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Experimental study of hydrostatic and shear deformation potential in $Ga_{1-y}In_yN_xAs_{1-x}$ alloys using a piezoelectric photothermal spectroscopy

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The band gap and exciton binding energies of dilute nitride $Ga_{1-y}In_yN_{0.012}As_{0.988}$ films with the thickness of 100 nm were determined as a function of indium composition for investigating the effect of strain on the electronic band structure. The high sensitive piezoelectric photothermal (PPT) methodology was used for measuring the optical absorption spectra. The fitting analysis was carried out to eliminate the influence of exciton and to determine precisely the band gap energy using the three dimensional direct allowed transition models with the Voigt function as a convolution profile. Comparing experimental result with the theoretical prediction for the strain free structures, the hydrostatic and shear deformation potentials were determined as −7.0 and −1.7 eV, respectively. We found that the shear deformation potential is almost the same as that for GaAs, conflicting to the reported results for GaNAs. The results demonstrated that the present PPT method is worth for investigating the effect of strain on the electronic structures of the dilute nitride semiconductor thin film structure.

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I. INTRODUCTION

The demand for optical-fiber communication devices raises the rapid development of III-V compound semiconductor heterostructures. Since the semiconductor lasers of the long wavelength of 1.3 or 1.55 μm are the most suitable for the optical-fiber application, the InGaAsP/InP system has been dominantly utilized for the devices corresponding to these wavelengths. However, the band offset between the clad and the active layer for the system is too small to effectively confine carriers within the quantum well especially at high temperature.[1] Recently, GaInNAs on GaAs substrate was proposed as a new material which can achieve a strong confinement of carriers in the quantum well. This quaternary GaInNAs thin film has also attracted a great attention due to both unusual fundamental physical properties greatly different from the established group III-V semiconductors,[2,3] and the realization of the high-performance long wavelength optoelectronic devices. Since GaInNAs can be lattice matched to GaAs when the suitable amounts of indium and nitrogen were introduced, a high efficient infrared emission device can be materialized.

In our previous studies, the optical properties of GaInNAs single quantum well (SQW) were investigated by using a piezoelectric photothermal (PPT) spectroscopy[4,5] from the viewpoint of the nonradiative electron transition. We could measure the optical absorption spectra of thin GaInNAs/GaAs-SQW of less than 10 nm and determine the various physical parameters concerning with the quantum well structures. However, in order to fit theoretical predictions to the experimental results, it was inevitable to introduce an uncertain amount of the biaxial strain-induced band gap variation produced by the lattice mismatch with the substrate. This is because the thickness of the quantum well layer was smaller than that of the critical thickness for lattice relaxation. It then becomes necessary to study the effect of band gap change on the induced strain in more detail with evaluating the deformation potential of this compound. It should also be noted that practical GaInNAs lasers require strained quantum wells as an active layer.[6] Therefore, accurate values on both of hydrostatic and shear deformation potentials of GaInNAs are necessary in designing devices. However, no thorough experimental work about those values has not been reported up to now. Reluctantly, in most cases, values of host III-V material, i.e., GaAs or GaInAs, are substituted without certainty.

Regarding the shear deformation potential of III-N-V, two groups experimentally studied not for GaInNAs but GaNAs. They reported similar results in which shear deformation potential increases extraordinarily with the increase of N content up to 1.5%–2% and decreases after having a peak.[7,8] Shear deformation potential is determined by measuring the splitting of heavy and light hole bands. Since the addition of nitrogen hardly affects on the valence band,[2,9] it will slightly affect shear deformation potential. Hence, it would be constructive to examine the above reported results with different experimental techniques.

In this paper, optical absorption spectra of rather thick GaInNAs/GaAs films of 100 nm were investigated to discuss the strain-induced effect on the band gap of GaInNAs. Since exciton binding energy of GaInNAs is as large as over 10 meV due to the increased reduced mass,[10,11] exciton af-

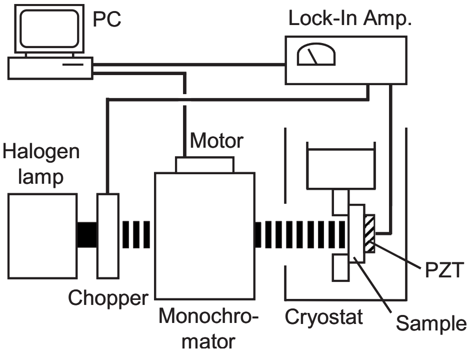

FIG. 1. Schematic configuration of the PPT measurements. The generated heat by the nonradiative transition of the photoexcited carrier in the sample was detected by a PZT sensor directly attached to the sample surface.

