CHARACTERISTIC OF $GaAs_{1-x}Sb_x$ LAYERS GROWN BY MOCVD ON SI-GaAs SUBSTRATE USING TDMAAs AND TDMASb

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ABSTRACT

The $GaAs_{1-x}Sb_x$ layers have been grown by metalorganic chemical vapor deposition (MOCVD) on semi insulating gallium arsenide (SI-GaAs) substrate using a new group V source, trisdimethylaminoarsenic (TDMAAs) and tridimethylaminoantimony (TDMASb), and they are characterized by using X-ray diffraction (XRD), Scanning Electron Microscope (SEM), and Hall effect measurement. From the XRD pattern we determined the Sb solid-phase composition using Vegard's law equation, from the SEM image, we examined the surface morphologies of the epilayers, and from Hall efect measurements using the Van der Pauw geometry, we described the electrical properties of epilayers. The results suggest that the input V/III ratio and growth temperature are critical factors for obtaining compositions inside the miscibility gap without phase separation. For a V/III ratio of unity, the Sb distribution coefficient is nearly unity. Sb incorporation into the solid is reduced with increasing V/III ratio for value of > 1. The quality of surface morphology of epilayer strongly depends on V/III ratio and growth temperature. Good surface morphologies were obtained when the V/III ratio nearly unity and low growth temperature. The epilayers were p-type semiconductors with background carrier concentrations of approximately 10^{17} cm^{-3}. This carrier concentration decreases when the V/III ratio improved.

Keywords : Characterization, $GaAs_{1-x}Sb_x$ layer, MOCVD, TDMAAs, TDMASb

1. INTRODUCTION

Sb-containing alloys are attractive materials for long range optical communications, photonic devices operating at infrared wavelengths, and ultra-high speed electronic switching devices. For example, a 1.3 μm long wavelength GaAsSb type II quantum well lasers on GaAs substrate, high cutoff frequencies (300 GHz) and breakdown voltage InP/GaAsSb/InP double heterojunction bipolar transistor, and low turn-on voltage GaAs heterojunction bipolar transistors with a pseudomorphic GaAsSb base [1].

GaAsSb is known to have very large miscibility gaps with critical temperatures estimated from reguler solution model calculations to be 760°C [2]. Alloys with compositions inside the miscibility gap are virtually impossible to grow by the liquid-phase epitaxy (LPE) technique [3]. Since the first organometalic vapor-phase epitaxial (OMPVE) growth of GaAsSb was reported by Manasevit [4], there have been continuous efforts to obtain alloy compositions inside the miscibility gap. Cooper et al. [5] reported the OMVPE growth of GaAsSb with compositions of $0 < x < 0.26$ and $0.64 < x < 1$. Shin et al. [6] reported MOCVD growth of GaAsSb in the range of the miscibility gap on GaSb and InAs substrate. Subsequently, Stringfellow and Cherng demonstrated the successful growth of GaAsSb and GaInAsSb with compositions throughout the miscibility gaps [7].

There has been rapid progress in the development of new organometallic precursor to replace the conventional sources, especially the group V hydrides that are highly toxic. Trisdimethylaminoarsenic (TDMAAs) has been reported [8] to be much less hazardous than AsH_3. It has a decomposition temperature, T_{50}, of approximately 340^{o}C [9], much less than that for arsine (T_{50} ~ 600^{o}C). This source also has a convenient vapor pressure for MOCVD growth.

Although trimethylantimony (TMSb) has been successfully used to grow several Sb-containing compounds and alloys by MOCVD, it is not convenient for low-temperature growth due to the low decomposition rate at temperatures of 500^{o}C and below [10]. In additions, high carbon contaminations levels are reported due to the CH_3 radicals produced [11]. In this regard, significant efforts have been devoted to developing new Sb precursors during the last several years. Trisdimethylaminoantimony (TDMASb)[12] has been used for the growth of Sb containing compounds by MOCVD in the temperature ranges 325-650^{o}C. The layer grown using this precursor showed good crystalline quality with no serious impurity contamination.

TDMAAs and TDMASb releases As and Sb at low temperature (350-450^{o}C) [13], So with using these metalorganic source one can decrease the growth temperature. With the lower growth temperatures one can minimize both interdiffusion between layers and incorporporation of native defects foreign impurities during growth [12]. Decomposition products of these precursors are As or Sb, reactive amino groups like $N(CH_3)_2$, aziridine ($HN(CH_2)_2$) and atomic hydrogen [8]. Highly reactive amino groups react with other reactive hydrocarbons (from i.e. TMGa, or TEGa) forming volatile molecules and significantly reduce the amount of incorporated carbon impurities in GaAsSb layer [14].

To the best of our knowledge, there are no reports on the growth of GaAsSb using group V sources TDMASb and TDMAAs. In this paper, the MOCVD growth of metastable GaAsSb alloy using these sources with the conventional group III sources, TMGa is reported. Good morphology layers with compositions inside the region of solid immiscibility were obtained.

