*J. Basic. Appl. Sci. Res.*, 3(3)495-501, 2013
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ISSN 2090-4304
**Journal of Basic and Applied Scientific Research**
*www.textroad.com*

# Study of Zinc Diffusion Behavior at Theingaasp/Inphetero-Structure Grown by Liquid Phase Epitaxial Method

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## ABSTRACT

In this study Zinc diffusion through InGaAsP/InPepitaxial layers was investigated. Hetero-structure has been fabricated by Liquid Phase Epitaxial (LPE) method. Secondary ion mass spectrometry (SIMS) profiling was performed to determine the total atomic zinc concentration in the grown layers. Results revealed that the Zn doping profile has specific discontinuity at the hetero-junction in In GaAsP/InP hetero-structures. Comparing experimental diffusion profile with theoretical diffusion equation revealed good agreement between experiment and theory. Investigation results showed that zinc atoms diffused through interstitial-substitutional phenomena with double ionized zinc atom from substrate to neighbor doped InP layer and with single ionized zinc atom from doped In P layer to undoped In Padjacent layer.

**KEYWORD:** InGaAsP/InP, SIMS,LPE, Zinc, Diffusion, single ionized, double ionized.

## 1. INTRODUCTION

Epitaxial layers of the III–V compound semiconductors InGaAsP/InP are vastly used for the manufacturing of optoelectronic devicesas the materials in wavelength of (1.0 μm < λ <1.7 μm ) region [1,2].Diffusion of Zn into InP, InGaAs or InGaAsP, Zn-doped InP epitaxial layers is an important technique for creating p-n junctions in optoelectronic devices. Most common p-type diffusants is zinc that is technologically crucial for III-V compound Semiconductors [3,4]Exact control of the doping in the p-type semiconductor layers is important for fabrication of optoelectronic structures. One of the biggest challenges associated with the use of zinc as a diffused dopant in InP is the control of diffusion, Because impurities in the heavily doped layer are automatically doped into the undoped or lightly doped layer, particularly in the case of the p-type impurities, Zn which have a higher vapor pressure causing to the contamination of the adjacent layers during the melt soaking period [5]. The higher diffusivity of Zn in the crystal also leads to diffusion of the dopants through the layer interfaces during or after epitaxial growth [6].

The diffusion of Zn in semiconductors has been widely studied. It has been generally accepted that Zn diffusion occurs via aninterstitial-substitutional mechanism involving intrinsic point defects [7-9].An interstitial Zn atom diffuses quickly until it is trappedby a group III vacancy and thus incorporated as a substitutional Zn atom, which is much less mobile. The high diffusivity of Zninterstitials was confirmed by the observation of double diffusion front in InP [10,11].It is concluded that diffusion occurs by an interstitial-substitutional mechanism with the interstitial mode being dominant. The charge states of the various species involved in the diffusion are believed to be: (1) interstitial zinc atoms are doubly ionized donors; (2) substitutional zinc atoms are either neutral or singly ionized acceptors[12].Simulated profiles were created with solving of convection – diffusion equation that has been resulted in error function and error function embodied the (m) parameter indicating the zinc ionized status [13].

$$Zn_i^{m+} + V \leftrightarrow Zn_s^- + (m+1)h \qquad (1)$$

Where $Zn_i^{m+}$ is an interstitial donor with positive charge and $Zn_s^-$ is an acceptor, V is a vacancy in lattice of III crystal and h is a cavity.

Most research at impurity diffusion in semiconductors focus on quantity of zinc diffused across the layers and semiconductors which was fabricated by metal-organic vapor phase epitaxy (MOVPE) or metal-organic chemical vapor deposition (MOCVD) methods[11,16,17,18]. In contrast with those studies, at this paper, semiconductor manufactured by LPE method and obtained profile from SIMS apparatus analyzed to determine the compatibility of diffusion theory with experiment.

In this study the behavior of diffused Zn impurities in the InGaAsP/InP hetero-structure grown by LPE has been investigated using SIMS technique to determine concentration and distribution of Zn impurity and mechanism of diffusion. Although diffusion mechanism in semiconductor has been investigated by abovementioned researchers, but fitting the experimental diffusion profile with theoretical diffusion profile is an

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innovation was used in this study. In other word this study performed In order to show the precise mechanism of Zinc diffusion in hetero-structure semiconductor to determine which mechanism is dominant in each adjacent layer, by realizing the behavior of Zinc diffusion through layers, controlling of quality and quantity of Zinc through various layers of semiconductor would be possible during manufacturing.

