Refractive index expressions for $Ga_{1-x}ln_xAs$, $GaAs_{1-x}N_x$ and $Ga_{1-x}ln_xN_yAs_{1-y}$ alloys

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Received 8 December 2014; accepted 21 April 2015

An expression suitable to estimate the refractive index of $Ga_{1-x}ln_xN_yAs_{1-y}$ with $0 \leq x \leq 0.4$ and $0 \leq y \leq 0.04$ for band gap energies from 0.8 to 1.1 eV is presented. In case of $Ga_{1-x}ln_xAs$, an improved expression, which shows better agreement with experimental data than previously reported expression, is proposed.

Keywords: GaInNAs; GaAsN; diluted nitrides semiconductors; refractive index; optical properties.

PACS: 78.20.Ae; 78.20.Bh; 78.20.Ci

1. Introduction

Dilute nitride alloys have attracted considerable interest in recent years because their potential for optoelectronic device applications. Particularly, GaInNAs/GaAs laser diodes (LDs) are one of the strongest candidates as alternative to GaInPAs/InP devices commonly used in telecommunication systems at 1.3-1.5 μm. However, while GaInNAs/GaAs LDs at 1.3 μm with low threshold currents and high values of characteristic temperature (T_0), have been obtained by several groups [1-3], there are still serious problems to experimentally achieve optical emission at 1.55 μm.

Results indicate that to make real the full potential of dilute nitride LDs a further optimization of the structures is needed. For this purpose an accurate knowledge of materials parameters such as the refractive index is required. An exact knowledge of the refractive index is needed to properly design the laser waveguide.

While for $Ga_{1-x}ln_xAs$, experimental data and expressions for the refractive index have been published [4-7], $GaAs_{1-x}N_x$ and $Ga_{1-x}ln_xN_yAs_{1-y}$ have been less studied.

Due the lack of accurate data for $Ga_{1-x}ln_xN_yAs_{1-y}$, values of the refractive index between 3.6 and 3.8 have been used in simulation of lasers structures emitting at lasing wavelength of 1.3 μm [8,9], but there are some inconsistencies in the published data.

For example Miloszewski *et al* [10] in simulation of MQW $Ga_{0.62}In_{0.38}N_yAs_{1-y}$ laser structures used values of the refractive index of: 3.725, 3.722 and 3.712 (y = 0.1, 0.5, 1.8), in contradiction with the experimental observation that the refractive index of $Ga_{1-x}ln_xN_yAs_{1-y}$ increases in proportion to the nitrogen content, as in others III-V alloys.

Report by Kitatani *et al* [11], give $Ga_{1-x}ln_xN_yAs_{1-y}$ refractive index data for samples with x = 33% and nitrogen compositions of 0.5% and 0.6%, obtained from spectroscopy ellipsometry (SE) in the wavelength range from 1.15 to 1.50 μm. Their results shown that the refractive index increases as N concentration increases, according to the trend observed in conventional III-V semiconductor alloys in which a decrease in the band gap energy is accompanied by the increase of the refractive index.

Leibiger *et al* [12] reported the refractive index of $Ga_{1-x}ln_xN_yAs_{1-y}$ in the wavelength range from 0.95 to 1.65 μm for five combinations of indium and nitrogen concentrations. Jin *et al* [13] reported values of the refractive index between 3.6 and 3.8 for a 1.3 μm $Ga_{1-x}ln_xN_yAs_{1-y}$ MQW Fabry-Perot laser. The modal refractive index was obtained by measuring the longitudinal mode separation between two adjacent modes from the laser emission spectra. On the other hand Li *et al* [14] studied the refractive indices of $Ga_{1-x}ln_xN_yAs_{1-y}$ in the wavelength range $400 < \lambda < 700$ nm, which is below the range of interest for practical telecom lasers.

Since the indium mole fraction used in the $Ga_{1-x}ln_xN_yAs_{1-y}$ active layers of lasers diode is around of 0.36%, it is important to accurately know the refractive index for samples with this composition. MacKenzie *et al*, measured the amplified spontaneous emission spectra for a $Ga_{0.613}In_{0.387}N_{0.012}As_{0.988}$ QW edge emitting laser and extracted a refractive index value of 3.75 [15].

In this work, we carefully evaluates the available refractive index data and propose an expression suitable to estimate the refractive index of $Ga_{1-x}ln_xN_yAs_{1-y}$ alloys for the nitrogen composition and wavelengths range of interest, including the cases of $Ga_{1-x}ln_xAs$, $GaAs_{1-x}N_x$ alloys.