fects optical measurements even at room temperature. The exciton trapping is a common feature for the carrier transitions in dilute nitrides. For a precise analysis, the influence of exciton should be taken into account. The sensitive PPT experimental methodology was used and the analysis of the absorption spectra decomposing the excitonic and band to band transition was carried out. The deformation potentials are then estimated by comparing the observed band gap change with the theoretical prediction deduced from the case of strain free conditions.

II. EXPERIMENTAL PROCEDURES

High quality pseudomorphic GaInNAs films were grown at 460 °C on GaAs(001) substrate by solid source molecular beam epitaxy technique using elemental source of gallium, indium, and arsenic, as well as nitrogen radicals.[12] For $Ga_{1-x}In_xN_yAs_{1-y}$ samples in the present case, N composition was fixed at 1.2%, at which an extraordinary value of shear deformation potential was reported in Refs. 7 and 8. Composition was changed from 0%, 1.8%, and 3.4% to 4.5%. The thicknesses of all the GaInNAs films were fixed at 100 nm. These layers were sandwiched by *n*-GaAs cap (0.15 μm) and buffer layer (0.3–0.5 μm). Composition and the amount of induced strain for the samples were determined by an x-ray diffraction (XRD).

Experimental setup for PPT technique is schematically shown in Fig. 1. Details of this method have been reported elsewhere.[4] The generated heat by the nonradiative transition of the photoexcited carriers was detected by a piezoelectric transducer (PZT) sensor. The sample was mounted on the cold finger of a liquid nitrogen cryostat using copper adhesive tape. The PZT detector was attached on the GaInNAs layer side and the probing light was irradiated from the GaAs substrate side. Since the band gap energy of GaAs is larger than that of GaInNAs, the illuminated light sufficiently reach the GaInNAs layer investigated. This means that the observed intensity of PPT signal is proportional to the optical absorption coefficient.[4] The modulation frequency for the PPT measurements was set at 100 Hz.

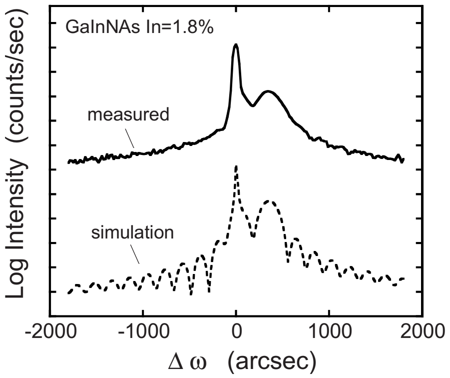

FIG. 2. X-ray diffraction spectrum of the GaInNAs sample. The center of the horizontal axis corresponds to the diffraction angle of 33.01° for the GaAs(004) diffraction.

III. RESULTS AND DISCUSSION

A. Determination of composition and strain by x-ray diffraction

The amount of induced strain and composition of GaInNAs films were determined by XRD. Figure 2 shows $\omega-2\theta$ XRD spectrum of a GaInNAs sample. The measurement configuration was GaAs(004) diffraction. Thus, the center of the horizontal axis corresponds to the diffraction angle of 33.01° for the GaAs(004) diffraction. The measured spectrum agrees well with a simulation for a coherently grown 100-nm-thick epilayer. The procedure of N plasma ignition makes the heterointerface between GaInNAs and GaAs layers dim. Therefore, the lack of the fringes may be due to the unclear heterointerface. Anyway, the agreement between both the spectra indicates no lattice relaxation. The similar results were also obtained in the other samples. All samples do not have any dislocations under microscope observations. Hence, we can conclude that strain in all samples used in this study is not relaxed. We calculated the lattice constant for the growth-direction $a_\perp$ of GaInNAs layer from the difference in diffraction angle ω between epilayer and GaAs substrate based on the Bragg condition. Then, the In composition and strain for the samples were evaluated.