## 2. EXPERIMENTAL

The test structure is a InGaAsP/ InP epitaxial structure schematically shown in Fig.1. This test structure was grown by the liquid phase epitaxy growth technique. The LPE-grown hetero-structure, on Zn doped InP substrate (C =$1\times10^{18}cm^{-3}$) consists of four layers. The various layer and thicknesses are given in table 1. LPE growth was carried out by using a conventional sliding graphite boat with multi-melt bins. Method for LPE semiconductor growth discussed in [14]. In-depth SIMS analysis of the hetero-structures was performed with CAMECA IMS 6F instrument (Fig 2), in the Plasma Physics Research Center of science and research branch of Islamic Azad University. Samples under investigation were bombarded by Cs+ primary ions. The diffused Zn profiles were measured with secondary ion mass spectrometry (SIMS) using a $Cs^+$ beam and detecting the $CsZn^+$ cluster in a Cameca IMS-6F instrument [15] principle and procedure of SIMS analysis and various sections of SIMS apparatus was illustrated in[19].The detection of Zn atoms was carried out using ZnCs+ positive secondary ions, because it has a higher sensitivity (~$1\times10^{15}$ $cm$–3) than Zn.The impact energy of Cs+ ions were 5.5 KeV, and by this energy, Zn, In and P depth profiles, were obtained (Figure3). Figure 3 shows zinc numeration per second versus sput time through the various layers. Also the depth was calibrated with measuring the craters depth which created by primary ion beam. By conversion and calibration of horizontal axis (sput time) of figure 3 to specimen depth and conversion of vertical axis (quantity of zinc/second) to concentration of zinc, profile of zinc concentration-depth can be obtained, Figure 4.

Table 1:epilayers and thicknesses of specimen

| Layer | Thickness |
|---|---|
| Zn-doped InP ( $p = 4.5 \times 10^{17}\ cm^{-3}$ ) | $d = 1\ \mu m$ |
| undoped InP | $d = 2\ \mu m$ |
| undoped InGaAsP | $d = 0.3\ \mu m$ |
| undoped InGaAs | $d = 1\ \mu m$ |

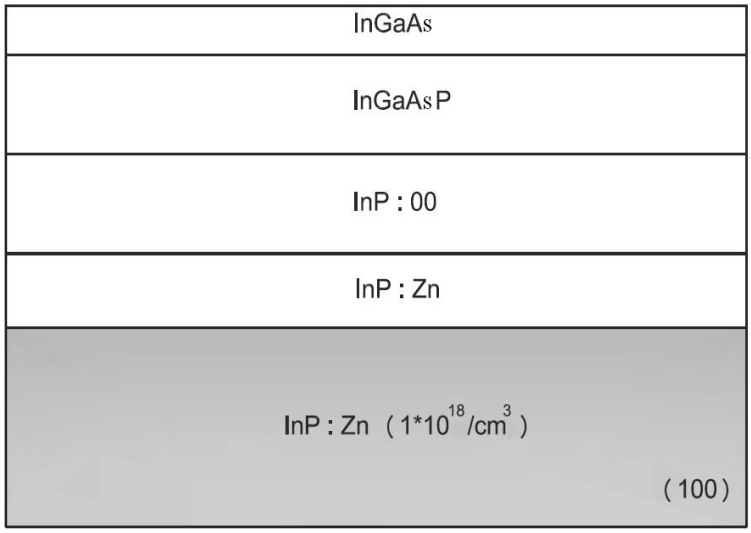


Fig.1 Schematic diagram of InGaAsP/InP test structure.

Fig.2 secondary ion mass spectrometry apparatus (SIMS)