2. Refractive index of $Ga_{1-x}ln_xAs$

Takagi [4] measured the refractive index of $Ga_{1-x}ln_xAs$ layers with indium compositions from 0 to 0.5, at photon energies of 0.5, 0.6, 0.9 and 1.2 eV. He obtained the composition

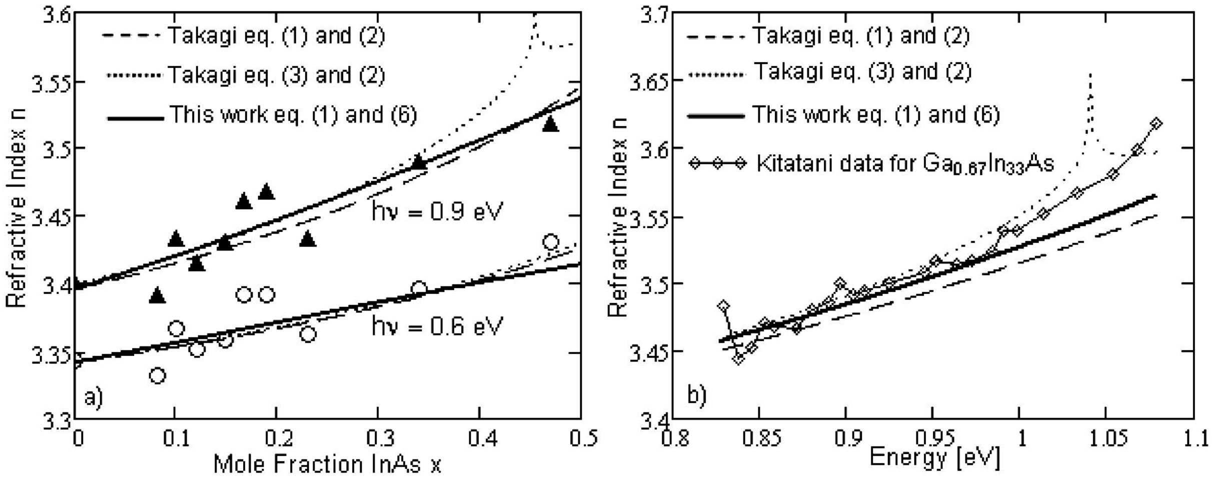

FIGURE 1. Dependence of refractive index of $Ga_{1-x}ln_xAs$: a) with indium composition at photon energies 0.6 and 0.9 eV; b) with photon energies for $Ga_{0.67}In_{0.33}As$. In both cases solid curves correspond to the fitting obtained in this work with expressions (1) and (6).

dependence of the refractive index by fitting his data to the expression proposed by Wemple and DiDomenico [16]:

$$n^2 - 1 = \frac{E_0 E_d}{E_0^2 - (h\nu)^2} \tag{1}$$

where $h\nu$ is the photon energy and E_0 and E_d the two fitting parameters. According to this model, E_0 is the energy of the single-effective-oscillator in the intrinsic absorption region where the imaginary part of the complex dielectric constant reaches a maximum, and E_d is the dispersion energy, related to the strength of interband optical transitions.

Takagi reported the following dependencies of parameters E_0 and E_d on the indium composition x:

$$\left.\begin{array}{l} E_0 = 3065 - 2.15x \\ E_d = 3601 - 19.9x \end{array}\right\} \tag{2}$$

Takagi also compared his data to the expression proposed by Afromowitz [17], which results from a modification to the Wemple and DiDomenico single-oscillator, model and according to which the refractive index can be estimated by:

$$n^2 - 1 = \frac{E_d}{E_0} + \frac{E_d}{E_0}(h\nu)^2 + \frac{\eta}{\pi}(h\nu)^4 \ln\left[\frac{2E_0^2 - E_g^2 - (h\nu)^2}{E_g^2 - (h\nu)^2}\right] \tag{3}$$

where

$$\eta = \frac{\pi E_d}{2E_0^3(E_0^2 - E_g^2)} \tag{4}$$

and Eg is the $Ga_{1-x}ln_xAs$ band gap energy gap given by [4]:

$$E_g = 1.425 - 1.337x + 0.270x^2 \tag{5}$$

Takagi concluded that, while for photon energies below the band gap the refractive index is good represented by both, expressions (1) and (3), the last one is a better approximation for photon energies near the band gap.

In this work we use the more recent Kitatani *et al* data [11] for a $Ga_{0.67}In_{0.33}As$ layer, to improve the expressions for parameters E_0 and E_d obtained by Takagi. Best fit was obtained by using second order polynomial expressions:

$$\left.\begin{array}{l} E_0 = 3.65 - 2.812xx1.16x^2 \\ E_d = 36.1 - 25.953x + 9.436x^2 \end{array}\right\} \tag{6}$$

Figure 1a) shows the refractive index as a function of the indium content of $Ga_{1-x}ln_xAs$ layers for two values of photon energies, 0.6 and 0.9 eV. Solid lines are the refractive indices obtained using the new fitting parameters given in (6). For comparison, calculated refractive indices with expressions (1) and (3) using Takagi's original expressions (2) for parameters E_0 and E_d are also plotted. Triangles and circles are the experimental data given by Takagi.

Figure 1b) shows the refractive index evaluated according expression 1 for a fixed value of indium composition $x = 0.33$ at the photon energy range from 0.827 to 1.078 eV and using our fitting parameters E_0 and E_d. In this case the data reported by Kitatani [11] is also depicted.

From both figures we can conclude that the modified dependencies for parameters E_0 and E_d proposed in this work describe in a better way the experimental reported data for $Ga_{1-x}ln_xAs$.