2. EXPERIMENTAL PROCEDURE

The GaAsSb epitaxial layers were grown using TMGa as the Ga sources in an low pressure (~50 torr) vertical MOCVD reactor. Palladium-diffused hydrogen was the carrier gas for both As, Sb and Ga Sources. Separate stainless-steel tubing was used for the group III and V reactans in order to minimize possible parasitic reactions. TMGa, TDMAAs and TDMASb held in temperature-controlled bubblers at -10, 25, and 28^{o}C, respectively, were the precursors. Exactly (100) semi-insulating GaAs substrates were used. This substrate has a convenient electrical property for Hall effect measurements. The V/III ratio was varied between 1 and 5. The growth temperature was adjusted to explore the condition for optimum morphology at each V/III ratio (between 500 and 600^{o}C). The composition of the vapor phase input was adjusted with equation X_v = [TDMASb]/([TDMAAs + TDMASb])

The substrates were first degreased by boiling in trichloroethylene (TCE), then cleaned by ultrasonic vibration in acetone and subsequently methanol for 5 minutes, then chemically etched using a mixed solution of sulphuric acid, hydrogen peroxide, and deionized water (H_2SO_4 : H_2O_2 : DI-Water = 3 : 1 : 1) for 2 min. Finally the substrates were rinsed in DI-Water and dried quickly with a nitrogen jet. They were then immediately loaded into the reactor. In order to eliminate carbon-oxygen bonding onto the substrate was performed thermal cleaning (650^{o}C) for 15 min. After the temperature was raised to the final growth temperature, the TMGa, TDMAAs, and TDMASb were introduced into the growth chamber.

The Sb-solid composition onto GaAsSb layers was determined using X-ray diffraction assuming Vegard’s law. The surface morphologies of the epilayers were examined using Scanning Electron Microscope (SEM). Room-temperature Hall effect measurements were performed using the Van der Pauw geometry. Gold (Au) was used to form the four point ohmic contact, which were annealed under nitrogen at 300^{o}C for 2 min. The magnetic field was varied between 3.2 and 355 mT.

3. RESULTS AND DISCUSSION

Similar to the results of Cerng [7] using AsH_3 (or TMAs) and TMSb, and Shin [6] using TBAs and TBDMSb, the input V/III ratio and growth temperature are critical factors for obtaining compositions inside the miscibility gap without phase separation when using TDMAAs and TDMASb. Using a V/III ratio of unity, a nearly random mixture of As and Sb atoms can apparently be trapped in the solid by the next layer of GaAsSb deposited the atoms simply do not have time to rearrange into a two phase mixture before they are immobilized by being covered over [2].

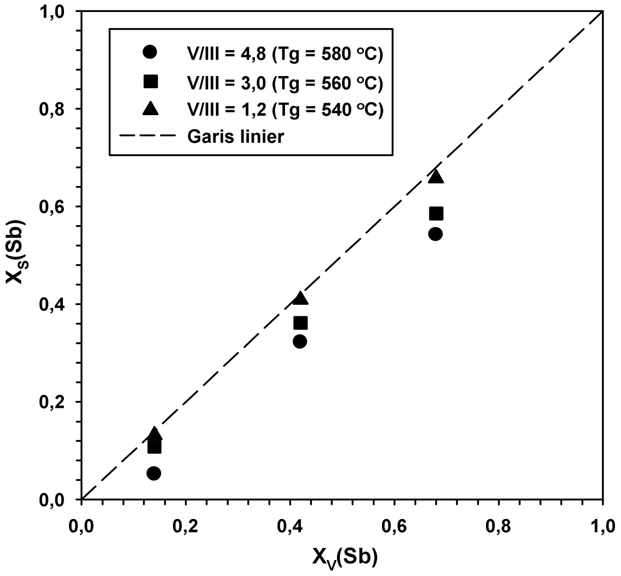


Fig. 1. Sb distribution coefficient for $GaAs_{1-x}Sb_x$ layers grown on GaAs substrate

Fig. 1 shows the results obtained for the solid-phase composition against the vapor-phase composition. For values of input V/III ratio approximately equal to unity, the Sb distribution coefficient is nearly unity due to the all As and Sb atoms reaching the interface are incorporated. But, using a V/III ratio that much greater than unity, causes the Sb atom is rejected from the solid due to the greater thermodynamic driving force for GaAs formation so Sb distribution coefficient smaller than unity [5].

Fig. 2 shows the typical surface morphologies of several $GaAs_{0.68}Sb_{0.32}$ layers grown on SI-GaAs substrate with various V/III ratios correspond to its optimum growth temperature. In the range of the V/III ratio used in this study, the surface morphology is improved by decreasing the V/III ratio corresponding with decreasing growth temperature. The surface morphology of $GaAs_{0.68}Sb_{0.32}$ layer grown at low growth temperature is mirror-like to naked eye. Good surface morphologies at low V/III ratios due to the effective pyrolisis of TDMASb and TDMAAs.

