Measurement of Refractive Indices of $(Al_xGa_{1-x})_{0.51}In_{0.49}P$ Grown by Low Pressure Organometallic Vapor Phase Epitaxy

LIAN Peng[1], MA Xiao-yu[2], ZHANG Guang-ze[2] and CHEN Liang-hui[2]

(1 *Department of Electronic Engineering, Beijing Polytechnic University, Beijing* 100022, *China*)

(2 *Institute of Semiconductors, The Chinese Academy of Sciences, Beijing* 100083, *China*)

Abstract: The refractive indices of disordered $(Al_xGa_{1-x})_{0.51}In_{0.49}P$, which is grown by low-pressure organometallic vapor phase epitaxy and lattice-matched to GaAs substrate, have been determined by measuring their reflectance spectra when the wavelength ranges between 0.5 to 2.5 micrometer. A single-oscillator dispersion model is used to verify the experiment data and calculate the reflectance spectrum. The refractive indices are used to analyze the waveguide of strain quantum well GaInP/AlGaInP visible laser diode. The simulated far field pattern is consistent with the experimental results very well.

Key words: LP-OMVPE; refractive index; measurement; GaInP/AlGaInP

PACC: 8115H; 7820

CLC number: TN304.07 **Document code**: A **Article ID**: 0253-4177(2001)04-0398-04

1 Introduction

The rapid development of visible laser diodes[1,2] and ultra-high brightness light emitting diode (UHB-LED)[3] has made $Ga_{0.51}In_{0.49}P/(Al_xGa_{1-x})_{0.51}In_{0.49}P$ widely used as an optoelectronic material system. The properties of this material have been extensively studied. Refractive index is one of the most important parameters to analyze and design the device structures, especially the waveguide structure of visible laser diodes, because it is of a narrow far field diverge, which is crucial to the applications of 630—670nm visible laser diodes, including CD/VCD/DVD players.

Because of the difficulty in obtaining bulk $Ga_{0.51}In_{0.49}P/(Al_xGa_{1-x})_{0.51}In_{0.49}P$ sample, some accurate measurement methods, including prism minimum deviation, are not available. In practice, the refractive index is obtained by measuring the reflective spectrum of epitaxial $Ga_{0.51}In_{0.49}P/(Al_xGa_{1-x})_{0.51}In_{0.49}P$ layers. MBE grown $Ga_{0.51}In_{0.49}P/(Al_xGa_{1-x})_{0.51}In_{0.49}$ sample has been measured by Hidenao Tanaka *et al.* in 1986[4]. In their work, the refractive indices were calculated from the reflectance spectrum of infrared region (0.95—2μm). In fact, the refractive index of visible wavelength region is much interesting from the viewpoint of structure design of visible laser diodes. Most of visible lasers and UHB-LED are produced by using MOVPE method today. In this work, the measurement of the refractive index of LP-MOVPE grown disordered $Ga_{0.51}In_{0.49}P/(Al_xGa_{1-x})_{0.51}In_{0.49}$epitaxial layers has been taken within the wavelength region from 0.5 to 2.5μm.

2 Experiment

Undoped disordered $Ga_{0.51}In_{0.49}P/(Al_xGa_{1-x})_{0.51}$

LIAN Peng male, born in 1971, Ph. Doctor. He has been engaged in the research on the MOCVD growth and novel optoelectronic devices, including high power semiconductor lasers and multi-quantum well infrared photodetector since 1994.

Received 25 October 2000, revised manuscript received 15 December 2000

$In_{0.49}P$ samples were grown on the silicon doped (100) GaAs substrate with a misorientation of 10 degree off towards (111) A in a commercial AIXTRON 200 LP-MOVPE system. The Al composition x of $Ga_{0.51}In_{0.49}P/(Al_xGa_{1-x})_{0.51}In_{0.49}P$ samples were 0, 0.4, 0.55, 0.75 and 1.0, respectively. At room temperature, the carrier concentration of n-type GaAs substrate was $2\times10^{18}cm^{-3}$, which was measured via Hall effect measurement. The metal organic precursors were trimethylaluminium (TMAl), trimethylgallium (TMGa) and trimethylindium (TMIn). The hydride sources were phosphine (PH_3) and arsine (AsH_3). Palladium-diffused hydrogen was used as the carrier gas. The growth temperature, V/III ratio and growth rate were 680—720℃, 180—450 and 1.8—4μm/h, respectively. The growth pressure was 50—100 mbar. The lattice mismatch ($\Delta a/a$) of GaInP/AlGaInP samples to GaAs substrate was controlled below 1×10^{-3}.

Metal film and alloy were lapped and deposited orderly on the backside of the samples to avoid the reflection on the backside. And the samples were bathed in diluted HF to eliminate the oxidation of Al atoms from the sample surface. Normal incidence reflectance spectrum was measured immediately after cleaning procedure with a high precision double-beam spectrophotometer. A standard mirror was used to ensure the measuring accuracy.