We assumed that the strain was introduced in the entire region of the GaInNAs films. If the thickness of the sample is small as in the case for quantum well structure,[13] the biaxial strain is introduced by the lattice mismatch between the film and substrate. This also deforms the band structure and becomes a very important physical parameter to control the band gap energy. We then considered that the strain due to the lattice mismatch would also be introduced for the rather thick sample of 100 nm. This is why we assume that the induced strain is the mean value for the entire region of the present sample.

The sample thicknesses of all the GaInNAs films were 100 nm and thinner than the minimum critical thickness among the samples used in this study of 130 nm calculated by using Matthews' model for GaNAs film (In=0%, N =1.2%), which has the maximum absolute strain value among the samples used in this study of 0.25%. Thus, we can expect pseudomorphic or coherent growth without lattice re-

TABLE I. Parameters used or obtained for GaInNAs samples studied. Two alternative models are used for estimating ΔE.

In composition (%)	0	1.8	3.4	4.5
Strain (%)	−0.251	−0.125	−0.010	+0.071
Measured E_g (eV)	1.220	1.195	1.190	1.179
Calculated E_g^1 by model (I) (eV)	1.238	1.213	1.191	1.176
$\Delta E^{(1)}$ (eV)	−0.018	−0.018	−0.001	+0.003
Calculated E_g^2 by model (II) (eV)	1.243	1.215	1.191	1.174
$\Delta E^{(2)}$ (eV)	−0.023	−0.020	−0.001	+0.005

laxation. In this case, the amount of strain ε in an epilayer was directly given by $a_\perp$ measured in (004) diffraction as in the form by

$$\varepsilon = \frac{a_0 - a_s}{a_s} = \frac{\Delta a_0}{a_s} = \frac{c_{11}}{c_{11} + 2c_{12}} \frac{\Delta a_\perp}{a_s} = \frac{c_{11}}{c_{11} + 2c_{12}} \frac{a_\perp - a_s}{a_s}, \tag{1}$$

where a_0 is lattice constant of the epilayer in the free space without strain, a_s is the lattice constant of GaAs substrate, and c_{11} and c_{12} are the elastic stiffnesses. Since the elastic stiffnesses hardly depend on the compositions of the alloys, they are assumed to be the same as those of GaAs. The N composition was measured by using a GaNAs film.

Since the dilute nitride alloy exhibits many unusual properties compared to the normal III-V alloy, the validity of the linear dependence of the lattice constants and the element compositions should be reminded. Li *et al.* reported that the lattice parameters in GaNAs epilayers deviate from the Vegard law.[14] However, the composition of our sample with N =1.2% was less dilute than the reported critical value of 1.5%. This means that Vegard's law is applicable in our GaNAs sample. The In composition in the GaInNAs samples was evaluated assuming that Vegard's law is applicable also in GaInNAs and that the N composition is unchanged at 1.2%. The obtained In composition and strain for the samples are listed in the first and second rows of Table I, respectively. A GaInNAs sample (In=3.4%, N=1.2%) is almost completely lattice matched. We grew a GaInAs sample without N supply under the same growth conditions as the GaInNAs samples. The In composition of the GaInAs agreed well with that of the GaInNAs. This reveals that our estimation way in the compositions is reasonable.

B. Measurement of the transmission spectra

The conventional optical transmission measurements were carried out from room to liquid nitrogen temperature for investigating the variation of the band gap energy of GaInNAs. Typical transmission spectra for the sample of In =3.4% at different temperatures are shown in Fig. 3. Transmission intensity decreased very rapidly near the band gap energy of GaAs substrate around 1.4 eV at room temperature. However, the absorption edges of the GaInNAs films were hard to estimate. For example, small hump of the signal was only observed around 1.15 eV at room temperature. Although it is found that the band gap energy may shift to the higher energy side when the temperature decreased, the accurate values could not be estimated. Since the thickness of the sample is 100 nm, most of the incident light transmitted through the GaInNAs film. Therefore, we found that the conventional transmission spectroscopy is not suitable for determining the band gap energies with good accuracy for the present sample. Accordingly, we decided to use our developed PPT spectroscopy that had a high sensitivity for the thin film samples.[4]

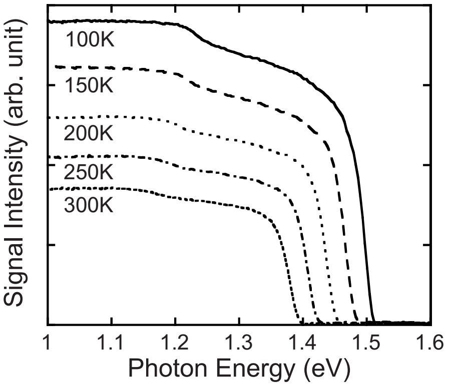

FIG. 3. Temperature variation of the transmission spectra of GaInNAs with In=3.4%. The small humps observed around 1.15–1.25 eV correspond to the absorption edges of GaInNAs.