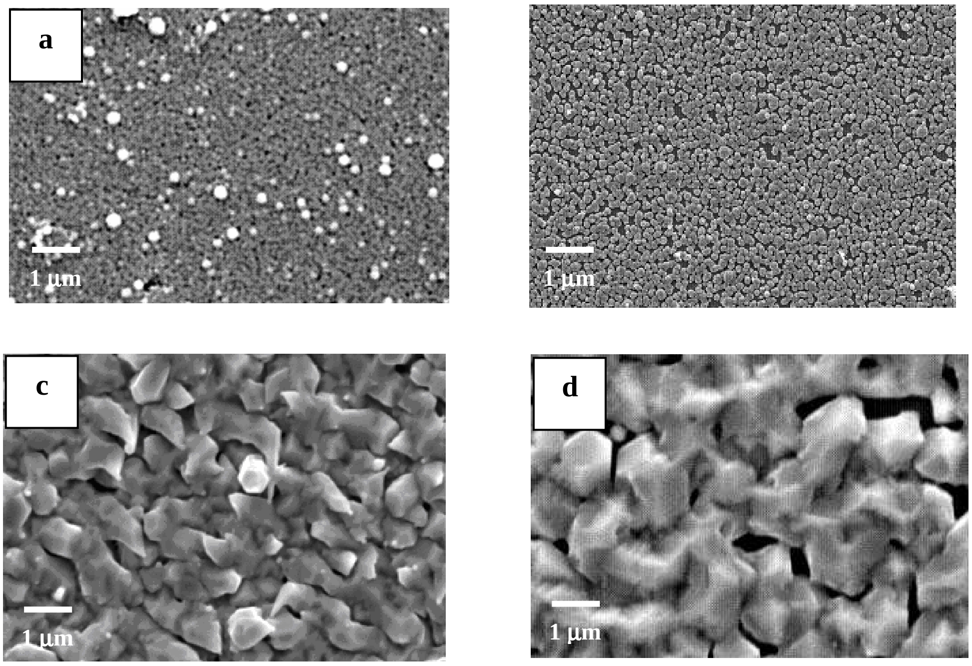
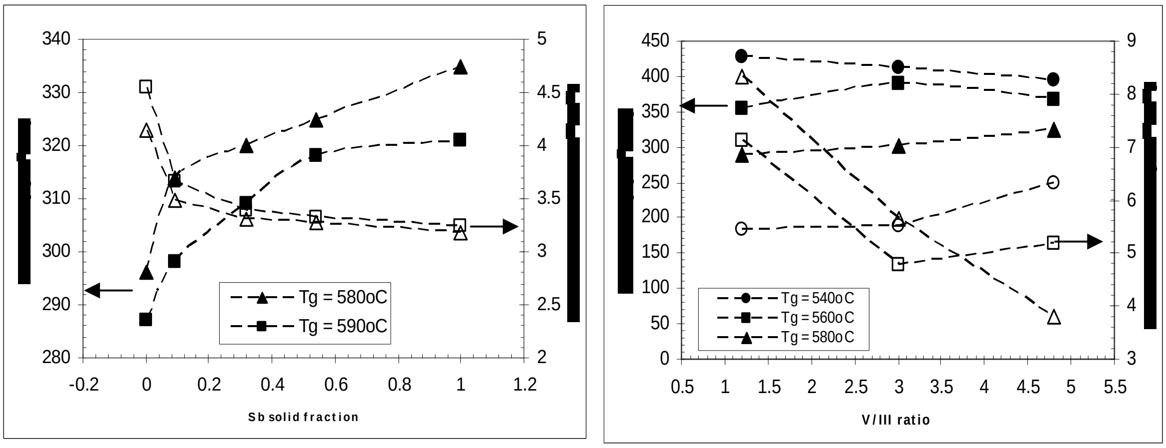


Fig. 2. Typical surface morphologies of GaAsSb layers grown on SI-GaAs substrate (x_v = 0,42) with the values of V/III ratio and growth temperature of about (a) V/III = 1.2, Tg = 540°C, (b) V/III = 3.0, Tg = 560°C, (c) V/III = 4.8, Tg = 580°C, and (d) V/III = 4.8, Tg = 590°C

Unintentionally doped GaAsSb layers grown using TDMASb and TDMAAs are p-type with a background concentration of approximately $10^{17}cm^{-3}$. The p-type doping is probably caused by either residual impurities in the source or native defects existing in the epitaxial layer. Room temperature mobility and carrier concentration for undoped GaAsSb grown at 580 and 590°C and ratio V/III = 4.8 as a function of Sb content are shown in fig. 3a. From the figure, we can look that when the Sb content into GaAsSb layer is increase, the mobility increases and the carrier concentration decreases. Since the GaAs antisite defect (Ga atoms in As sites) is presumed responsible for the acceptors in GaAs, it is suggested that Sb more readily occupies Ga sites and that the incorporation of carbon is reduced by introducing Sb into GaAs growth, this further decreases the acceptor concentrations. The RT mobilities for the growth temperature of 580°C and 590°C are similar, but the mobility is higher for layers grown at 580°C.