3. Refractive index of $GaAs_{1-x}N_x$

Leibiger *et al* [18] measured the refractive index of $GaAs_{1-x}N_x$ (nitrogen content: $x = 0\%$, 0.1%, 0.32%, 0.6%, 1.65%, 3.7%) by spectroscopic ellipsometry for photon energies from 0.75 to 1.5 eV ($0.28 < \lambda < 1.65$ μm), and used Adachi's composite Model Dielectric Function (MDF) [19,20] to analyze the data, obtaining a very good agreement between experiment and model.

Critical points (CPs) are known to play an important role in the dielectric function (DF) and according Adachi's model, the contribution of the critical points: E_0 and $E_0+\Delta_0$ to the optical functions $\varepsilon=\varepsilon_1+\varepsilon_2$ and $N=\sqrt{\varepsilon}=n+ik$ are given by the following terms [19]:

$$\varepsilon_j^{\text{Adachi}}(E)=A_jE_j^{-1.5}\times\left(\chi_j^{-2}[2-\sqrt{1+\chi_j}-\sqrt{1-\chi_j}]\right) \quad (7)$$

where $\chi_j=(E_j+i\Gamma_j)/E_j$ j= "0", "Δ_0" for E_0 and $E_0+\Delta_0$, respectively). A_j, E_j, and Γ_j are, amplitude, transition energy, and broadening parameter of each CP structure respectively [19].

The dielectric function is then composed of the following terms:

$$\varepsilon(E)=\varepsilon_0^{\text{Adachi}}(e)\varepsilon_{\Delta_0}^{\text{Adachi}}(E)+c+dE^2+fE^4 \quad (8)$$

where $c+dE^2+fE^4$ accounts for contributions from higher energy CP structures to the real part of dielectric function [19].

In this way and taking constant values for the spin-orbit splitting: $\Delta_0=350$ meV, and ratios: $A_{\Delta_0}/A_0=0.28$ and $\Gamma_{\Delta_0}/\Gamma_0=2$ Leibiger *et al* obtained the best-fit MDF parameters: A_0, E_0, Γ_0, c, d and f needed to calculate the $GaAs_{1-x}N_x$ dielectric function spectra $\varepsilon(E)$ at photon energies from 0.75 to 1.5 eV for the six nitrogen compositions studied.

We took the parameters reported by Leibiger for each one of the six nitrogen compositions studied, and refitted to a second-order polynomial expression: $p(x)=C_0+C_1x+C_2x^2$. In this way is possible to obtain the refractive index for $GaAs_{1-x}N_x$ layers with nitrogen compositions over the range 0% $< x <$ 3.7%. The fitting coefficients obtained for each parameter are listed in Table I.

For a rough estimate of the accuracy of our amendment, we use the error function:

$$\text{Error}=1-\frac{\sum(fit(x)-\nu y)^2}{\sum(\nu y-\text{mean}(\nu y))^2} \quad (9)$$

TABLE I. Best fit MDF coefficients for refractive index of $GaAs_{1-x}N_x$ ($0\%<x<3.7\%$) obtained in this work using the expression: $p(x)=C_0+C_1x+C_2x^2$.

Parameter	Coefficients			Error
	C_0	C_1	C_2	
E_0 (eV)	1.395	-20.975	304.629	0.995
A_0 (eV)$^{1.5}$	4.308	-156.149	2991	0.908
Γ_0 (meV)	4.927	2801	-5390	0.983
E_{Δ_0} (eV)	1.745	-20.975	304.629	0.995
A_{Δ_0} (eV)$^{1.5}$	1.205	-43.218	826.655	0.903
Γ_{Δ_0} (meV)	9.855	5603	-10780	0.983
c	10.057	27.209	-561.038	0.869
d (eV)$^{-2}$	0.561	-10.261	407.96	0.999
f (eV)$^{-4}$	0.081	9.967	-291.762	0.977

where x and νy denote the indium content and the reported value of the parameter respectively. Results are included in Table I, showing small deviations from the values reported by Leibiger [18].

4. Refractive index of $Ga_{1-x}ln_xN_yAs_{1-y}$

Leibiger *et al* in Ref. 12 studied the optical properties of $Ga_{1-x}ln_xN_yAs_{1-y}$ samples with the indium and nitrogen concentrations listed in Table II.

Applying the model dielectric function, with a constant spin-orbit value $\Delta_0=286$ meV, and ratios: $A_{\Delta_0}/A_0=0.8$, $\Gamma_{\Delta_0}/\Gamma_0=4.1$ Lebiger *et al* obtained the fitting parameters: A_0, E_0, Γ_0, c, d and f, for each one of the five samples studied at photon energies ranging from 0.75 to 1.3 eV (wavelength range from 0.95 to 1.65 μm).

We took these parameters for $Ga_{1-x}ln_xN_yAs_{1-y}$ and those reported in Ref. 18 for $GaAs_{1-x}N_x$ and fitted to a second order surface expression with two variables:

$$s(x,y)=C_0+C_1x+C_2y+C_3xy+C_4x^2+C_5y^2 \quad (10)$$

The best-fit coefficients obtained in this way are given in Table III. In Fig. 2 a) -e) a comparison between the refractive index of the $Ga_{1-x}ln_xN_yAs_{1-y}$ calculated by using the modified expressions for the MDF fitting parameters proposed in this work (Table III) and with the parameters reported by Leibiger *et al* [12] is shown for photon energies from 0.75 to 1.3 eV.