C. Measurements of the room temperature piezoelectric photothermal spectra

Figure 4 shows PPT spectra of thick GaInNAs films of 100 nm with different In compositions at room temperature. Broad spectra were observed in the present PPT spectra measurements. The sudden decrease of the signal above 1.4 eV is due to the band gap absorption of the GaAs substrate. This is

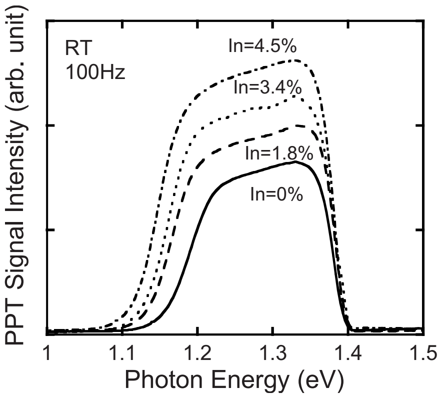

FIG. 4. Room temperature PPT spectra of GaInNAs films with the different In composition as the parameters. The sudden decrease above 1.4 eV is due to the band gap absorption of GaAs substrate. The observed band edge for GaInNAs shifts to the lower energy side as In composition increases.

definitely contrasting to the results for the conventional transmission spectra in Fig. 3 and the usefulness of the PPT measurements may be demonstrated. The observed band edge defined by the increase of the signal between 1.1 and 1.2 eV in the PPT spectra shifts to the lower energy side as the indium composition increases. The band gap energies of GaInNAs films were then calculated from the PPT spectra by fitting the data to the theoretical expectations.

D. Determination of the band gap and the exciton binding energies from piezoelectric photothermal spectra

The unusual physical properties of GaInNAs are the consequences of the exceptional chemical characteristics of nitrogen as compared to the other elements in groups III and V. Since the researchers worldwide have devoted a lot of effort to examine the properties of this material, most of its properties have been established.[15] Adding nitrogen affects mostly on the conduction band but hardly on the valence band.[2,9] The energy level of the conduction band bottom is lowered. Thus, band gap is reduced and band lineup is greatly changed.[3] The band structure variation at the conduction band bottom increases density of state of the conduction band and electron effective mass.[10] Increased combined density of state and increased reduced mass change various physical properties such as increased refractive index[16] and increased exciton binding energy.[17]

The formula for the optical absorption spectrum $\alpha(\hbar\omega)$ proposed by Elliott[18] that includes the three dimensional theory for the direct allowed transition was used for calculating the energy gap and the exciton binding energy from the PPT spectra. In order to get a more realistic picture, we developed the model proposed by Camassel *et al.*[19] We have used the Voigt function for the convoluted integral for the theoretical expression for $\alpha(\hbar\omega)$ instead of a Lorentzian broadening function. The formula is then given by

$$\alpha_c(\hbar\omega) = \int_{-\infty}^{+\infty} \alpha(\hbar\omega - E)V(E)dE, \qquad (2)$$

where $V(E)$ is the Voigt function that consists of the convolution of the Lorentzian $L(t)$ and the Gaussian $G(t)$ profile functions expressed by

$$V(x) = \int_{-\infty}^{+\infty} G(t)L(x-t)dt. \qquad (3)$$

The unbroadened absorption coefficient is written by[18]

$$\alpha(\hbar\omega) = A\left(\sum_{n=1}^{\infty} \frac{2R_0}{n^3}\delta(\hbar\omega - \hbar\omega_n) + \frac{U(\hbar\omega - E_g)}{1 - e^{-2\pi Z}}\right). \qquad (4)$$

In the above equation, A is normalization constant including the effective masses, dimensionless interband oscillator strength, and the refractive index. The band gap energy is written by E_g and the exciton binding energy R_0. $U(x)$ is the unit step function and $Z = [R_0/(\hbar\omega - E_g)]^{1/2}$. The physical parameters such as the band gap and the exciton binding energy were determined in order to obtain the best fit to the observed spectra.

