Epitaxial Growth and Characterization of Hexagonal and Cubic Gallium Nitride Grown by Metalorganic Chemical Vapor Deposi

林偉宗、武東星

E-mail: 8918615@mail.dyu.edu.tw

ABSTRACT

The growth and characteristics of hexagonal and cubic gallium nitride (GaN) grown by metalorganic chemical vapor deposition (MOCVD) were investigated in this study. Optical grade polished (0001) orientation (C-face) sapphires are used as the standard substrates for the growth of hexagonal-GaN (h-GaN). The cubic-GaN (c-GaN) epilayers were grown on (001) GaP and (001) GaAs substrates. The abstract was separated into three parts as following: (1) h-GaN grown on sapphire substrate The role of temperature ramping rate during the two-step growth of GaN-on-sapphire by MOCVD is explored. The surface morphology and crystalline properties of the low-temperature-deposited GaN buffer layer annealed under various ramping rates (20~60?C/min) to 1000?C were investigated by atomic force microscopy (AFM) and X-ray measurements. For the lower ramping rates employed, a dramatic re-evaporation of the GaN buffer layer was observed. This makes the buffer layer thinner, yielding the GaN epilayer of hexagonal morphology. However, as the higher ramping rates applied, the surface becomes rougher and exhibits hexagonal three-dimensional islands. It could be due to the fact that the grains of the GaN buffer layer have no enough time to coarse. Under a temperature ramping rate of 40?C/min, a smooth buffer-layer surface can be maintained and result in a subsequent high-quality overlayer deposition. The mirror GaN epilayer shows a near-band-edge peak (25 K) centered at 3.477 eV with a full width at half maximum as narrow as 13.1 meV. The observed temperature-ramping-rate effects can be interpreted by the coalescence mechanism of the GaN buffer layer involving Ostwald ripening, sintering and cluster migration. (2) c-GaN grown on GaP substrate The GaN epilayers are grown on (001) GaP substrates by low-pressure MOCVD using the three-step growth method, which includes the growth of the GaN buffer, interlayer and high-temperature epilayer. From AFM examinations, it is indicated that the surface roughness of the GaN buffer layer grown at 515?C increases drastically with increasing the annealing temperature from 700 to 850?C in an NH3 ambient. The thickness and growth temperature of the GaN interlayer were optimized based on the X-ray and morphology measurements. It was found that a 0.2-?m-thick GaN interlayer grown at 750?C can improve the morphology of the high-temperature epilayer, which is an essential step for the subsequent growth at high temperature (900?C). Furthermore, as the epilayer thickness increased, the GaN surface became rougher due to the increase in the composition of the hexagonal component. The 77-K photoluminescence (PL) spectrum of the mirror GaN epilayer (0.6 ?m in thickness) exhibits a near-band-edge emission peak at 3.36 eV as well as a yellow emission at 2.29 eV. The corresponding electron mobility and carrier concentration at 300 K were 15 cm2 /V?s and 6.7x1018 cm-3, respectively. (3) c-GaN grown on GaAs substrate GaN epilayers are grown on (001) GaAs substrates by low-pressure MOCVD using a three-step growth method, which includes the growth of the GaN buffer, interlayer and high-temperature epilayer. From AFM examinations, the surface roughness of the GaN buffer layer (25 nm thick) grown at 515?C increases drastically as the annealing temperature increases from 700 to 850?C in an NH3 ambient. An enhancement in cubic crystalline quality was observed as the GaN buffer layers annealed at low temperatures (?750?C). However, the crystallinity of the buffer layer becomes poor and even disappears after high-temperature annealing (?800?C). It is found that a 0.2-?m-thick GaN interlayer grown at 750?C can improve the morphology of the final GaN epilayer grown at 880?C. In addition, the cubic component of the GaN epilayer can achieve over 99 %. The 300-K PL spectrum of the c-GaN epilayer (0.67 ?m thick) exhibits a near-band-edge emission peak at 3.39 eV. The blue shift in the PL peak as compared with the theoretically predicted value (3.2~3.3 eV) could be attributed to the heavily isoelectronic doping of As. A shrinkage in lattice constant of c-GaN were also observed by X-ray measurements. The degree of autodoping can be greatly improved by depositing a SiO2 film on the backside of the GaAs substrate.