Solid lines stand for the refractive index calculated using a second order surface expression (10) to fit the MDF parameters, and dashed lines+symbol correspond to a calculation with the parameters reported by Leibiger *et al* in [12]. As can be seen the modified MDF parameters proposed in this work and parameters given by Leibiger are in excellent agreement with each other. Note that the dashed and dotted lines are visually almost indistinguishable below 1.1 eV.

To further extend the validity of our approximation we used expression 10 and coefficients given in Table III to calculate the refractive index of $Ga_{1-x}ln_xAs$ and $GaAs_{1-x}N_x$ alloys considering zero the nitrogen or indium content in each case. In Fig. 2 f) a comparison between results obtained in this way for two values of indium composition (solid lines) and those obtained by means of the Eqs. (1) and (6) (dashed lines+ symbol) are presented showing a very good agreement between the two approaches.

TABLE II. Indium (x) and nitrogen (y) compositions of the $Ga_{1-x}ln_xN_yAs_{1-y}$ layers studied in Ref. 12

x	0.09	0.11	0.11	0.12	0.09
y	0.013	0.019	0.022	0.024	0.029

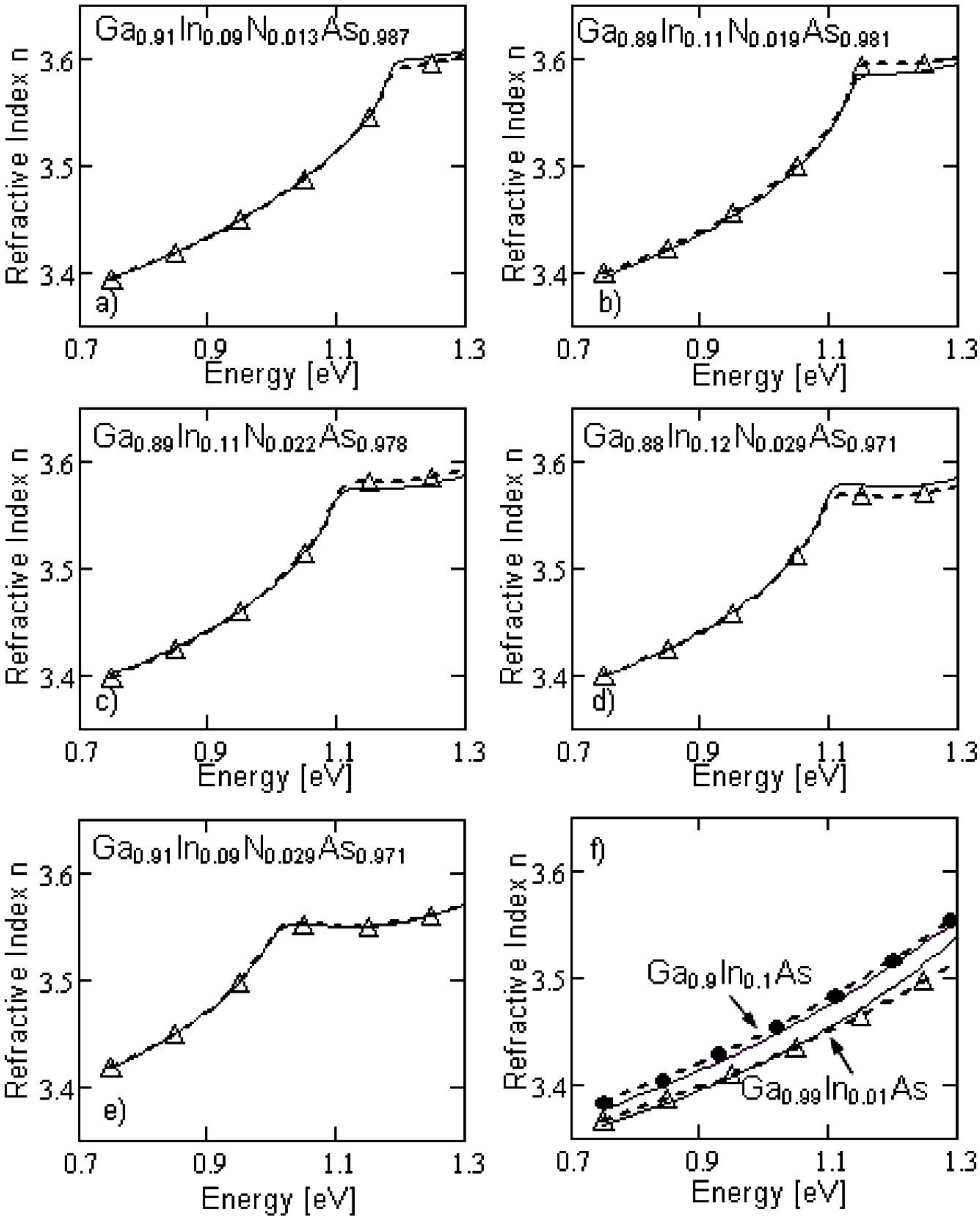

FIGURE 2. a) - e) Comparison of the refractive indices for $Ga_{1-x}ln_xN_yAs_{1-y}$ calculated using the MDF fitting parameters proposed in this work (solid lines) and parameters given by Leibiger in reference 12 (dashed lines+ symbol). f) Calculated refractive index for $Ga_{1-x}ln_xAs$ with two different indium compositions compared with the result obtained by means of the Eqs. (1) and (6).