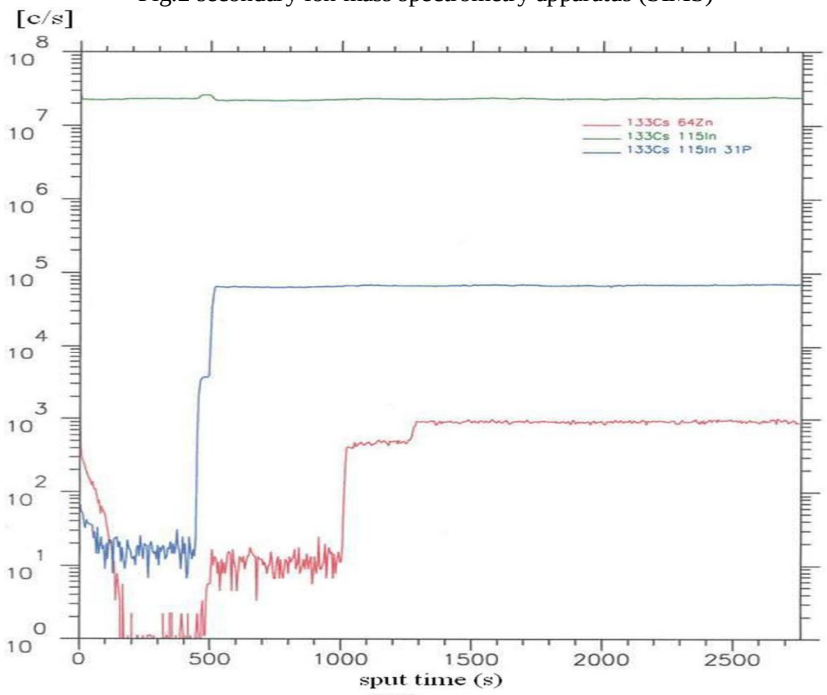


Fig.3zinc numeration per second versus sput time through the various layers

## 2. RESULT AND DISCUSSION

By considering Figure.4 It was found that the Zn doping profile has specific discontinuity at the hetero-junction in InGaAsP/InP hetero-structures. As seen in Figure. 4, Zn concentration in substrate is ($1 \times 10^{18} \frac{atom}{cm^3}$) and distributed uniformly in this layer. Obviously it can be seen that substrate thickness is 4 $\mu m$.zinc concentrations in first layer after substrate is about $6 \times 10^{17} cm^{-3}$ and uniformly distributed. Due to gradient of Zn concentration between this layer and substrate, diffusion from substrate to first layer occurs. In second layer after substrate or InP: 00 layer ($1.3\mu m < x < 2.8\mu m$), Zn concentration is about ($1 \times 10^{16} cm^{-3}$).In third layer; InGaAsP ($1\mu m < x < 1.3\mu m$) and forth layer; InGaAs ($0 < x < 1\mu m$) diffusion tends to zero in compare with calibrated substrate. The first peak in forth layer e.g. ($x < 0.5\ \mu m$)is due to phenomena in SIMS analyzer apparatus that called artifact and can be neglected.

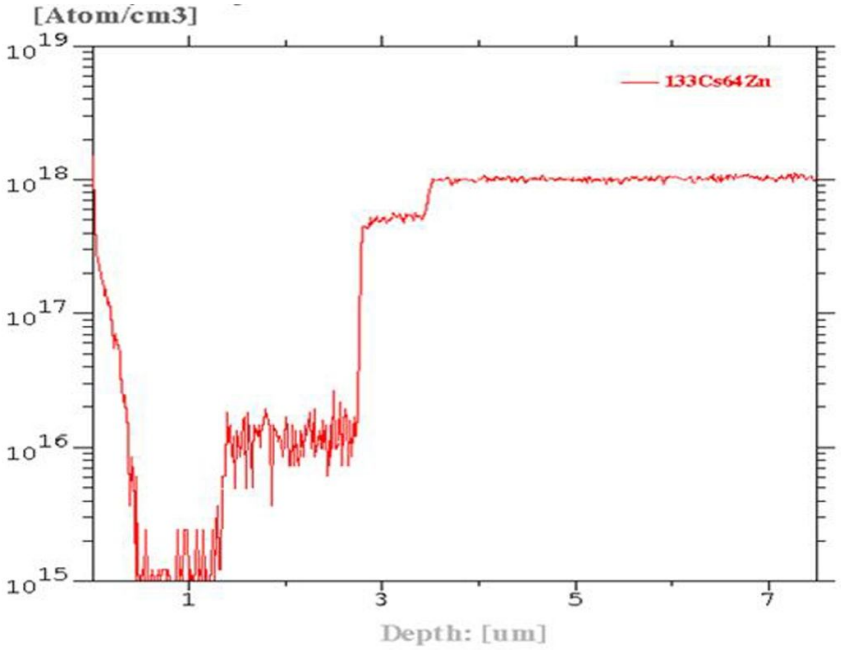


Fig.4zinc diffusion profiles; the zinc do-pant concentration versus diffusion depth