The effect of the V/III ratio on the materials electrical transport properties was also investigated. Pyrolisis of metalorganic source in the trimethyl (TM) form can result the methyl radicals which can adsorb onto surface substrate, if the V group species is less, decomposition of this radicals will result the carbene species ($=CH_2$) which have strongly bond onto film , as the result carbon will incorporate onto film on which act as p-type doping. To reduce this carbon contamination can be performed by increasing V group species [14]. The high V/III ratio can affect to decrease in the number of V group vacancies on which C can be incorporated, so the carbon concentration decreases, this further decreases the acceptor concentration. But, for any V/III ratio be any correspond optimum growth temperature. The lower and higher V/III ratios than its optimum value correspond to any growth temperature caused surface degradation of the epilayers, leading to a high defect density, the hole concentration further increases. It was found that the electrical mobility is critically dependent on the V/III ratio as shown in Figure 3b.



a

b

Fig. 3. Typical electrical properties as a function of growth temperature for GaAsSb (x_v = 0,42) layers grown on SI-GaAs

4. CONCLUSIONS

The new group V precursor TDMAAs and TDMASb have been used to grow GaAsSb epitaxial layers with compositions inside the miscibility gap. The efficient decomposition of the new group V precursors at low temperatures facilitates low-temperature growth. The input V/III ratio and the growth temperature are found to be the crucial factors for obtaining good quality layers. The distribution coefficient of Sb is about unity for GaAsSb layers on GaAs substrate when the V/III ratio is approximately unity. Good surface morphologies were obtained when the V/III ratio nearly unity. This surface morphology is degrade when the V/III ratio is increased for value of >1. Undoped GaAsSb layers are p-type semiconductor with hole concentrations of about 10^{17} cm^{-3}.

Acknowledgement

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REFERENCES

[1]. S. D. Wu L, W. Guo, W. X. Wang, Z. H. Li, X. Z. Shang, H. Y Hu, Q. Huang, J. M. Zhou, Journal of Crystal Growth, 2004, **270,** 359-363

[2]. G.B Stringfellow, , "Metalorganic Vapor Phase Epitaxy : Theory and Practice", 2nd edition, , 1999, San Diego, California, Academic Press

[3]. J. Passeto, G. B. Stringfellow, J. Crystal Growth, 1983, 62, 1.

[4]. H. M. Manasevit, J. Crystal Growth, 1981, 55, 1.

[5] C. B. Cooper, R. R. Saxena, M. J. Lodowise, J. Electron. Mater. 1982, 11, 1001

[6]. J. SHIN, T. C. HSU, G. B. STRINGFELLOW, Journal of Crystal Growth, 1997, **179**, 1-9

[7] M. J. Cerng, G. B. Stringfellow, D. W. Kisker, A. K. Srivastava, J. L. Zyskind, Appl. Phys. Lett., 1986, 48, 419.

[8] D. Marx, H. Asahi, X. F. Liu, M. Higashiwaki, A. B. Villaflor, K. Miki, K. Yamamoto, S. Gonda, S. Shimomura, S. Hiyamizu, J. Crystal Growth, 1995, 150, 551-556.

[9] A. C. JONES, P. O'BRIEN, CVD of Compound Semiconductors, 1997, Weinheim, Germany, VCH

[10] C. A. Larsen, S. H. Li, G. B. Stringfellow, Chem. Meter., 1991, 3, 39.

[11] T. F. Kuech, E. Verhoff, J. Crystal Growth, 1984, 68, 48.

[12] J. Shin, A. Verma, G. B. Stringfellow, R. W. Gedridge J.r., J. Crysral Growth, 1994, 143, 15.

[13] K. Yamamoto, H. Aasahi, T.Hayasahi, K. Hidaka, S. Gonda, Journal of Crystal Growth,1997, 175/176, 1236-1241.

[14] C. R., Abernathy, S. J.Pearton, , F. A Baiocchi,., T., Ambrose, A. S Jordan, D. A. Bohling, G. T. Muhr, J. Crystal Growth, 1991, 110, 547.

KARAKTERISTIK LAPISAN $GaAs_{1-x}Sb_x$ YANG DITUMBUHKAAN DENGAN MOCVD DI ATAS SUBSTRAT SI-GaAs MENGGUNAKAN TDMAAs AND TDMASb

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ABSTRAK

Lapisan tipis $GaAs_{1-x}Sb_x$ telah berhasil ditumbuhkan dengan metode *metalorganic chemical vapor deposition* (MOCVD) di atas substrat *semi insulating gallium arsenide* (SI-GaAs) menggunakan sumber-sumber golongan V baru yaitu *trisdimethylaminoarsenic* (TDMAAs) dan *tridimethylaminoantimony* (TDMASb). Film GaAsSb yang ditumbuhkan selanjutnya dikarakterisasi dengan menggunakan sistem *X-ray diffractometer* (XRD), *Scanning Electron Microscope* (SEM), dan pengukuran efek Hall. Berdasarkan pola XRD komposisi fase padat unsur Sb dalam lapisan dapat ditentukan dengan menggunakan persamaan Vegard, dari hasil citra SEM dapat analisis morfologi permukaan lapisan, dan dari pengukuran efek Hall menggunakan geometri Van der Pauw, dapat dideskripsikan sifat-sifat listrik lapisan. Hasil karakterisasi menunjukkan bahwa rasio input V/III dan temperatur penumbuhan merupakan faktor-faktor penting untuk dapat menumbuhkan lapisan dengan konposisi dalam rentang miscibility nya tanpa pemisahan fase. Untuk rasio input V/III yang mendekati satu, nilai koefisien distribusi Sb juga mendekati satu. inkorporasi Sb ke dalam padatan GaAsSb berkurang terhadap peningkatan rasio V/III untuk nilai-nilai di atas 1. Kualitas morfologi permukaan film juga sangat bergantung pada rasio V/III dan temperatur penumbuhan. Morfologi permukaan yang baik diperoleh ketika penumbuhan dilakukan dengan rasio V/III mendekati satu dan temperatur penumbuhan rendah. Lapisan GaAsSb yang ditumbuhkan merupakn semikonduktor bertipe-p dengan konsentrasi pembawa muatan berorde 10^{17} cm^{-3}. Konsentrasi pembawa muatan ini menurun ketika rasio V/III ditingkatkan.