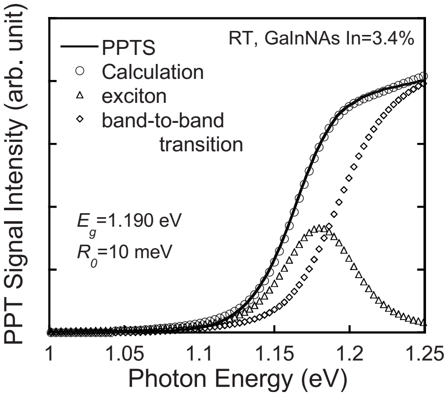

FIG. 5. The best-fitted result for the exciton and band to band transitions of GaInNAs sample with In=3.4%. The Voigt function was used for the convolution function. The band gap and the exciton binding energies were determined within the error of 3 meV.

Figure 5 shows the result of the fitting using Eqs. (2)–(4). In this case, the best fit was obtained when we used the broadening parameters of 80 and 50 meV for the Gaussian and the Lorentzian components in Eq. (3), respectively. The figure also shows the decomposition of the exciton and band to band transition. Good agreement was obtained up to 1.25 eV, and E_g and R_0 were determined to be 1.190 eV and 10 meV, respectively. The observed best-fitted band gap energies of other GaInNAs films were 1.220, 1.195, and 1.179 eV for In=0%, 1.8%, and 4.5%, respectively, and were summarized in Table I.

Obtained exciton binding energies for investigating four samples are as follows: 8–12 meV for In=0%, 10–13 meV for In=1.8%, 7–13 meV for In=3.4%, and 10–13 meV for In=4.5%. They are constant at 10 meV within an error margin of 3 meV. Constant exciton binding energies are the result of the same N content in samples. This is because electron effective mass and exciton binding energy mostly depend on the N content but hardly on the In content. Exciton binding energy in a bulk semiconductor is given as follows:

$$R_0 = 13.6\mu/\kappa^2 \text{ (eV)}, \qquad (5)$$

where μ is reduced mass (unit: electron rest mass) and κ is static dielectric constant, respectively. Adding In by 4.5% to GaAs decreases hardly the exciton binding energy from 4.5 to 4.3 meV. Therefore, the exciton binding energy caused by the In composition variation in this study (0%–4.5%) is much smaller than the experimental error of 3 meV. Adding N by 1.2% to GaAs increases electron effective mass by about twice.[20] As far as we know, there is no experimental report on the static dielectric constant of III-N-V. Neglecting the variation in static dielectric constant, we can expect exciton binding energy of our samples to be about 9 meV. It agrees well with the measured value of 10 meV. A key point in our study is the constant N content in all samples, while previous reports[7,8] used samples with different N contents. The constant N content enables us to make reliable measurements under the little influence of the exciton trapping that is the common feature in excitonic transitions in dilute nitrides.

E. Energy gap in the free space as a function of In composition

Before continuing the further discussion for the effect of the strain on the band gap energies, the band gap energy (E_g) of GaInNAs films in the free space can be calculated as a function of indium composition from the theoretical prediction using the published relations. Here, we consider two models: (I) GaInNAs in an alloy among GaNAs and InNAs, or (II) a nitrogen-introduced alloy into GaInAs.

1. Model (I): An alloy among GaNAs and InNAs

Since the band gap bowing is known to be important in the dilute nitride semiconductors, the band gap energy of $Ga_{1-y}In_yNAs$ system may be written as

$$E_g^{\mathrm{GaInNAs}}(y) = E_{g_{(\mathrm{GaNAs})}} + py + qy(1-y), \tag{6}$$

where p and q are the constants and the latter q is known to be a bowing parameter. It is then necessary to determine the parameters of the present case for $Ga_{1-y}In_yN_{0.012}As_{0.988}$. The band gap energy of GaN_xAs_{1-x} as a function of nitrogen has been reported as[12]