If diffusion interface between substrate and first layer ($3.3\mu m < x < 3.7\mu m$) be magnified and be converted from logarithmic profile to linear profile, by fitting this profile with complementary error function(erfc) using of Math Lab software, it can be seen that two curve overlapped, Figure 5. In this section (m) parameter in error function is equal to 2, e.g. Zn ions diffuse as interstitial doubly ionized status ($Zn^{++}$).Similarly as seen in Fig.4 A significant amount of zinc diffused through first to second layer; InP:00,$1.3\mu m < x < 2.8\mu m$. if section of profile between first and second layer (InP: Zn and Inp:00) be magnified and be shown in linear form, by fitting it with error function curve, good agreement between theory and experiment can be achieved, Figure 6.In this section (m) parameter in error function is equal to 1, e.g. Zn ions diffuse as interstitial single ionized format ($Zn^{+}$).It can be seen that a good agreement is obtained between the experimental results and the Corresponding simulated profiles. Simulated profiles were created with solving of convection –diffusion equation that resulted the error function and error function embodied the (m) parameter indicating the zinc ionized status.

During analysis with SIMS, small craters appear on specimen surface due to sputtering beam impact on surface; Fig.7.as illustrated in Fig.7 crater is in uniform rectangular cubic shape. Scanning Probe Microscopy (SPM) was used to determine crater dimension. Figure.8 shows three dimensional view of a quarter part of crater with depth of $7.64\mu m$.

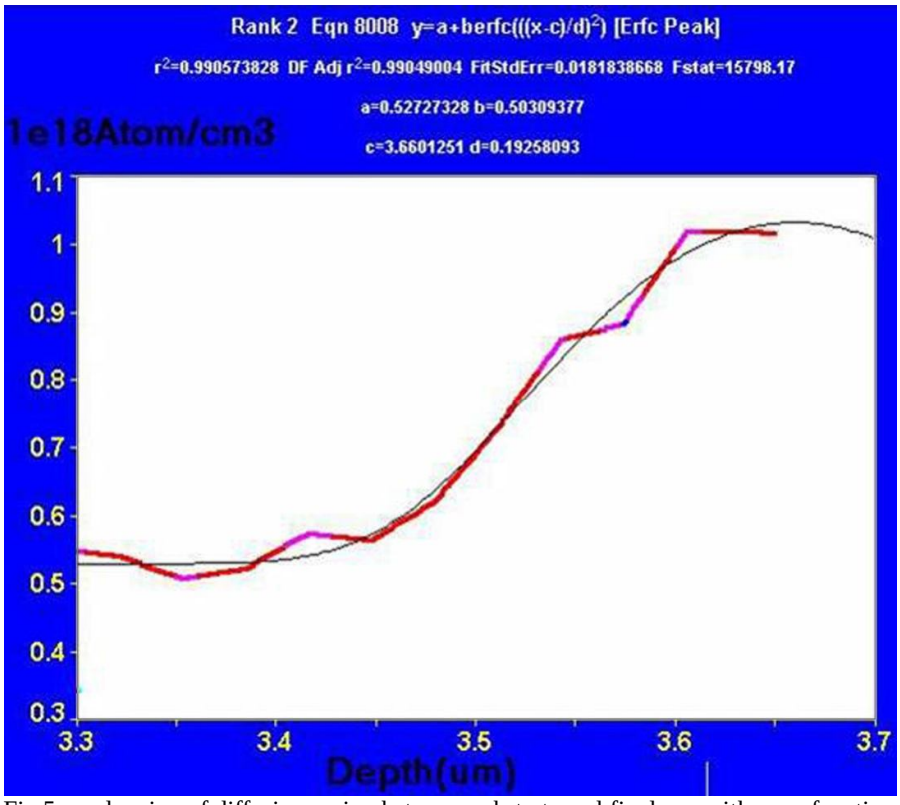


Fig.5 overlapping of diffusion region between substrate and firs layer with error function