Kata kunci : Sifat,Lapisan $GaAs_{1-x}Sb_x$, MOCVD, TDMAAs, TDMASb

2. PENDAHULUAN

Aloy-aloy yang mengandung unsur Sb merupakan material-material yang sangat atraktif untuk diaplikasikan pada sistem komunikasi serat optik benjangkauan jauh, divais-divais fotonik yang beroperasi pada panjang gelombang inframerah, dan divais-divais elektronik berkecapatan ultra tinggi. Sebagai contoh, dioda laser GaAsSb berstruktur sumur kuantum tipe II di atas substrat GaAs yang mampu memancarkan laser dengan panjang gelombang 1.3 μm, transistor bipolar *heterojunction* ganda InP/GaAsSb/InP yang memiliki frekuensi cutoff (300 GHz) dan tegangan *breakdown* tinggi, dan transistor bipolar *heterojunction* GaAs dengan basis GaAsSb *pseudomorphic* [1].

GaAsSb dikenal sebagai material yang memiliki rentang *miscibility* sangat lebar dengan temperature kritis berdasarkan estimasi perhitungan dengan model solusi regular sekitar 760°C [2]. Aloy-aloy dengan komposisi dalam rentang *miscibility* nya sangat tidak mungkin untuk ditumbuhkan dengan metode *liquid-phase epitaxy* (LPE) [3]. Sejak dilaporkannya keberhasilan penumbuhan GaAsSb dengan metode organometalic vapor-phase epitaxial (OMPVE) untuk yang pertama kali oleh Manasevit [4], there have been continuous efforts to obtain alloy compositions inside the miscibility gap. Cooper dkk. [5] melaporkan keberhasilannya menumbuhkan GaAsSb dengan metode OMVPE dengan komposisi Sb dalam rentang $0 < x < 0.26$ dan $0.64 < x < 1$. Shin dkk. [6] melaporkan keberhasilannya menumbuhkan GaAsSb dengan MOCVD dalam rentang komposisi *miscibility* di atas substrat GaSb and InAs. Sementara, Stringfellow dan Cherng mendemonstrasikan keberhasilannya menumbuhkan GaAsSb dan GaInAsSb dengan komposisi dalam rentang *miscibility* [7].

Terjadi kemajuan yang begitu pesat dalam pengembangan sumber-sumber metalorganik baru untuk mengganti sumber-sumber konvensional, terutama hidrida-hidrida golongan V yang sangat beracun. *Trisdimethylaminoarsenic* (TDMAAs) dilaporkan [8] to be much less hazardous dibanding AsH_3. Bahan ini memiliki temperature dekomposisi, T_{50}, sekitar 340°C [9], jauh lebih rendah disbanding temperature dekomposisi arsine ($T_{50} \sim 600$°C). Sumber ini juga memiliki tekanan uap yang cocok untuk penumbuhan dengan MOCVD.

Meskipun trimethylantimony (TMSb) telah sukses dipergunakan untuk menumbuhkan beberapa material semikonduktor paduan dan alloy yang mengandung unsure Sb dengan MOCVD, tetapi bahan ini tidak cocok untuk penumbuhan pada temperature rendah, dikarenakan memiliki laju dekomposisi yang rendah pada temperatur 500°C dan dibawahnya [10]. Ditambah lagi, tingkat kontaminasi karbon yang tinggi dari penggunaan bahan ini telah dilaporkan akibat dihasilkannya radikal-radikal CH_3 [11]. Dengan alasan-alasan tersebut, significant efforts have been devoted to developing new Sb precursors during the last several years. *Trisdimethylaminoantimony* (TDMASb)[12] dilaporkan telah sukses dipergunakan untuk menumbuhkan semikonduktor paduan yang mengandung unsur Sb dengan MOCVD dalam rentang temperatur 325-650°C. Lapisan-lapisan semikonduktor yang ditumbuhkan dengan sumber ini menunjukkan kualitas kristal yang baik dengan derajat kontaminasi ketakmurnian yang rendah.