$$E_g^{\mathrm{GaNAs}}(x) = 1.425 - 15.6x, \tag{7}$$

where x is the nitrogen composition. The composition x and the band gap were determined by XRD and photoluminescence measurements, respectively, assuming that the crystal is in the strain free condition. The band gap energy of InN_xAs_{1-x} is also given by[21]

$$E_g^{\mathrm{InNAs}}(x) = 0.36 + 1.53x - 4.22x(1-x). \tag{8}$$

Since the valence-band discontinuity between InAs and InN has not been determined experimentally, Harrison's model for the valence band offset, $\Delta E_V = E_V(\mathrm{InAs}) - E_V(\mathrm{InN}) = 3.79$ eV, has been assumed. This induced the bowing parameter as −4.22 eV. Because the band gap energies of InAs ($x=0$) and InN ($x=1$) are 0.36 and 0.65 eV,[22] respectively, the parameters in the equation were determined as in Eq. (8). By using Eqs. (7) and (8), the band gap energies of GaNAs and InNAs were determined to be 1.238 and 0.328 eV, respectively, for the nitrogen content of 1.2%. Since the nitrogen composition is as low as 1.2%, at the present case, we also assumed that the bowing parameter of GaInNAs in Eq. (6) is the same as that of GaInAs ($q=-0.494$).[23] Then, the band gap energy of $Ga_{1-y}In_yNAs$ sample as a function of indium composition was obtained as

$$E_g^1(y) = 1.238 - 0.91y - 0.494y(1-y). \tag{9}$$

Accordingly, the band gap energies for the present samples in the case for strain free condition were calculated and were shown in Table I as model (I).

2. Model (II): A nitrogen-introduced alloy into GaInAs

We have an alternative way to calculate the energy gap of GaInNAs. Since the band gap energies for InNAs and GaNAs are still controversial, the calculation given above may result in the uncertainty for the estimation of E_g. We then consider GaInNAs as a nitrogen-added alloy into GaInAs. The band gap of $Ga_{1-y}In_yAs$ as a function of the indium composition is written by

$$E_g^2(y) = 1.43 - 1.537y \tag{10}$$

for the low indium composition below 5%. We also found from Ref. 24, that adding 1.2% nitrogen decreases E_g by 0.187 eV. The energy gap of GaInNAs is finally obtained by

$$E_g^2(y) = 1.243 - 1.537y. \tag{11}$$

The band gap energies of the present samples were then determined and were listed in Table I as a model (II). Table I also shows that the obtained parameters from the two proposed models are almost the same for the present samples. This may be due to the fact that the nitrogen composition is sufficiently small.

F. Determination of the deformation potentials

Two research groups reported similar results not for GaInNAs but for GaNAs that shear deformation potentials increase extraordinarily with an increase in N content up to 1.5%–2.0%, and decrease after having a peak.[7,8] Since adding nitrogen affects hardly on the valence band, it may slightly affect shear deformation potential. Hence, the above reported results should be rechecked by using a different technique from theirs.

Now, we can discuss the effect of induced strain ε by alloying on the band gap energy by using Table I. The energy differences ΔE between the theoretical and experimental results are shown in the table for the two proposed models [(I) and (II)]. The sample with indium composition of 3.4% is considered to be a strain free sample because ΔE is zero, as shown in Table I. Since ΔE has a positive value for the sample with In=4.5%, the film is considered to be in compression ($\varepsilon > 0$). On the other hand, the samples with In =0% and 1.8% are in tension ($\varepsilon < 0$). Taking into account the fact that the atomic radius for gallium is smaller (1.24 Å) than that of indium (1.62 Å), the obtained results are reasonable for understanding. Figure 6 shows ΔE as a function of induced strain. The band gap shift with elastic strain ε has been reported by Gavini and Cardona.[25] They reported the relation between ΔE and ε as

$$\Delta E = \left\{ -2a\left(1 - \frac{c_{12}}{c_{11}}\right) \mp b\left(1 + \frac{2c_{12}}{c_{11}}\right) \right\}\varepsilon, \tag{12}$$

where c_{11} and c_{12} are the elastic stiffnesses and then $c_{12}/(c_{11}+c_{12})$ is the Poisson ratio, a the hydrostatic deformation potential, and b the shear deformation potential. The sign between the first and the second terms in the right hand side of the equation is for the heavy hole (plus) and the light hole (minus) bands.

