Interface-related in-plane optical anisotropy in GaAs/Al_xGa_{1-x}As single-quantum-well structures studied by reflectance difference spectroscopy

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The in-plane optical anisotropies of a series of GaAs/Al_xGa_{1-x}As single-quantum-well structures have been observed at room temperature by reflectance difference spectroscopy. The measured degree of polarization of the excitonic transitions is inversely proportional to the well width. Numerical calculations based on the envelope function approximation incorporating the effect of C_{2v}-interface symmetry have been performed to analyze the origin of the optical anisotropy. Good agreement with the experimental data is obtained when the optical anisotropy is attributed to anisotropic-interface structures. The fitted interface potential parameters are consistent with predicted values.

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I. INTRODUCTION

The difference of chemical bonds along the [110] and the [1$\bar{1}$0] directions reduces the crystal symmetry from T_d to C_{2v} for an (001)-oriented semiconductor interface, and has an important influence on the optical properties of quantum wells (QW's), especially in creating in-plane optical anisotropy due to the mixing of the heavy and light hole at the zone center.[1–4] An ideal QW with symmetric interfaces has higher D_{2d} symmetry than an abrupt interface, and exhibits no optical anisotropy in the QW plane. In this case, the contribution of one interface to anisotropy is compensated by the other interface. A practical QW, however, always shows asymmetry in the growth direction to some extent, thus, the symmetry is reduced to C_{2v}.[5–10] An interface-related contribution to optical anisotropy is therefore expected, due to the broken balance of the anisotropy of the two interfaces.

The asymmetry of a QW can be either bulklike or interfacelike. Bulk asymmetry can be caused by an electric field or compositional variation across the QW,[5,6] while the difference in interface bonds, interface composition profile (segregation effect), the anisotropic-interface structures, etc., may cause the interface asymmetry.[7–11] We are interested in the interface-related optical anisotropy of the QW due to the unbalance of the two interfaces. Because of the inherent nonequivalence of the interface bonds, the in-plane optical anisotropy in ''no-common-atom'' (NCA) QW's is very strong, and therefore can be observed easily by common polarization-resolved spectroscopy.[7–11] The degree of polarization (DP) between the [110] and [1$\bar{1}$0] directions is usually of the order of 10% for such NCA-QW samples. Since ''common-atom'' (CA) QW's like GaAs/Al_xGa_{1-x}As and InGaAs/GaAs lack the intrinsic nonequivalence of two interfaces, the optical anisotropy, if it exists, is believed to be much less than that of NCA QW's. For this reason, so far there are few experimental data that allow detailed discussion of the interface-related optical anisotropy in CA systems. Kwok *et al.* reported optical anisotropy of GaAs/Al_xGa_{1-x}As multiple QW's under an electric field, which was known as the quantum-confined Pockels effect.[5,6] The unusual electric-field dependence of a forbidden transition could be well explained by the C_{2v} symmetry of interfaces.[8] The apparent effects of C_{2v}-interface symmetry on the optical anisotropy in In_xGa_{1-x}As/GaAs QW's were evidenced by reflectance difference spectroscopy (RDS).[12] By using RDS technique, the hole-mixing coefficients due to interface and electric field in GaAs/Al_xGa_{1-x}As superlattices could be determined experimentally,[13] and the different line shapes in symmetric and asymmetric GaAs/Al_xGa_{1-x}As QW's were clearly revealed.[14,15] Very recently, the important influence of the interface profile asymmetry on the optical anisotropy has been confirmed in CdTe-based CA QW's.[16] However, a systematic study of the role of the interfaces on the in-plane optical anisotropy of CA QW's was not attempted until now. In this paper, we report a well-width dependence of optical anisotropies of (001)-oriented GaAs/Al_xGa_{1-x}As single-quantum-well (SQW) structures studied by RDS. The DP of the ground-state transition is less than 1.5%, and varies inversely with the well width. On the basis of the generalized envelope function theory, including the effect of the C_{2v} interface symmetry, we clearly show that the observed well-width dependence of DP can be well interpreted by the interface asymmetry arising from the anisotropic-interface structures.

