas's first result[25] led us to an isotropic valence-band splitting independent of the orientation of the stress and equal to 87±3 meV/GPa.[6] From the data reported by Wardzinski *et al.*[26] we estimate a value of ~94.3 meV/GPa for [001]-oriented stress. Secondly, we consider additional experimental data obtained from biaxial stress results. CdTe can be biaxially stressed when growing thin epilayers on lattice-mismatched substrates. Two experiments have been reported: CdTe grown on a GaAs substrate[27] and CdTe grown on a $\mathrm{Cd_{0.96}Zn_{0.04}Te}$ substrate.[28] Olego *et al.*[27] report a shift of the CB-$|\frac{3}{2},\frac{3}{2}\rangle$ transition at a rate of 5.78 meV/GPa toward low energy and a valence-band splitting of 98 meV/GPa, while Magnea *et al.*[28] report a larger splitting of ~130 meV/GPa. Careful examination of these papers reveals that in both cases the authors measured the deformation of the CdTe epilayers in the growth direction using x-ray diffraction, and obtained the magnitude of the built-in strain, but then they used different values for S_{12} in CdTe. These two authors measured the corresponding valence-band splittings at liquid-helium temperature. Using appropriate values (2 K values) for the elastic constants of CdTe, which can be calculated by extrapolation of the temperature-dependent experiment of Berlincourt *et al.*,[29] all experiments become consistent with each other within the limit of the experimental uncertainty (a reassessment of the data of Ref. 28 suggests ~100 meV/GPa). Consequently we retain an average value of the valence-band splitting Δ_{001} of 95±5 meV/GPa and a corresponding deformation potential $b = -0.95 \pm 0.05$ eV.

Under hydrostatic pressure the direct band gap of ZnTe is significantly sublinear:

$$\begin{aligned} E_g(P) &= E_g(0) + (C_{\rm ZnTe} - a_{v_{\rm ZnTe}})(S_{11} + 2S_{12})P \\ &= E_g(0) + \mu P + \nu P^2 \ . \end{aligned}$$

This has been obtained independently by Weinstein *et al.*[9] ($\mu = 115 \pm 5$ meV/GPa and $\nu = -5 \pm 0.3$ meV/GPa^2) and Strössner *et al.*[10] ($\mu = 104 \pm 5$ meV/GPa and $\nu = -2.8 \pm 0.5$ meV/GPa^2) from transmission measurements at room temperature in the DAC. In this paper we took the average of these two experiments:

$$\langle \mu \rangle = 109 \pm 5 \text{ meV/GPa} \ ,$$

$$\langle \nu \rangle = -3.9 \pm 1.1 \text{ meV/GPa}^2 \ .$$

The division between the conduction and valence bands of the hydrostatic pressure coefficients has been

TABLE I. Physical constants of the calculation.

	CdTe	ZnTe
a (Å)	6.481	6.103
E_{go} (meV)	1606.3±0.2	2394.5±0.5
S_{11} (10^{-1} MPa)[a]	3.581	2.38
S_{12} (10^{-1} MPa)[a]	−1.394	−0.857
m_e^*	0.099±0.003	0.116±0.003
γ_1	4.11±0.15	4.07±0.13
γ_2	1.08±0.15	0.78±0.14
$\mu = dE_{go}/dP$ (meV/GPa)[a]	65±2	109±5
$\nu = \frac{1}{2} d^2E_{go}/dP^2$ (meV/GPa^2)	0	−3.9±1.1
Δ_{001} (meV/GPa)	95±5	78
b (eV)[a]	−0.95±0.5	−1.2

[a] These values are given their conventional signs.

taken identical to the one obtained for CdTe from the self-consistent tight-binding calculation of Ref. 24, which gives results close to the prediction of the early approach proposed by Camphausen *et al.*,[30] but for ZnTe c and a_v are now pressure dependent. Concerning the tetragonal deformation potential b of ZnTe, three results have been reported in the literature[26,31,32] from which we take $b=-1.2$ eV.