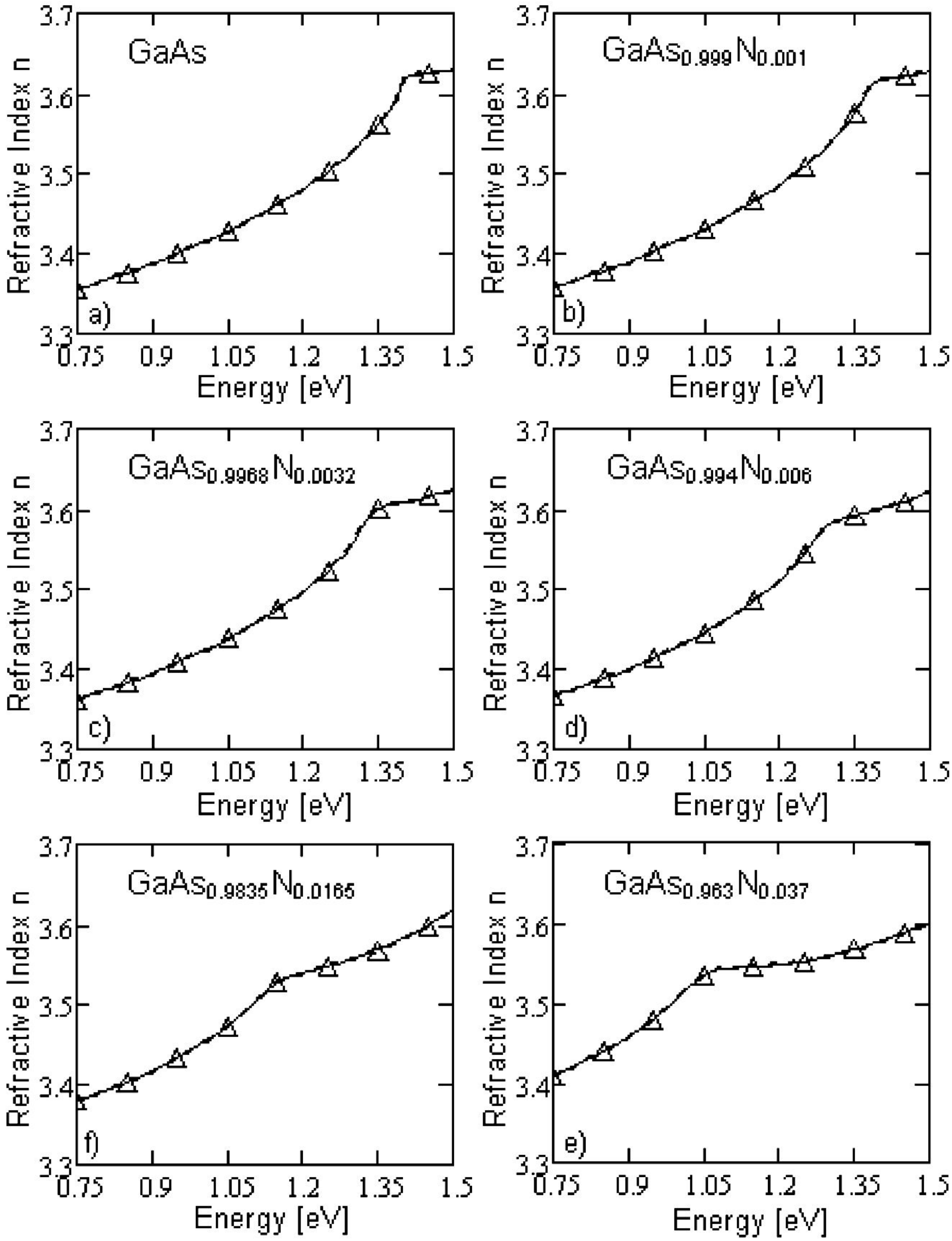

FIGURE 3. Dependence of refractive index with photon energy for $GaAs_{1-x}N_y$ layers calculated using the second order surface expression to fit the MDF parameters (solid lines) and with the MDF parameters reported in Ref. 18 (dashed lines+ symbol).

TABLE III. Best fit MDF coefficients for refractive index of $Ga_{1-x}In_xN_yAs_{1-y}$ obtained in this work using a second order surface expression (10).

Parameter	Coefficients						Error
	C_0	C_1	C_2	C_3	C_4	C_5	
E_0 (eV)	1.394	-1.029	-20.891	-37.115	18.239	302.498	0.997
A_0 (eV)$^{1.5}$	4.296	-18.429	-153.083	211.353	190.604	2914	0.896
Γ_0 (meV)	5.015	-391.341	2780	4006	272.683	-53368	0.981
E_{Δ_0} (eV)	1.744	-2.278	-20.88	-37.396	24.303	302.214	0.998
A_{Δ_0} (eV)$^{1.5}$	1.198	16.615	-41.499	11.985	1.76	783.518	0.99
Γ_{Δ_0} (meV)	10.126	-512.017	5537	28301	-4271	-106209	0.972
c	10.061	1.469	26.201	-84.403	-23.379	-534.824	0.848
d (eV)$^{-2}$	0.561	6.103	-10.175	-140.308	-40.799	404.948	0.978
f (eV)$^{-4}$	0.081	-1.513	10.057	27.413	10.852	-293.929	0.984

TABLE IV. Best-fit parameters to Eq. (11) for $Ga_{0.67}In_{0.33}N_yAs_{1-y}$ layers.