II. SAMPLES AND EXPERIMENTAL SETUP

A series of GaAs/$Al_{0.36}Ga_{0.64}$As SQW structures with different well widths were grown on (001) semi-insulating GaAs at 630 °C by molecular beam epitaxy. The SQW was sandwiched between two thick Al_xGa_{1-x}As layers, about 100 nm away from the surface (5-nm GaAs and 95-nm Al_xGa_{1-x}As.) All epilayers were intentionally undoped. The relative reflectance difference between the [110] and [1$\bar{1}$0] directions, $\Delta r/r=2(r_{110}-r_{1\bar{1}0})/(r_{110}+r_{1\bar{1}0})$, was measured by the RDS technique at room temperature. The setup of our

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RDS is almost the same as Aspnes *et al.*,[17] except the position of the monochromator. The light from a 250-W tungsten lamp goes sequentially through a monochromator, a polarizer (Glan-Taylor prism), a photoelastic modulator (PEM-90_{TM}), and then is reflected by the samples, and goes through an analyzer (Glan-Taylor prism), and finally is focused on a silicon photodiode. The anisotropic dielectric function of the single-QW structure between the $[110]$ and $[1\bar{1}0]$ directions, denoted as $\Delta\varepsilon=\varepsilon_{110}-\varepsilon_{1\bar{1}0}$, is related to $\Delta r/r$ through the equation

$$\frac{\Delta r}{r}=-\frac{4\pi \; wie^{i\phi}\Delta\varepsilon}{\lambda(\varepsilon_s-1)}, \tag{1}$$

with the phase shift ϕ of the cap layer given by $\phi=4\pi n_s t/\lambda$. Here n_s (ε_s) is the refractive index (the dielectric function) of the matrix material, t is the thickness of the cap layer, w is the well width, and λ is the wavelength of light in vacuum. From Eq. (1), one can determine $\Delta\varepsilon$ from RDS results.

In order to obtain DP of the samples from RDS spectra, one has to do reflectance measurements. Denoting the reflectance of a SQW sample as R and the reflectance of the similar sample without the SQW layer as R_0, we then can define a new spectrum, i.e., $\Delta R/R=(R-R_0)/R_0$, which is given by

$$\frac{\Delta R}{R}=2\,\mathrm{Re}\left\{-\frac{4\pi \; wie^{i\phi}(\varepsilon-\varepsilon_s)}{\lambda(\varepsilon_s-1)}\right\}, \tag{2}$$

where $\varepsilon=(\varepsilon_{110}+\varepsilon_{1\bar{1}0})/2$ is the averaged dielectric function of the QW layer. This equation means that the averaged dielectric function of the QW (ε) can be obtained from reflectance measurements. For QW structures of high quality, resonance structures arising from band-edge optical transitions in the QW's can be observed in the spectra of both $\Delta r/r$ and $\Delta R/R$. In this case, the DP of the transitions, which is defined as $(M_{110}-M_{1\bar{1}0})/(M_{110}+M_{1\bar{1}0})$ in the literature (M_{110} denotes the transition probability with light polarized along the $[110]$ direction), can be determined straightforwardly from their intensities in $\Delta r/r$ and $\Delta R/R$ spectra. Noting that $\Delta\varepsilon$ is proportional to $(M_{110}-M_{1\bar{1}0})$ while $\varepsilon-\varepsilon_s$ is essentially proportional to $(M_{110}+M_{1\bar{1}0})/2$ with the same coefficient, one immediately obtains $\mathrm{DP}=|\Delta r/r|/|\Delta R/R|$ according to Eqs. (1) and (2). Here $|\Delta r/r|$ and $|\Delta R/R|$ are the intensities of the discussed transition in the spectra of $\Delta r/r$ and $\Delta R/R$, respectively. High quality of our GaAs/$Al_xGa_{1-x}As$ QW samples enables us to obtain DP by this method.