Applying Eq. (12) to the results in Fig. 6, the hydrostatic and shear deformation potential should be calculated. The energy differences ΔE between the experimental and the calculated band gap energies using Eqs. (9) and (11) were plotted by solid diamonds and open circles, respectively. Although the number of the data is not enough to obtain the

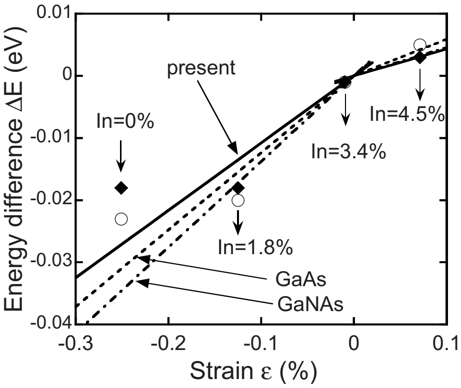

FIG. 6. The energy difference ΔE between the experimental and the calculated band gaps as a function of induced strain ε. The calculated lines using the parameters of GaAs and GaNAs are also shown in the figure. The fitting parameters are $a=-7.0$, -8.4, and -8.4 eV and $b=-1.7$, -1.7, and -2.4 eV for the present GaInNAs, GaAs, and GaNAs, respectively.

best fit to the experimental result, the solid lines drawn in Fig. 6 may well interpret the data. The parameters for those solid lines are $a=-7.0$ eV, $b=-1.7$ eV, and $c_{12}/c_{11}=0.46$. The measured hydrostatic deformation potential of -7.0 eV also agrees with the reduced hydrostatic pressure dependence in the band gap.[2] The deformation potential and the elastic stiffness ratio of GaAs were reported to be $a=-8.40$ eV, $b=-1.7$ eV, and $c_{12}/c_{11}=0.45$ by Andersson *et al.*[26] Using these parameters of GaAs, the relation between ΔE and ε can be drawn by dashed lines in Fig. 5. According to Refs. 7 and 8, the shear deformation potential of GaNAs at a nitrogen content of 1.2%, b is about -2.4 eV. If we set $b=-2.4$ eV for the present case for GaInNAs, the calculated lines are drawn by dash-dotted lines. The deviation from the data for $\varepsilon<0$ became large and could not obtain the best-fitted parameters as shown in the figure. The line laid lower side than that for GaAs for the value of a around -8 eV. Although the less value for a around -6 eV gives us a better fit for $\varepsilon<0$, the deviation became large for $\varepsilon>0$. Our fitted value for shear deformation potential is the same as that of GaAs, but not consistent with that previously reported in GaNAs.[7,8] Present results may imply that we can substitute deformation potentials of host III-V material, i.e., GaAs or GaInAs, for those of GaInNAs.

In the present study, we could observe the band gap energies with high accuracy. One of the reasons is that we could observe detailed absorption spectra of sample films, moreover, could clearly decompose the exciton and band to band transition. This indicates the usefulness of the present PPT experimental methodology for investigating the effect of induced strain on the electronic band structure of dilute nitride compounds.

IV. CONCLUSION

The band gap and exciton binding energies of dilute nitride $Ga_{1-y}In_yN_{0.012}As_{0.988}$ films with the thickness of 100 nm have been determined as a function of indium composition for investigating the effect of the strain on the electronic band structure. The high sensitive PPT methodology was used for measuring the optical absorption spectra. The fitting analysis was carried out using the three dimensional direct allowed transition models with the Voigt function as a convolution profile. Since the good fit to the data was obtained, the band gap change with the indium composition in $Ga_{1-y}In_yNAs$ film was discussed comparing with the theoretical prediction of the band gap variation for the strain free structures. The hydrostatic and shear deformation potentials were then determined as $a=-7.0$ eV and $b=-1.7$ eV. Present results may imply that we can substitute deformation potentials of host III-V material, i.e., GaAs or GaInAs, for those of GaInNAs. Although the fitting procedure should be improved by accumulating more experimental data for different indium compositions, we found that the deformation potentials and the Poisson ratio of GaInNAs were successfully estimated from the PPT measurements. The absorption spectra obtained by this methodology gave us a precise determination of the band gap and the exciton binding energy for the samples with different indium compositions. This demonstrated that the present PPT method is worth for investigating the electronic structures of the thin film structure.

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