Parameter	Samples		
	$Ga_{0.67}In_{0.33}As$	$Ga_{0.67}In_{0.33}N_{0.005}As_{0.995}$	$Ga_{0.67}In_{0.33}N_{0.0066}As_{0.9934}$
a	7.669	3.286	3.520
b	3.333	8.342	8.508
$c[\mu$m]	0.701	0.499	0.499

In Fig. 3 we compare the refractive index calculated for $GaAs_{1-x}N_x$ layers with different nitrogen contents: 0%, 0.1%, 0.32%, 0.6%, 1.65% and 3.7%, using the modified expressions for the MDF fitting parameters proposed in this work (solid lines) with the parameters reported by Leibiger *et al* [18] (dashed lines+ symbol); the photon energy was varied from 0.75 to 1.5 eV.

From Figs. 2 and 3 we can conclude that the modified expressions to fit the MDF parameters proposed in present work (Eq. 10 and Table III), allows to calculate with a good accuracy, the refractive indices of $Ga_{0.62}In_{0.38}N_yAs_{1-y}$ alloys ($x \leq 0.12$ and $y \leq 0.04$) in the photon energy range from 0.75 to 1.3 eV (wavelengths from 0.95 to 1.65 μm).

5. Refractive index of $Ga_{0.67}In_{0.33}N_yAs_{1-y}$

Note that the expression obtained in previous section in not valid for the indium content commonly used in the active region of $Ga_{1-x}In_xN_yAs_{1-y}$ laser diodes which as previously said is around of 0.36%. In order to include this composition, we took the refractive index data reported by Kitatani *et al* [11] for $Ga_{0.67}In_{0.33}N_yAs_{1-y}$ samples with nitrogen compositions: $y = 0$, 0.005 and 0.0066 measured in the photon energy range of 0.8 to 1.07 eV (wavelengths from 1.15 to 1.50 μm). While in Sec. 2 we only used the data for $y = 0$, here we fitted the data reported for the three values of nitrogen compositions to the well known Sellmeier equation:

$$n(y,\lambda) = \sqrt{a + \frac{b\lambda^2}{\lambda^2 - c^2}} \qquad (11)$$

where a, b and c are fitting parameters and λ is in μm. Values of the fitting parameters obtained are listed in Table IV.

To extend this approximation for the whole nitrogen compositions of interest, $0 \leq y \leq 0.0066$ we fitted the data to the Sellmeier equation. The best fits for $a(y)$, $b(y)$ and $c(y)$ were found by using second order polynomial expressions: $p(y) = C_0 + C_1 y + C_2 y^2$. In Table V the values of the coefficients obtained for each parameter are listed.

The refractive indices resulting from plotting Eq. 11 with the parameters given in Table V are shown in Fig. 4. The solid lines + symbols correspond to the experimental data of Kitatani [11] for compositions: $y = 0.00$, 0.005, and 0.0066. Dotted lines are refractive indices obtained by Sellmeier equation for these compositions and solid lines correspond to other values of nitrogen composition.

TABLE V. Values of the coefficients in the polynomial expression: $p(y) = C_0 + C_1 y + C_2 y^2$ to fit parameters $a(y)$, $b(y)$ and $c(y)$ in Sellmeier equation.

Parameter	Coefficient		
	C_0	C_1	C_2
a	7.669	-1651.486	154977.273
b	3.333	1682.141	-136068.182
$c[\mu$m]	0.701	-71.006	6121.212

TABLE VI. Coefficients to fit the parameters of the Sellmeier equation to a second order surface expression for $Ga_{1-x}ln_xN_yAs_{1-y}$ ($0 \leq x \leq 0.4$ and $0 \leq y \leq 0.04$).

Parameter	Coefficients						Error
	C0	C1	C2	C3	C4	C5	
A	6.393	10.002	219.165	-77.359	-55.502	-4181	1
B	4.594	-13.117	-224.028	375.269	66.045	4339	0.99
C(μm)	0.466	0.264	10.07	-18.741	-1.773	-234.546	0.942

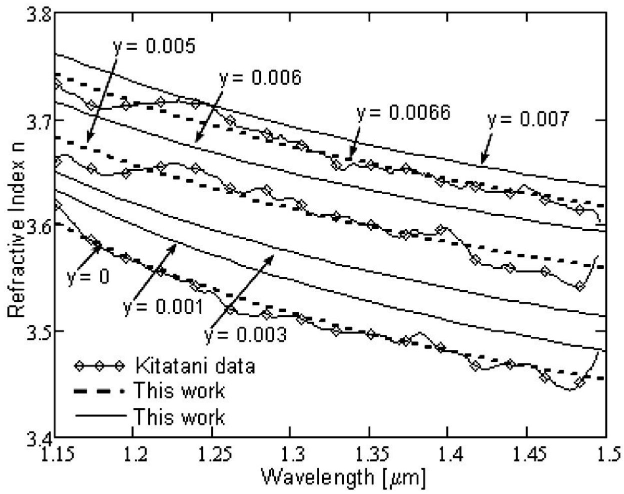

FIGURA 4. A comparison of refractive index of $Ga_{0.67}In_{0.33}N_yAs_{1-y}$ evaluated for six nitrogen compositions using the Sellmeier equation with coefficients obtained in this work (dotted and solid lines) and experimental curves reported by Kitatani [11] (solid lines + symbol).