III. EXPERIMENTAL RESULTS

Figure 1 shows the real part of RD and $\Delta R/R$ spectra of five SQW samples with different well widths measured at room temperature. In each $\Delta R/R$ spectrum, two negative peaks, originating from the excitonic transitions between the first subbands of conduction and valence bands (named as $1H1E$ and $1L1E$), are observed except in the sample with a well width of 18 nm. As expected, the intensities of the $1H1E$ peaks are about three times larger than those of the $1L1E$ peaks. The absence of the $1L1E$ peak for the 18-nm sample is due to the small energy separation between $1H1E$ and $1L1E$ (about 6 meV). With decreasing well width, the $\Delta R/R$ peaks of $1H1E$ and $1L1E$ broaden and decrease in intensity due to interface roughness and alloy compositional fluctuations in the barriers. Compared to the $\Delta R/R$ spectra, the RD spectra exhibit much different line shapes and well-width dependence. The five RD spectra show a similar resonance structure in the range of the $1H1E$ and $1L1E$ transitions. As indicated by the arrow pairs in Fig. 1, the resonance structure mainly consists of one positive peak and one negative peak with approximately equal intensity, which is more clear for the samples with narrower well width. This polarization characteristic means that the $1H1E$ and $1L1E$ transitions have opposite optical anisotropy. The most striking feature of RD spectra is that the optical anisotropy of $1H1E$ and $1L1E$, as a whole, increases with decreasing well width, which is in contrast to the behavior of the $1H1E$ and $1L1E$ transitions in $\Delta R/R$ spectra. In addition, all samples show additional structures at $\sim$1.88 eV in the RD spectra. In Fig. 1(a), only the structure of the 1-nm sample is plotted. According to their energy positions, these structures are no doubt assigned to the exciton of the $Al_{0.36}Ga_{0.64}As$ layers. Such optical anisotropy probably comes from residual electric field or residual strain in the layers, and will not be discussed in this paper.

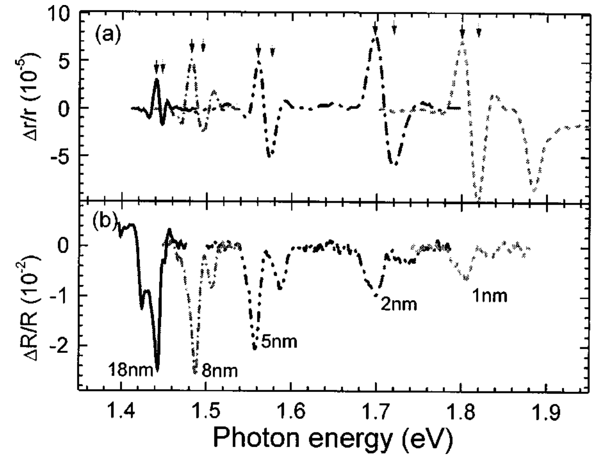

FIG. 1. (a) RD spectra and (b) $\Delta R/R$ spectra of a series of GaAs/$Al_{0.36}Ga_{0.64}As$ single-quantum wells with various well widths. The numbers in the $\Delta R/R$ spectra indicate the well widths. All spectra are measured at room temperature.

The DP of $1H1E$ obtained from RD and $\Delta R/R$ spectra by $\mathrm{DP}=|\Delta r/r|_{1H1E}/|\Delta R/R|_{1H1E}$ is presented in Fig. 2. Here $|\Delta r/r|_{1H1E}$ is the intensity of the $1H1E$ transition in RD spectrum, which is given by one half of the peak-to-peak amplitude of the $1H1E$ and $1L1E$ resonance since this intensity of the optical anisotropy is equally shared by the two transitions. Clearly, the DP of $1H1E$ of all samples is less than 1.5% and has a linear dependence on the reciprocal of the well width. This well-width dependence strongly suggests that the observed optical anisotropies are related to interface effects, as verified by the following calculations. In addition, the small value of DP explains why it is very dif-