3 Results and Discussion

During the analysis procedure, these samples were treated as flatten optical films on the substrate. By using the characteristic matrix method[5], the reflectance spectra were simulated. In this method, optical properties of the thin film deposited on the thick substrate are written as the following expression.

$$\begin{bmatrix} B \\ C \end{bmatrix} = \begin{bmatrix} \cos\delta & \dfrac{i\sin\delta}{n} \\ in\sin\delta & \cos\delta \end{bmatrix} \times \begin{bmatrix} 1 \\ y_{sub} \end{bmatrix}$$

where $\delta = \dfrac{2\pi nd}{\lambda}$, $y_{sub} = n_{sub} - i\,k_{sub}$. n, d and λ represent the refractive index, thickness and light wavelength in vacuum, respectively. The 2×2 matrix is known as the characteristic matrix of the optical film. The reflectance spectrum is then obtained by calculating B and C according to $R = \dfrac{(B-C)(B-C)^*}{(B+C)(B-C)^*}$, which is seen to be an oscillation due to the interference of the film. It can be easily proved that the minimum values have nothing to do with the thickness of the films, i.e., only the minimum values and their respective wavelengths should be taken into consideration during the elimination of the deviation due to the thickness fluctuation.

Figure 1 shows the comparative result between the measured reflection spectrum and the calculated minimum values of GaInP sample. The thickness of this layer is about 0.6μm. Within the wavelength region from 0.65 to 2.5μm, the reflection spectrum regularly oscillates, as is due to the interference. When the wavelength is shorter than 0.65μm, the reflection departs this kind of oscillation because the photon energy is higher than the band gap of GaInP and absorbed into the thin film.

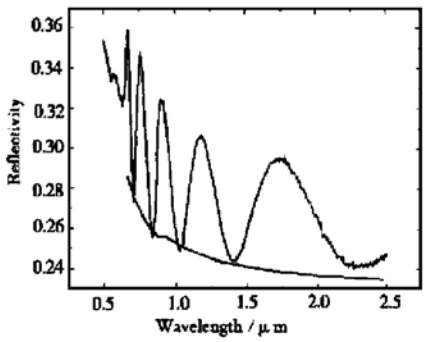

FIG. 1 Comparison Between the Calculated Minimum Reflection Spectrum and the Measured One of GaInP Layer Grown on GaAs Substrate
The thickness of GaInP layer is about 0.6μm.

The single-oscillator model was adopted to calculate the dispersion of GaInP/AlGaInP for the sake of simplification. Two parameters, E_0 and E_d, are necessary in this mode, where the imaginary part of the dielectric constant of the material at energy E_0 is assumed to be a delta function and the strength of an effective oscillator at energy E_0 is defined as $\pi E_d/2$. So the real part of the dielectric constant can be obtained from Kramers-Kronig transformation as: $n^2-1=\frac{E_0E_d}{E_0^2-E^2}$, in which E represents the photo energy.

The refractive index and extinction coefficient of n-GaAs substrate reported by D. D. Sell *et al*.[6] has been applied in the calculation. The refractive index and extinction coefficient of N-type GaAs substrate can not be considered as constants in the visible wavelength region, so it is difficult to write an explicit formulation of reflectance spectrum. The minimum reflectivity values of the GaInP samples and their corresponding wavelength can be obtained by numerical calculation. From Figure. 1, it is found that the simple single-oscillator model fits the experimental results quite well over a wide wavelength region.

Two dimensional search within a reasonable region is necessary to obtain the approximate values of the parameters E_0 and E_d. An iterative procedure is carried out to find the convergent accurate values. The simulated E_0 and E_d values in Figure 2 are as functions of Al composition of $Ga_{0.51}In_{0.49}P/(Al_xGa_{1-x})_{0.5}In_{0.5}P$ samples. The relationship between E_0, E_d and Al composition are found not simply linear as reported by Hidenao Tanaka *et al*.[4] The E_0 and E_d is observed in the obvious saturation while x is higher than 0.7, which is reasonable because the energy band structure of $(Al_xGa_{1-x})_{0.5}In_{0.5}P$ has changed directly first, and then indirectly when the Al composition is higher than 0.7. The band gap value does not increase so rapidly as those do under a lower Al composition condition. In addition, under the same growth condition, the order of AlGaInP will upgrade while the Al composition increases.

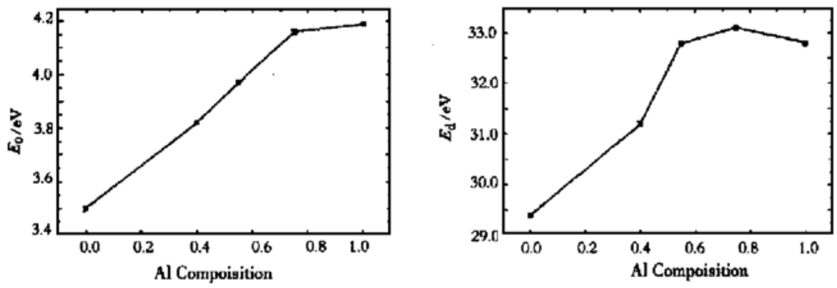

FIG. 2 Simulated E_0 and E_d as Functions of Al Composition x of Disordered $GaInP/(Al_xGa_{1-x})_{0.5}In_{0.5}P$ Layers Grown by LP-MOVPE Method

Figure 3 shows the simulated refractive indices of GaInP/AlGaInP. These results were applied in the simulation of far field pattern of visible GaInP/AlGaInP multi-quantum well laser diodes with typical structure parameters. The measured and calculated far field patterns have been illustrated in Figure 4, which agree with each other quite well.