From Fig. 4 we can conclude that our approximation describe in a better way the experimental data reported by Kitatani *et al*, and can be used to calculate the refractive index of $Ga_{0.67}In_{0.33}N_yAs_{1-y}$ layers up to $y = 0.0066$ in the photon-energy range between 0.8 and 1.07 eV (wavelengths from 1.15 to 1.50 μm).

6. Refractive index for $Ga_{1-x}ln_xN_yAs_{1-y}$ ($0 \leq x \leq 0.4$ and $0 \leq y \leq 0.04$) for photon energies from 0.8 to 1.1 eV

In order to estimate, through a simple formula, the refractive index of $Ga_{0.62}In_{0.38}N_yAs_{1-y}$ for compositions $0 \leq x \leq 0.4$ and $0 \leq y \leq 0.04$, resulting in the emission wavelengths of interest (1.3 and 1.55 μm) for lasers diode, we used the Sellmeier equation. In this case we estimated the refractive of $Ga_{1-x}ln_xN_yAs_{1-y}$ by shifting the refractive index of GaAs according to the difference in band-gap energy between the solid solution and GaAs as proposed by Bergman and Casey [21]:

$$n(x,y,E) = \eta_{\text{GaAs}}(E - [E_g(xy) - E_g(\text{GaAs})]) \quad (12)$$

where $E_g(x,y)$ is the band gap energy of the $Ga_{1-x}ln_xN_yAs_{1-y}$ alloy.

Assuming this approximation the refractive index can be obtained by means of the Sellmeier equation rewritten in the following form [7]:

$$n(x,y,\lambda) = \sqrt{A + \frac{B}{1 - \left(c\frac{E_{g_{\text{GaAs}}}}{\lambda E_{g_{\text{GaInNAs}}}}\right)^2}} \quad (13)$$

The band gap energy of $Ga_{1-x}ln_xN_yAs_{1-y}$ was calculated according to the band anticrossing model (BAC) [22] that predicts a splitting of the conduction band into two subbands E_- and E_+:

$$E_{\pm} = 0.5\{E_N + E_M \pm [(E_N - E_M)^2 + 4yV_{MN}^2]^{0.5}\} \quad (14)$$

Where E_N and E_M are the energies of the $Ga_{1-x}ln_xAs$, matrix conduction band edge and of the nitrogen level relative to the top of the valence band, respectively, and V_{MN} is the matrix element describing the interaction between those two states.

For E_N, V_{MN} and the band gap energy of $Ga_{1-x}ln_xAs$ we adopted the expressions reported in reference 23:

$$E_g(\text{Ga}_{1-x}\text{ln}_x\text{As}) = 0.417x + 1.42(1-x) - 0.477x(1-x) \quad (15)$$

$$E_N(x) = 1.65(1-x) + 1.44x - 0.38x(1-x) \quad (16)$$

$$V_{MN}(x) = 2.7(1-x) + 2.0x - 3.5x(1-x) \quad (17)$$

The fitting parameters A, B and C in Eq. 13 were fitted to a second order surface Eq. (10) starting from the expressions previous studied. In Table VI the fitting coefficients are listed.

In Fig. 5 refractive indices obtained with Sellmeier expression (13) and fitting parameters from Table VI are compared whit those obtained by using the MDF approach, and results from expression (1) using our fitting coefficients (6). Results are also compared to the experimental of Kitatani *et al* [11] for $Ga_{0.67}In_{0.33}N_yAs_{1-y}$. In Table VII the maximum difference obtained between refractive index calculated by expression 13 and those obtained by the other models and experimental values is presented.