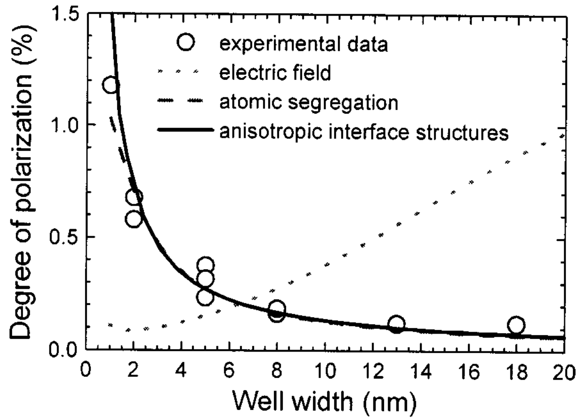

FIG. 2. Degree of polarization of the $1H1E$ transition in $GaAs/Al_{0.36}Ga_{0.64}As$ single-quantum wells as functions of the well width. Circles are experimental data, curves are the calculated optical anisotropy induced by an electric field of 10^4 V/cm (dotted), atomic segregation (dashed) and anisotropic-interface structures (solid), respectively.

ficult to study such optical anisotropy by the common polarized transmission or photoluminescence measurements.[11]

IV. OPTICAL ANISOTROPY INDUCED BY ELECTRIC FIELD (QUANTUM-CONFINED POCKELS EFFECT)

As is well known, the in-plane optical anisotropy of QW's is attributed to the mixing between heavy and light holes.[5–8] For an (001)-oriented SQW with perfectly abrupt interfaces at $z=\pm w/2$, the hole-mixing induced by an electric field and the two interfaces can be included in the frame work of the classical envelope function theory by a perturbation Hamiltonian,[13]

$$H'=\{Dd_{14}F+[P_0\delta(z-w/2)-P_0\delta(z+w/2)]\}\{\hat{J}_x\hat{J}_y\} \tag{3}$$

with

$$\{\hat{J}_x\hat{J}_y\}=\begin{pmatrix} 0 & i & 0 & 0 \\ -i & 0 & 0 & 0 \\ 0 & 0 & 0 & i \\ 0 & 0 & -i & 0 \end{pmatrix}. \tag{4}$$

Here F is the electric field along the z direction, D is the deformation potential of the valence band, d_{14} is the piezoelectric constant, P_0 is the interface potential parameter describing the effect of C_{2v} interface symmetry, $\hat{J}_x$ and $\hat{J}_y$ are the angular momentum operators, and the bases in Eq. (4) are

$$\left|\frac{3}{2},\frac{3}{2}\right\rangle,\left|\frac{3}{2},-\frac{1}{2}\right\rangle,\left|\frac{3}{2},\frac{1}{2}\right\rangle,\ \text{and}\ \left|\frac{3}{2},-\frac{3}{2}\right\rangle.$$

There are two theoretical models estimating the value of P_0. Ivchenko and Kaminski show that the value of P_0 is given by $t_{l-h}\hbar^2/2m_0a_0$,[1] where the dimensionless parameter t_{l-h} characterizes the anisotropy of the interface, m_0 is the free electron mass, and a_0 is the lattice constant. For GaAs/AlAs heterostructures, t_{l-h} is determined to be between 0.32 and 0.9, leaving the interface potential parameter P_0 varying in the range of 0.2–0.6 eV Å. The other model (known as H_{BF}) suggests that P_0 is related to the valence-band offset ΔE_v of the interface through $P_0=a_0\Delta E_v/4\sqrt{3}$.[7] Adopting $\Delta E_v=0.6$ eV for GaAs/AlAs interfaces (at room temperature), one gets $P_0=0.5$ eV Å, in agreement with that of Ivchenko and Kaminski. Therefore, the theoretical value of P_0 for the discussed $GaAs/Al_{0.36}Ga_{0.64}As$ interfaces should be in the range of 0.07–0.22 eV Å by linear interpolation.

Based on the Luttinger 4×4-hole Hamiltonian and the above hole-mixing Hamiltonian, the electric-field-induced in-plane optical anisotropy of $GaAs/Al_{0.36}Ga_{0.64}As$ SQW structures can be calculated straightforwardly.[13] The dotted curve in Fig. 2 shows the calculated DP of $1H1E$ at the zone center $(k_x=k_y=0)$ when the QW's are subjected to a residual electric field ($F=10^4$ V/cm). In the calculations the interface potential parameter $P_0=0.144$ eV Å (corresponds to $P_0=0.4$ eV Å for GaAs/AlAs interfaces) is adopted, and the other parameters, such as the band offsets and the effective masses, are the same as those in Ref. 13. It can be seen that the optical anisotropy of $1H1E$ first decreases and reaches a minimum at about 2 nm, and then increases almost linearly with the well width. Obviously, it is in contradiction with the experimental results. This kind of well-width dependence remains unchangable even if the strength of the electric field and/or the value of P_0 are modified.