TDMAAs dan TDMASb melepaskan atom-atom As dan Sb pada temperature rendah (350-450°C) [13], Sehingga dengan menggunakan sumber-sumber metalorganik ini temperature deposisi dapat diturunkan. Dengan temperatur penumbuhan yang rendah, terjadinya interdifusi antar lapisan dan inkorporasi natif defek selama penumbuhan dapat direduksi [12]. Hasil dekomposisi dari precursor-prekursor ini adalah As dan Sb, kelompok amino reaktif seperti $N(CH_3)_2$, *aziridine* ($HN(CH_2)_2$) dan atom-atom hidrogen [8]. Sebagian besar kelompok-kelompok amino reaktif ini dengan hidrokarbon-hirdrokarbon reaktif lainnya (dari TMGa atau TEGa) membentuk molekul-molekul volatile dan secara signifikan mereduksi kandungan ketakmurnian karbon yang terinkorporasi ke dalam lapisan GaAsSb [14].

Sejauh pengetahuan kami, hingga saat ini belum dijumpai laporan tentang penumbuhan GaAsSb dengan menggunakan sumber-sumber golongan V TDMASb dan TDMAAs secara bersamaan. Dalam paper ini, dibahas tentang penumbuhan aloy GaAsSb dengan menggunakan sumber-sumber ini dengan sumber golongan III konvensional, TMGa. Lapisan GaAsSb dengan morfologi permukaan baik dengan komposisi di dalam rentang miscibility berhasil diperoleh.

2. PROSEDUR PENELITIAN

Lapisan epitaksi GaAsSb ditumbuhkan dengan menggunakan reaktor MOCVD vertical bertekanan rendah (~50 torr) dengan menggunakan TMGa sebagai sumber Ga. Palladium-diffused hydrogen was the carrier gas for both As, Sb and Ga Sources. Pipa-pipa stainless-steel yang terpisah digunakan untuk mengalirkan reaktan-reaktan golongan III dan V untuk meminimalkan kemungkinan terjadinya reaksi parasitik. TMGa, TDMAAs dan TDMASb disimpan pada bubbler-bubbler yang temperaturnya dijaga pada -10, 25, and 28°C, secara berturut-turut, sebagai precursor-prekursor. Kristal semi-insulating GaAs (100) telah digunakan sebagai substrat. Substrat ini sangat cocok untuk pengukuran sifat listrik lapisan dengan metode efek Hall. Rasio input V/III divariasikan antara 1 dan 5. Temperatur penumbuhan di atur untuk mendapatkan kondisi optimum untuk mendapatkan morfologi optimum pada setiap rasio V/III (antara 500 dan 600°C). Komposisi masukan fase uap telah diatur dengan menggunakan persamaan X_v = [TDMASb]/([TDMAAs + TDMASb])

Substrat dibersihkan The substrates were first degreased by boiling in *trichloroethylene* (TCE), kemudian direndam dalam by ultrasonic vibration in aseton dan metanol berturut-turut selama 5 menit, lalu dietsa secara kimiawi dengan menggunakan larutan yang merupakan campuran dari asam sulfat, hidrogen feroksida, dan *deionized water* ($H_2SO_4 : H_2O_2$: DI-Water = 3 : 1 : 1) untuk 2 menit. Akhirnya substrat dibilas dengan DI-Water dan dikeringkan dengan cara menyemprotkan gas nitrogen. Selanjutnya substrat dimasukkan ke dalam reaktor dengan segera. Untuk mengeliminasi ikatan karbon –oksigen pada permukaan substrat, dilakukan *thermal cleaning* (650°C) selama 15 menit. After the temperature was raised to the final growth temperature, the TMGa, TDMAAs, and TDMASb were introduced into the growth chamber.

The Sb-solid composition onto GaAsSb layers was determined using X-ray diffraction assuming Vegard's law. The surface morphologies of the epilayers were examined using Scanning Electron Microscope (SEM). Room-temperature Hall effect measurements were performed using the Van der Pauw geometry. Gold (Au) was used to form the four point ohmic contact, which were annealed under nitrogen at 300°C for 2 min. The magnetic field was varied between 3.2 and 355 mT.

3. HASIL DAN DISKUSI

Similar to the results of Cerng [7] using AsH_3 (or TMAs) and TMSb, and Shin [6] using TBAs and TBDMSb, the input V/III ratio and growth temperature are critical factors for obtaining compositions inside the miscibility gap without phase separation when using TDMAAs and TDMASb. Using a V/III ratio of unity, a nearly random mixture of As and Sb atoms can apparently be trapped in the solid by the next layer of GaAsSb deposited the atoms simply do not have time to rearrange into a two phase mixture before they are immobilized by being covered over [2].

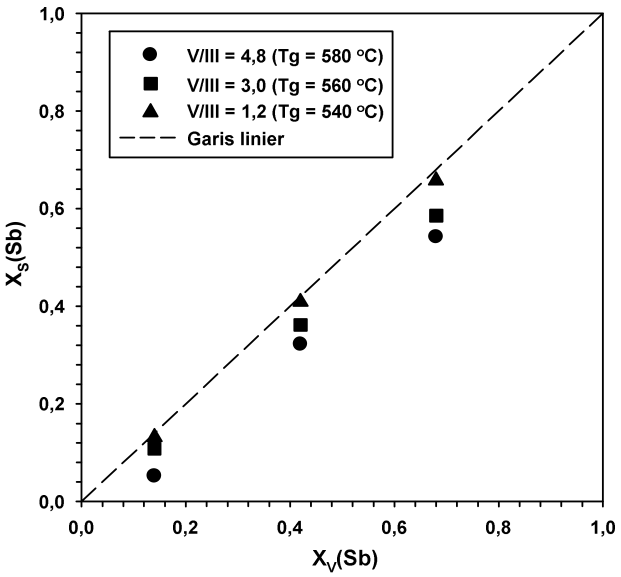

Fig. 1. Koefisien distribusi Sb untuk film tipis $GaAs_{1-x}Sb_x$ yang ditumbuhkan di atas substrat SI-GaAs