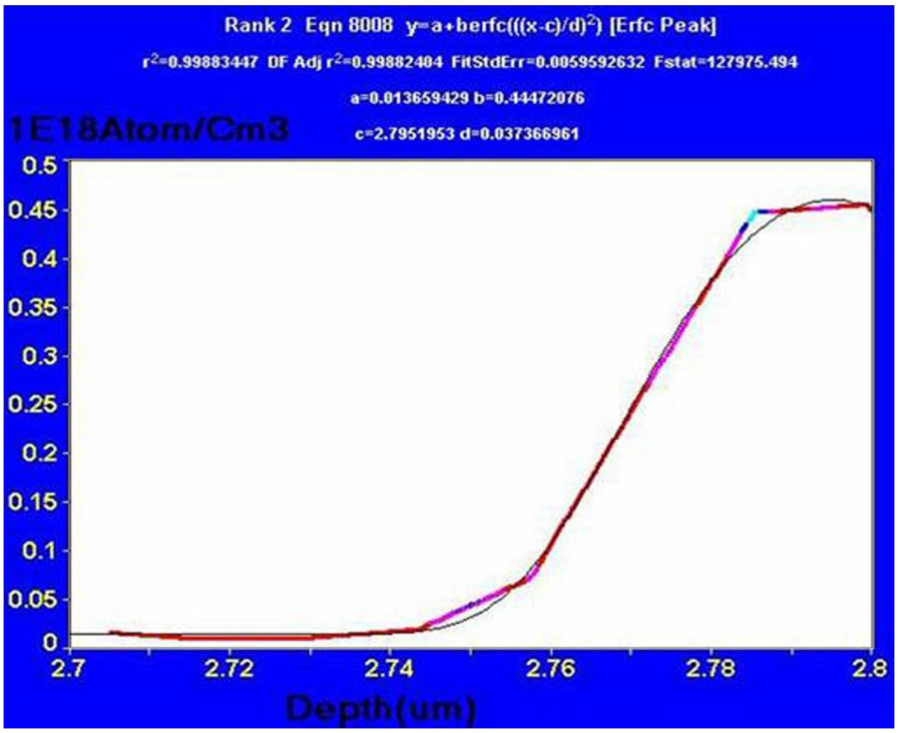


Fig.6overlapping of diffusion region between first and firs second layer with error function

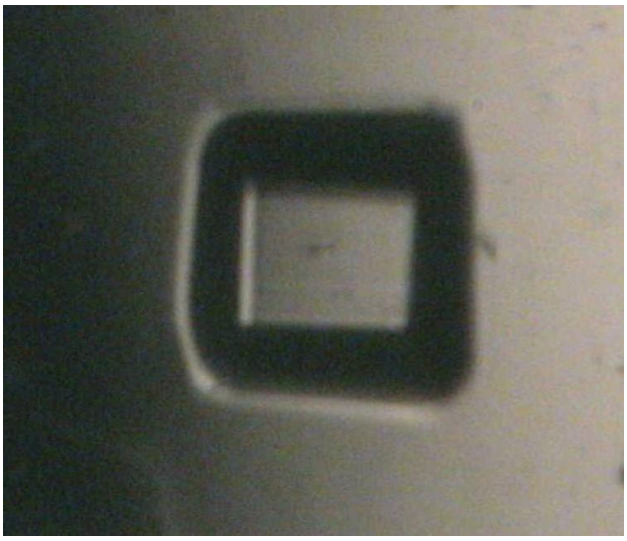

Fig.7 crater region

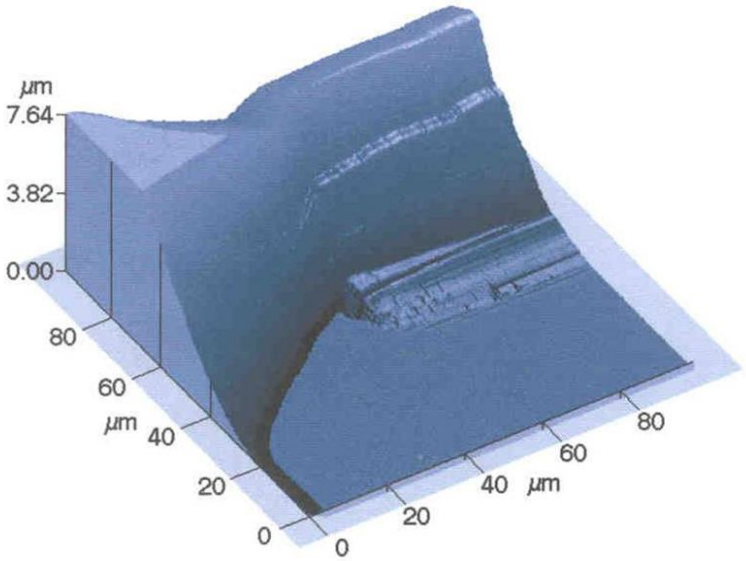


Fig.8 quarter part of crater scanned byScanning probe microscopy (SPM)

## REFERENCES

[1] J. Shibata, I. Nakao, Y. Sasai, S. Kimura, N. Hase and H. Serizawa, Operation principle of the InGaAsP/InP laser transistor, Appl. Phys, Vol.45, pp.191, 1984.