Note that the electric fields in all the samples are not the same. However, since all samples have a similar structure, it is not reasonable to assume that the built-in electric field increases with decreasing QW well width. Actually, we observed no electric-field-induced Franz-Keldysh oscillations above the band edges of GaAs or $Al_xGa_{1-x}As$ in the photoreflectance spectra of these samples.

V. OPTICAL ANISOTROPY INDUCED BY INTERFACE ASYMMETRY

There is much evidence indicating nonequivalence of interfaces in GaAs/AlAs QW's.[18–22] It is found that atomic segregation always leads to wider alloy regions at AlAs-on-GaAs interfaces as compared to GaAs-on-AlAs interfaces, and the AlAs-on-GaAs interfaces also exhibit anisotropic in-plane structures or anisotropic interface defects elongated along $[\underline{1}10]$,[19,20] which are probably related to step energy anisotropy on the reconstructed GaAs surface.[23,24] We believe that both effects can occur in the $GaAs/Al_xGa_{1-x}As$ system and contribute to the observed optical anisotropy.

The effect of interface composition profile (induced by the atomic segregation) on the interface potential parameter can be included into the calculations straightforwardly by substituting $dV(z)/dz$ for the δ functions in Eq. (3), supposing the composition profile is given by $V(z)$.[25] As to the anisotropic interface structures, clearly, they also reduce the local symmetry at the interface. If the averaged principal axes of the anisotropic-interface structures are identical with those of the interface bonds, it is reasonable to assume that the anisotropic-interface structures have essentially the

same symmetry reduction effect as the interface bonds. Therefore, the total C_{2v}-symmetry anisotropy of the $Al_xGa_{1-x}As$-on-GaAs interfaces will be enhanced or weakened, which can be taken into account simply by introducing a new interface potential parameter P_1 larger or less than P_0.

Now it is easy to include into the calculation the effects of interface composition profile and anisotropic interface structures. Supposing an exponential composition profile with a decay length l to account for the segregation effect at the $z=w/2$ interface, the confinement potential for the GaAs/$Al_xGa_{1-x}As$ QW takes the form[16]

$$\left\{\Theta(-z-w/2)+\Theta(z-w/2)\left[1-\exp\left(-\frac{z-w/2}{l}\right)\right]\right\}, \tag{5}$$

where $\Theta(z)$ is a step function, which equals to 1 for $z>0$ and vanishes otherwise. Accordingly, the interface-related terms in Eq. (3) are modified as

$$\left[\frac{P_1}{l}\exp\left(-\frac{z-w/2}{l}\right)\Theta[(z-w/2)-P_0\delta(z+w/2)]\right]\{\hat{J}_x\hat{J}_y\}. \tag{6}$$

When l approaches zero, i.e., no segregation occurs, the exponential term in the above expression reverts to a δ function. The difference between P_1 and P_0, $\Delta P=P_1-P_0$, is used to characterize the anisotropic-interface-structure effect.