4 Conclusion

In summary, the refractive indices of $Ga_{0.51}In_{0.49}P/(Al_xGa_{1-x})_{0.51}In_{0.49}P$ grown by low pressure metalorganic vapor phase epitaxy method have been obtained by measuring the reflection spectra. The single-oscillator model and characteristic matrix method have been used to verify the measured reflection spectra. The results are satisfying in comparing with reflection spectrum of samples and far field pattern of visible laser diodes. The values of E_0 and E_d do not vary linearly with the Al composition of $Ga_{0.51}In_{0.49}P/(Al_xGa_{1-x})_{0.51}In_{0.49}P$ simply.

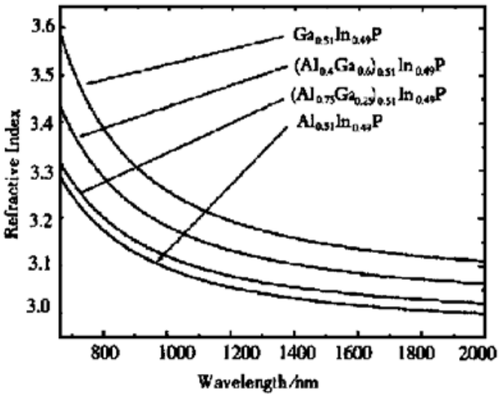

FIG. 3 Refractive Indices of GaInP/AlGaInP Epi-Layers Grown by LP-MOVPE Method

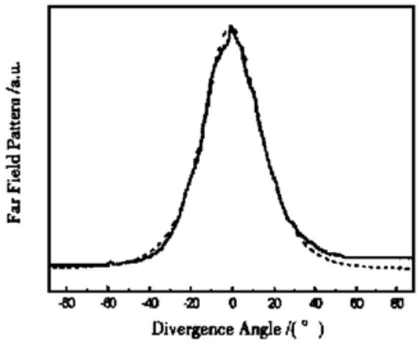

FIG. 4 Measured and Calculated Far Field Pattern of Typical Structure Visible Laser Diodes Sold line denotes the measured result. Dash line denotes the calculated one.

Acknowledgement The authors would like to thank Miss Song Xuemei from Department of Applied Physics of Beijing Polytechnic University for her help in reflectance spectrum measurement.

References

[1] Tanaka H., Kawamura Y. and Asahi H., Electron. Lett., 1986, **22**: 707.

[2] O. Imafuji, T. Fukuhisa, M. Yuri, M. Mannoh, A. Yoshikawa and K. Itoh, IEEE J. Selected Topics in Quant. Electron., 1999, **5**(3): 721.

[3] F. A. Fish, F. M. Steranka, D. C. Defevere *et al.*, Appl. Phys, Lett., 1994, **64**(21): 2839.

[4] Hidenao Tanaka, Yuichi Kawamura and Hajime Asahi, J. Appl. Phys., 1986, **59**(3): 985.

[5] Z. Knittl, Optica Acta, 1978, **25**: 167.

[6] D. D. Sell, H. C. Casey and K. W. Wecht, J. Appl. Phys., 1974, **45**(6): 2650.

低压金属有机化合物气相外延生长的$(Al_xGa_{1-x})_{0.51}In_{0.49}P$折射率测量

廉 鹏[1] 马骁宇[2] 张广泽[2] 陈良惠[2]

(1 北京工业大学电子工程学系, 北京 100022)

(2 中国科学院半导体研究所, 北京 100083)

摘要: 采用测量反射谱方法确定了低压金属有机化合物气相外延生长的与GaAs衬底匹配$(Al_xGa_{1-x})_{0.51}In_{0.49}P$外延材料的折射率. 实验中测量的反射谱波长范围为0.5—2.5μm. 在拟合实验数据过程中采用了单振子模型. 折射率数据用于分析应变量子阱GaInP/AlGaInP可见光激光二极管波导, 计算出的器件远场图与实验数据吻合很好.

关键词: 金属有机化合物气相外延; 折射率; 测量; AlGaInP

PACC: 8115H; 7820D

中图分类号: TN304.07 **文献标识码**: A **文章编号**: 0253-4177(2001)04-0398-04

廉 鹏 男, 1971年出生, 博士, 主要从事MOCVD的生长及新型光电子器件研究.

2000-10-25收到, 2000-12-15定稿