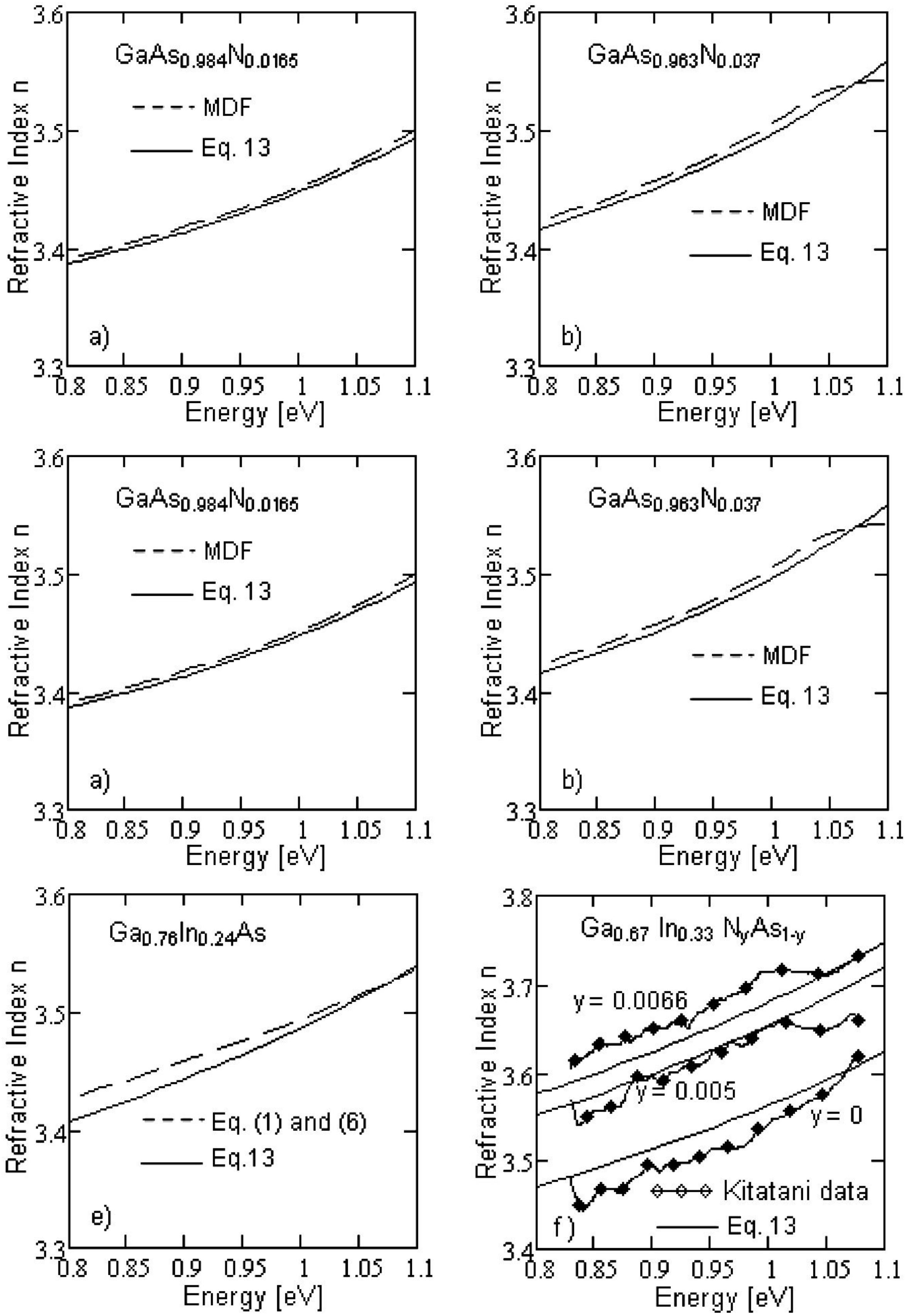

FIGURE 5. Comparison of refractive indices calculated by Eq. 13 and parameters from Table VI with others models by different compositions.

TABLE VII. Maximum difference between refractive index of $Ga_{1-x}In_xN_yAs_{1-y}$ calculated by expression 13 and those obtained by the other models.

Cases	x	y	Equation	Error
A	0	0	MDF	0.022
B	0	0.001	MDF	0.021
C	0	0.0032	MDF	0.02
D	0	0.006	MDF	0.019
E	0	0.0165	MDF	0.008
F	0	0.037	MDF	0.016
G	0.09	0.013	MDF	0.004
H	0.09	0.029	MDF	0.062
I	0.11	0.019	MDF	0.045
J	0.11	0.022	MDF	0.055
K	0.12	0.024	MDF	0.084
L	0	0	Eq. 1&6	0.009
M	0.01	0	Eq. 1&6	0.005
N	0.05	0	Eq. 1&6	0.014
O	0.1	0	Eq. 1&6	0.007
P	0.15	0	Eq. 1&6	0.069
Q	0.2	0	Eq. 1&6	0.181
R	0.33	0	Eq. 11	0.027
S	0.33	0.005	Eq. 11	0.023
T	0.33	0.0066	Eq. 11	0.031

From both Fig. 5 and Table VII is possible to see that not in all cases a good agreement was obtained and this is mainly due to the reduced data available to develop the fitting. From these results we can concluded that the Eq. 13 and coefficients given in Table VI can be used as a first approximation to estimate the refractive index of $Ga_{1-x}In_xN_yAs_{1-y}$ with and for band gap energies from 0.8 to 1.1eV.

7. Conclusions

In conclusion, we have compiled the refractive index data available for $Ga_{1-x}In_xAs$, $GaAs_{1-x}N_x$ and $Ga_{1-x}In_xN_yAs_{1-y}$ alloys and proposed an expression suitable to estimate the refractive index of $Ga_{1-x}In_xN_yAs_{1-y}$ with $0 \leq x \leq 0.4$ and $0 \leq y \leq 0.04$ for band gap energies from 0.8 to 1.1eV. The current lack of data reduces the accuracy of our calculation. In case of $Ga_{1-x}In_xAs$, the new fitting parameters proposed (6) shows a better agreement with experimental data than previously reported expressions.

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