If there is only the atomic segregation at the $Al_xGa_{1-x}As$-on-GaAs interface (i.e., $P_1=P_0$), one has two free parameters, P_0 and l, to fit the experimental results. It is reasonable to assume that the segregation decay is about several monolayers (ML) in the $Al_xGa_{1-x}As$-on-GaAs system. Assuming $l=2$ ML, the experimental data can be fit if $P_0=0.864$ eV Å (see the dashed line in Fig. 2). However, as discussed before, the both models of Ivchenko and Kaminski and H_{BF} predict that P_0 is less than 0.22 eV Å for the GaAs/$Al_{0.36}Ga_{0.64}As$ interface. Clearly $P_0=0.864$ eV Å is at least four times larger than the value predicted theoretically. Moreover, if the optical anisotropy is indeed induced by the segregation effect, then the optical anisotropy of the $1L1E$ and $2H1E$ transitions should be much larger than that of $1H1E$. Figure 3(a) shows the corresponding well-width dependence of the anisotropic transition strengths, $\Delta M=M_{110}-M_{1\bar{1}0}$, of the $1H1E$, $1L1E$, and $2H1E$ transitions. Here M_{110} ($M_{1\bar{1}0}$) denotes the optical transition intensity for light polarized along the [110] ([1$\bar{1}$0]) direction. Obviously, ΔM of $1L1E$ and $2H1E$ are about 5–10 times larger than that of $1H1E$. Noting that $\Delta\varepsilon$ is proportional to ΔM, this result will lead to the conclusion that the resonant structures in the RD spectra come from the $1L1E$ and $2H1E$ transitions. This is definitely in conflict with the experimental results shown in Fig. 1, where the anisotropic signals can only be attribute to the $1H1E$ and $1L1E$ transitions. Therefore, the observed optical anisotropy cannot be attributed completely to the segregation effect.

While if there is only anisotropic-interface structures at the $Al_xGa_{1-x}As$-on-GaAs interface (i.e., $l=0$ ML), the induced optical anisotropy is expected to be proportional to

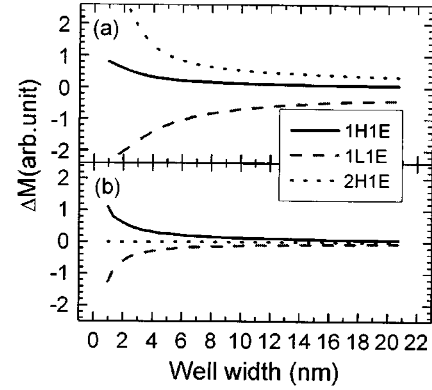

FIG. 3. Calculated anisotropic transition strengths ΔM in GaAs/$Al_{0.36}Ga_{0.64}As$ single-quantum wells as functions of the well width. The optical anisotropy is induced by (a) atomic segregation and (b) anisotropic-interface structures.

$\Delta P=P_1-P_0$. One can fix the value of P_0 in the theoretically predicted range (for example, $P_0=0.144$ eV Å) and use ΔP as a free parameter to fit the experimental data. The calculated result with $\Delta P=-0.016$ eV Å is shown as the solid curve in Fig. 2, clearly producing the $1/w$ dependence and fitting the experimental data very well. The corresponding ΔM of the $1H1E$, $1L1E$, and $2H1E$ transitions are shown in Fig. 3(b). Regardless of the well width, one always has $\Delta M_{2H1E}\ll\Delta M_{1H1E}\approx\Delta M_{1L1E}$. It means that the optical anisotropy in the RD spectra should come from the $1H1E$ and $1L1E$ transition, which is just what has been observed in Fig. 1. The above discussions strongly suggest the observed optical anisotropy results from the anisotropic-interface structures. Because of $\Delta P=-0.016$ eV Å, we have $P_1<P_0$, which implies that the $Al_xGa_{1-x}As$-on-GaAs interface has lower C_{2v}-symmetry anisotropy than the GaAs-on-$Al_xGa_{1-x}As$ interface due to the effect of the anisotropic-interface structures. However, considering the uncertainty of the sign of the RDS measurement, it is also possible that the experimental DP of $1H1E$ has negative signs instead of positive signs shown in Fig. 2. In this case, we obtain $\Delta P=0.016$ eV Å, leading to $P_1>P_0$. Therefore, due to the sign uncertainty of RDS, we still cannot distinguish which ($\Delta P=0.016$ eV Å or -0.016 eV Å) is the real case from the RDS experiments presented in this paper. Further research effort is needed to elucidate which interface (GaAs-on-$Al_xGa_{1-x}As$ or $Al_xGa_{1-x}As$-on-GaAs) has higher C_{2v}-symmetry anisotropy when there are anisotropic-interface structures at the $Al_xGa_{1-x}As$-on-GaAs interface. One possible method is to study the optical anisotropy of the QW's subjected to a varied electric field. Calculations show that more detailed information of interfaces, such as the sign of ΔP, can be clearly revealed from the electric-field dependence of the optical anisotropy.