With the stress values and their pressure dependences obtained above, we may now proceed to a calculation of the confined energy states of the superlattice structures. The first fitting calculation should be the determination of the valence-band offset. In fact, the calculation is sensitive in such a way that depending on the sign of the valence-band offset, the ground state of the SLS's could be either the type-I H transition or the type-II L one. It is thus necessary first to identify the two transitions observed; this may be done through their pressure coefficients. Applying the pressure in our calculation, *we always found a smaller slope for the type-II L transition than for the type-I H one,* as well as for the situation where the SLS's lowest optical transition is type-I H or -II L. This is a strong argument against the earlier identification of the SLS's lowest-energy transition as being type-I H,[4,33] and so we identify the lower transition as type-II L.

We first consider sample 1 [$(\mathrm{CdTe})_8/(\mathrm{ZnTe})_{11}$], for which we calculate a biaxial compression of ~ -1.8 GPa in the CdTe layers and a balancing tensile stress of ~ 1.3 GPa in the ZnTe layers. Using $\Delta E_v = 75$ meV (the superlattice should be type II in the absence of the built-in stress), the depth of the electron, heavy-hole, and light-hole potential wells are 765, 12, and 260 meV, respectively (we have a type-II situation for the electron–light-hole transition) at atmospheric pressure and the corresponding values of the optical transitions are $e(1)$-LH(1)$=1788$ meV and $e(1)$-HH(1)$=1811$ meV. The best fit of the experiment was obtained by increasing the magnitude of the valence-band offset by 4.5 meV/GPa. Then the agreement between the theory and experiment is fairly good, as is illustrated in Fig. 3 (dashed lines). The change in valence-band offset parameter ΔE_v is smaller but comparable to the value reported in the literature for GaAs/AlAs,[16] GaAs-(Ga,Al)As,[34] or $\mathrm{Ga}_{1-y}\mathrm{In}_y\mathrm{As}$-InP.[15]

Another important experimental report is the quenching of the type-I H transition for pressures larger than 3.5 GPa; this is consistent with our calculation which predicts a change of configuration from Type I to type II for the conduction–heavy-hole gap at a pressure of ~ 4 GPa. Above this crossover, both optical transitions are type II; this favors thermalization of the heavy holes into the light-hole band. This explains the disappearance of the heavy-hole transition for high pressures. Secondly, we consider sample 2 [$(\mathrm{CdTe})_7/(\mathrm{ZnTe})_6$], where the biaxial stresses experienced by CdTe and ZnTe are now -1.50 and 1.76 GPa, respectively. Still using $\Delta E_v = 75$ meV, we calculate $e(1)$-LH(1)$=1814$ meV and a pressure coefficient of 54 meV/GPa, which agrees closely with the experimental result, 53.5 ± 0.5 meV/GPa.

In the foregoing calculations, we have assumed throughout that, under pressure, the in-plane strain is determined by the GaAs substrate. It is possible that in fact the heavily dislocated buffer undergoes further deformation under high pressure so as to leave the superlattice still free-standing at high pressure. The in-plane lattice constant would then be determined by the II-VI elastic constants. We have calculated the electronic structure for this case, and do not arrive at a plausible fit to the data. In this model, because of the different values of the elastic constants of CdTe and ZnTe, the built-in biaxial strains decrease with pressure; as a result the heavy-hole–light-hole splitting decreases with pressure, in strong disagreement with the experimental data. This provides strong evidence in favor of the first model in which under pressure, the in-plane strain is determined by the GaAs substrate.

V. CONCLUSION

We have measured the electronic properties of CdTe/ZnTe strained-layer superlattices under hydrostatic pressure up to the phase-transition pressure of these structures. The optical transitions exhibit pressure dependences which differ for type II and type I configurations of the band structure. These dependences are a signature of the symmetry of valence-band states concerned in a given recombination process. The lowest transition line has been identified as type II in real space between electrons confined in the CdTe layers and light-hole subbands, with the light hole confined in ZnTe layers. Explanation of these data requires us to revise the previous identification of the lowest-energy luminescence lines in terms of type-I H recombination we proposed in Ref. 4, and is consistent with a small value of the valence-band offset (75 meV) which agrees with the value directly measured by x-ray photoemission spectroscopy (XPS) (100 meV).[35] Excellent agreement is obtained between experiment and calculation; in particular, the heavy-hole type-I–type-II crossover predicted at ~ 4 GPa agrees well with the quenching of the heavy-hole emission line above 3.5 GPa.

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*Permanent address: Department of Physics, University of Surrey, Guildford GU2 5XH, Surrey, United Kingdom.

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