Fig. 1 shows the results obtained for the solid-phase composition against the vapor-phase composition. For values of input V/III ratio approximately equal to unity, the Sb distribution coefficient is nearly unity due to the all As and Sb atoms reaching the interface are incorporated. But, using a V/III ratio that much greater than unity, causes the Sb atom is rejected from the solid due to the greater thermodynamic driving force for GaAs formation so Sb distribution coefficient smaller than unity [5].

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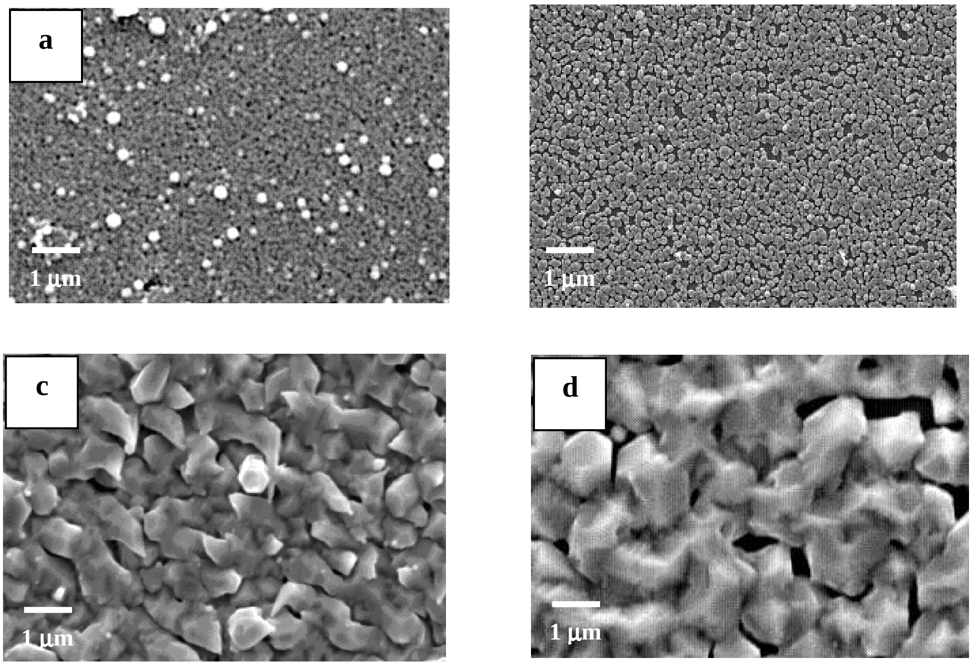
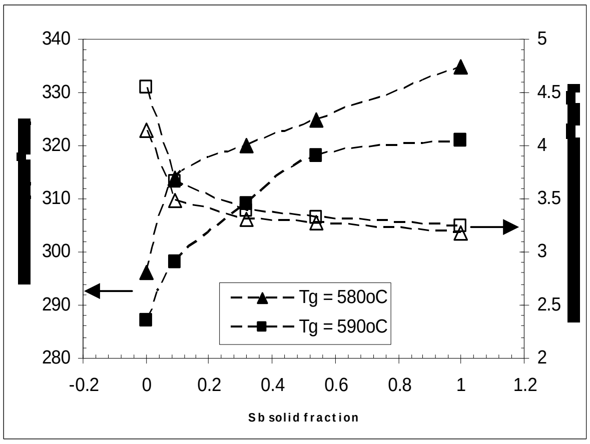
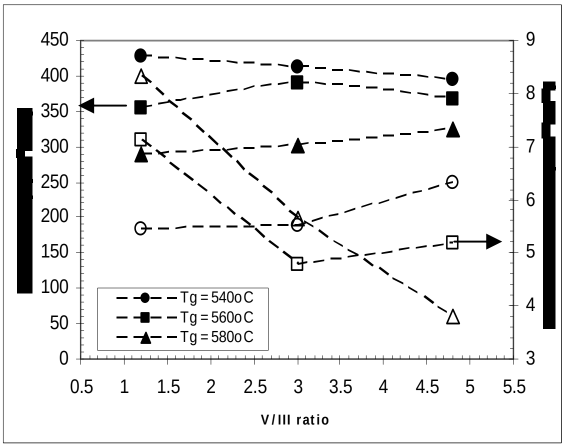


Gambar. 2. Gambaran morfologi permukaan film GaAsSb yang ditumbuhkan di atas substrat SI-GaAs (x_v = 0,42) dengan nilai-nilai rasio V/III dan temperatur penumbuhan sekitar : (a) V/III = 1.2, Tg = 540^{o}C, (b) V/III = 3.0, Tg = 560^{o}C, (c) V/III = 4.8, Tg = 580^{o}C, dan (d) V/III = 4.8, Tg = 590^{o}C