A perturbation approach can help us understand the above results. If there is a mixing between mH and nL caused by H', it is found that the anisotropic transition strength of $1EmH$ (mH denotes the mth heavy hole) is proportional to[14]

$$\frac{\langle 1E|mH\rangle\langle mH|H'|nL\rangle\langle nL|1E\rangle}{|E_{mH}-E_{nL}|}. \tag{7}$$

Here $\langle 1E|mH\rangle$ and $\langle nL|1E\rangle$ are the overlap integrals between the discussed electron and hole states, $\langle mH|H'|nL\rangle$ is the hole-mixing strength between mH and nL, and $|E_{mH}-E_{nL}|$ is the energy separation between mH and nL. The anisotropy of $1H1E$ mainly comes from the coupling of $1H$ with $1L$ while that of $2H1E$ mainly comes from the coupling of $2H$ with $1L$. In Case II ($P_1\neq P_0$ and $l=0$), $\langle 1H|H'|1L\rangle$ becomes nonvanishing due to $P_1\neq P_0$, which leads to anisotropies for $1H1E$ and $1L1E$. In the mean while, one always has $\langle 1E|2H\rangle=0$ due to the different parities of $1E$ and $2H$. Therefore no anisotropy is expected for $2H1E$ although there is strong mixing between $2H$ and $1L$. This is just what is shown in Fig. 3(b). In case I ($P_1=P_0$ and $l\neq 0$), the parities of the wave functions of all electron and hole states are lost due to the segregation effect ($l\neq 0$). Consequently, all terms of the expression (7) vanishing at $l=0$, such as $\langle 1E|2H\rangle$ and $\langle 1H|H'|1L\rangle$, become nonzero, and all allowed and forbidden transitions exhibit optical anisotropy. However, since $\langle 2H|H'|1L\rangle \gg \langle 1H|H'|1L\rangle$ and $|E_{2H}-E_{1L}|\ll|E_{1H}-E_{1L}|$, the anisotropy of $2H1E$ is much larger than that of $1H1E$. These are just the results shown in Fig. 3(a).

It is necessary to discuss the combined effects of the atomic segregation and the anisotropic-interface structures since both cases can actually occur at the $Al_xGa_{1-x}As$-on-GaAs interface. We have calculated optical anisotropy at different values of l with $P_0=0.144$ eV Å and $P_1=0.128$ eV Å, and found that the increase of l from zero greatly enhances the optical anisotropy of $1L1E$ and $2H1E$ while that of $1H1E$ stays almost unchanged. When $l=3.5$ ML, one has $\Delta M_{1H1E}\approx\Delta M_{2H1E}\approx -0.5\Delta M_{1L1E}$, i.e., the anisotropy of $2H1E$ becomes comparable to that of $1H1E$. It means that a structure related to $2H1E$ should be observable in RDS spectra for $l\geq 3.5$ ML. Careful comparison between calculated results and RDS spectra indicates that the segregation length l should be less than 2 ML. By the same method, the weaker atomic segregation effect at the GaAs-on-$Al_xGa_{1-x}As$ interface can also be included into our calculation model for further discussions. However, our calculations show that this detailed consideration leads to no essential modification to the above conclusion that the observed optical anisotropy is dominated by the anisotropic-interface structures. Therefore we will not discuss this case in detail.

IV. CONCLUSION

We have observed the in-plane optical anisotropy in GaAs/$Al_xGa_{1-x}As$ SQW structures and its inversely linear dependence upon the well width by RDS measurements. On the basis of the envelope function approximation, we have calculated the optical anisotropy induced by electric fields, interface composition profile due to atomic segregation, and anisotropic-interface structures. It is found that the experimental results can be well explained only by the anisotropic-interface structures. The obtained interface potential parameters agree well with the values predicted by recent models. Our analysis reveals an important influence of the anisotropic-interface structures on the in-plane optical anisotropy, which means that a detailed analysis of in-plane optical anisotropy can serve as a new powerful tool for the investigation of the interface properties.

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