[2] K. Ohnaka, K. Inoue, T. uno, K. Hasegawa. N. Hase and H. Serizawa, a Planar InGaAs PIN/JFET Fiber-Optic Detector, IEEE J. Quantum Electron, Vol.21, pp.1236, 1985

[3] M.G.Astles, F.G.H.Smith and E.W. Williams, Indium phosphide, J.Electrochem. Soc, Vol.120, pp.1750, 1973

[4] E.Kuphal, Preparation and characterization of LPE InP, J.Crystal Growth, Vol.54, pp.117, 1981

[5] I.Umebu and P.N. Robson, Evaporation of Cd from InP growth melts J. crystal Growth, Vol. 53, pp.292, 1981

[6] Wright, P.D.; Chai, Y.G.; Antypas, G.A., InGaPAs-InP double-heterojunction high-radiance LED's , IEEE, Trans. Electron Devices Vol.26, pp.1220, 1979

[7]G.J.Van Gurp, D.L.A.Tjaden, G.M.Fontijn, P.R.Boudewijn, Zinc diffusion in InGaAsP, Journal of Applied Physics, vol.64, no.7, pp.3468-71,1988

[8]G.J.Van Gurp, W.M.Van de Wijgert, G.M.Fontijn, P.J.A.Thijs, Zn diffusion-enhanced disordering and ordering of InGaAsP/InP quantum well structures **,** Journal of Applied Physics, vol.67, no.6, pp. 2919-26, 1990

[9]G.J.Van Gurp, T.Van Dongen, G.M.Fontijn, J.M.Jacobs, D.L.A.Tjaden, Interstitial and substitutional Zn in InP and InGaAsP, Journal of Applied Physics, vol.65, no.2, pp. 553-60,1989

[10] N. Otsuka, M. Kito, M. Ishino, Y. Matsui, F. Toujou, Control of double diffusion front unintentionally penetrated from a Zn doped InP layer during metalorganic vapor phase epitaxy, J. Appl. Phys, vol.84, pp.4239, 1998
[11] K. Kadoiwa, K. Ono, Y. Ohkura, Zn Diffusion Behavior At The Ingaasp/Inp Heterointerface Grown Using Mocvd, J. Crystal Growth,vol.44, pp.297, 2006
[12] L. L. Chang and G. L. Pearson, Diffusion Mechanism of Zn in GaAs and GaP Based on Isoconcentration Diffusion Experiments, J. Appl. Phys,vol.35, pp.1960,1964
[13] B Tuck, Mechanisms of atomic diffusion in the III-V semiconductors, J. Phys. D: Appl. Phys,vol.18,no.4 pp.557, 1985
[14]V.V.Volkov,J.Van Landuyt, K.Marushkin, R.Gijbel, C.Ferauge, M.G.Vasilyev, A.A.Sokolovsky,LPE growth and characterization of InGaAsP/InP heterostructure: IR light-emitting diodes at 1.66 $\mu m$ Application to the remote monitoring of methane gas, Sensors and Actuators Vol.62, pp.624-632, 1997
[15]C. Blaauw, F.R. Shepherd, D. Eger, Secondary ion mass spectrometry and electrical characterization of Zn diffusion in n-type InP, J. Appl. Phys, vol.66, no.2, pp. 605-610, 1989
[16] T. Lin, L. Jiang, X. Wei, G.H. Wang, G.Z. Zhang, X.Y. Ma, Growth of heavily Zn-doped InGaAs at low temperature by LP-MOCVD, Journal of Crystal Growth, vol.261, pp.490–495,2004
[17] Kenji Kurishima, Takashi Kobayashi, and Hiroshi Ito, Control of Zn diffusion in InP/InGaAs heterojunction bipolar transistor structures grown by metalorganic vapor phase epitaxy, J. Appl. Phys. Vol.79,no.8, pp.4017-4023,1996
[18] D. Franke, F.W. Reier, N. Grote, Post-growth Zn diffusion into InGaAs/InP in a LP-MOVPE reactor, Journal of Crystal Growth, vol.195, pp.112-116, 1998
[19] Robert G. Wilson, F. A. Stevie, C. W. Magee, 1989, Secondary ion mass spectrometry:a practical handbook for depth profiling and bulk impurity analysis, A Wiley-Interscience publication