Unintentionally doped GaAsSb layers grown using TDMASb and TDMAAs are p-type with a background concentration of approximately $10^{17}cm^{-3}$. The p-type doping is probably caused by either residual impurities in the source or native defects existing in the epitaxial layer. Room temperature mobility and carrier concentration for undoped GaAsSb grown at 580 and 590^{o}C and ratio V/III = 4.8 as a function of Sb content are shown in fig. 3a. From the figure, we can look that when the Sb content into GaAsSb layer is increase, the mobility increases and the carrier concentration decreases. Since the GaAs antisite defect (Ga atoms in As sites) is presumed responsible for the acceptors in GaAs, it is suggested that Sb more readily occupies Ga sites and that the incorporation of carbon is reduced by introducing Sb into GaAs growth, this further decreases the acceptor concentrations. The RT mobilities for the growth temperature of 580^{o}C and 590^{o}C are similar, but the mobility is higher for layers grown at 580^{o}C.

The effect of the V/III ratio on the materials electrical transport properties was also investigated. Pyrolisis of metalorganic source in the trimethyl (TM) form can result the methyl radicals which can adsorb onto surface substrate, if the V group species is less, decomposition of this radicals will result the carbene species (=CH_2) which have strongly bond onto film , as the result carbon will incorporate onto film on which act as p-type doping. To reduce this carbon contamination can be performed by increasing V group species [14]. The high V/III ratio can affect to decrease in the number of V group vacancies on which C can be incorporated, so the carbon concentration decreases, this further decreases the acceptor concentration. But, for any V/III ratio be any correspond optimum growth temperature. The lower and higher V/III ratios than its optimum value correspond to any growth temperature caused surface degradation of the epilayers, leading to a high defect density, the hole concentration further increases. It was found that the electrical mobility is critically dependent on the V/III ratio as shown in Figure 3b.





a b

Gambar 3. Gambaran sifat listrik sebagai fungsi temperatur penumbuhan untuk film tipis GaAsSb (x_v = 0,42) yang ditumbuhkan di atas SI-GaAs

4. KESIMPULAN

The new group V precursor TDMAAs and TDMASb have been used to grow GaAsSb epitaxial layers with compositions inside the miscibility gap. The efficient decomposition of the new group V precursors at low temperatures facilitates low-temperature growth. The input V/III ratio and the growth temperature are found to be the crucial factors for obtaining good quality layers. The distribution coefficient of Sb is about unity for GaAsSb layers on GaAs substrate when the V/III ratio is approximately unity. Good surface morphologies were obtained when the V/III ratio nearly unity. This surface morphology is degrade when the V/III ratio is increased for value of >1. Undoped GaAsSb layers are p-type semiconductor with hole concentrations of about 10^{17} cm^{-3}.

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REFERENCES

[1]. S. D. Wu L, W. Guo, W. X. Wang, Z. H. Li, X. Z. Shang, H. Y Hu, Q. Huang, J. M. Zhou, Journal of Crystal Growth, 2004, **270,** 359-363

[2]. G.B Stringfellow, , "Metalorganic Vapor Phase Epitaxy : Theory and Practice", 2nd edition, , 1999, San Diego, California, Academic Press

[3]. J. Passeto, G. B. Stringfellow, J. Crystal Growth, 1983, 62, 1.

[4]. H. M. Manasevit, J. Crystal Growth, 1981, 55, 1.

[5] C. B. Cooper, R. R. Saxena, M. J. Lodowise, J. Electron. Mater. 1982, 11, 1001

[6]. J. SHIN, T. C. HSU, G. B. STRINGFELLOW, Journal of Crystal Growth, 1997, **179**, 1-9

[7] M. J. Cerng, G. B. Stringfellow, D. W. Kisker, A. K. Srivastava, J. L. Zyskind, Appl. Phys. Lett., 1986, 48, 419.

[8] D. Marx, H. Asahi, X. F. Liu, M. Higashiwaki, A. B. Villaflor, K. Miki, K. Yamamoto, S. Gonda, S. Shimomura, S. Hiyamizu, J. Crystal Growth, 1995, 150, 551-556.

[9] A. C. JONES, P. O'BRIEN, CVD of Compound Semiconductors, 1997, Weinheim, Germany, VCH

[10] C. A. Larsen, S. H. Li, G. B. Stringfellow, Chem. Meter., 1991, 3, 39.

[11] T. F. Kuech, E. Verhoff, J. Crystal Growth, 1984, 68, 48.

[12] J. Shin, A. Verma, G. B. Stringfellow, R. W. Gedridge J.r., J. Crysral Growth, 1994, 143, 15.

[13] K. Yamamoto, H. Aasahi, T.Hayasahi, K. Hidaka, S. Gonda, Journal of Crystal Growth,1997, 175/176, 1236-1241.

[14] C. R., Abernathy, S. J.Pearton, , F. A Baiocchi,., T., Ambrose, A. S Jordan, D. A. Bohling, G. T. Muhr, J. Crystal Growth, 1991, 110, 547.