Keywords : Metalorganic Chemical Vapor Deposition ; cubic GaN ; hexagonal GaN ; sapphire substrate ; GaP substrate ; GaAs substrate ; GaN buffer layer

Table of Contents

REFERENCES

[1] H. Morkoc and S. N. Mohammad, Science vol. 267,51 (1995).
[2] S. C. Binari, K. Doverspike, G. Kelner, H. B. Dietrich and A. E. Wickenden, ‘‘GaN FETs FOR MICROWAVE AND HIGH-TEMPERATURE APPLICATIONS,’’ Solid-State Eletronics 41 (1997) 177.
[3] S. C. Binari, W. Kruppa, H. B. Dietrich, G. Kelner, A. E. Wickenden and J. A. Freitas, ‘‘FABRICATION AND CHARACTERIZATION OF GaN FETs,’’ Solid-State Eletronics 41 (1997) 1549.
[4] S. Yoshida and J. Suzuki, ‘‘Reliability of GaN Metal Semiconductor Field-Effect Transistor at High Temperature.’’ Jpn. J. Appl. Phys. 37 (1992) 482.
[5] R. Juza and H. Hahn, Zeitschr. Anorgan. Allgem. Chem. 239, 282 (1938).
[6] T. Detchprohm, K. Hiramatsu, K. Itoh and I. Akasaki, Jpn. J. Appl. Phys. 31, 1454 (1992).
[7] K. Naniwae, S. Itoh, H. Amano, K. Itoh, K. Hiramatsu and I. Akasaki, J. Cryst. Growth 99,381 (1990).
[8] I. F. Chetverikova, M. V. Chukichev, and L. N. Rastorguev, Inorg. Mater. 22, 53 (1986).
[9] E. K. Sichel and J. I. Pankove, J. Phys. Chem. Solids 38, 330 (1977).
[10] G. A. Slack, J. Phys. Chem. Solid 34, 321 (1973).
[11] S. Nakamura, ‘‘GaN Growth Using GaN Buffer Layer,’’ Jpn. J. Appl. Phys. 30 (1991) 1705.
[12] J. Wu, H. Yaguchi, K. Onabe, Y. Shiraki and R. Ito, ‘‘Metalorganic Vapor Phase Epitaxy Growth of High Quality Cubic GaN,’’ Jpn. J. Appl. Phys. 37 (1998) L1440.
[13] L. X. Zheng, H. Yang, D. P. Xu, X. J. Wang, X. F. Li, J. B. Li, Y. T. Wang, L. H. Duan and X. W. Hu, ‘‘Low-temperature growth of cubic GaN by metalorgnic chemical vapor deposition,’’ Thin Solid 326 (1998) 251.
[14] H. Okumura, K. Ohta, G. Feuillet, K. Balakrishnan, S. Chichibu, H. Hamaguchi, P. Hacke and S. Yoshida, ‘‘Growth and characterization of cubic GaN,’’ J. Crystal Growth 178 (1997) 113.
[15] T. Lei, T. D. Moustakas, R. J. Graham, Y. He and S. J. Berkowitz, ‘‘Epitaxial growth and characterization of zinc-blende gallium nitride on (001) silicon,’’ J. Appl. Phys. 71 (1992) 4933.
[16] J. Wu, H. Yaguchi, H. Nagasawa, Y. Yamaguchi, K. Onabe, Y. Shiraki and R. Ito, ‘‘Investigation of luminescence properties of GaN single crystals grown on 3C-SiC substrates,’’ J. Crystal Growth 189/190 (1998) 420.
[17] H. Tsuchiya, K. Sunaba, S. Yonemura, T. Suemasu and F. Hasegwa, Jpn. J. Appl. Phys. 36 (1997) L1.
[18] K. -N. Tu, J. W. Mayer, L.C. Feldman: Electronic Thin Film Science for Electrical Engineers and Materials Scientists, (Macmillan Publishing Co., New York, 1992), Chap. 7.
[19] M. Ohring, The Materials Science of Thin Films, (Academic Press Inc., California, 1992), Chap. 5.
[20] S. D. Hrsee, J. Ramer, K. Zheng, C. Kranenberg, K. Malloy, M. Banas and M. Goorsky, ‘‘The Role of the Low Temperature Buffer Layer and Layer Thickness in the Optimization of OMVPE Growth of GaN on Sapphire,’’ J. Electron. Mater. 24 (1995) 1519.
[21] O. Briot, J. P. Alexis, M. Tchounkeu, R. L. A. Ulombard, ‘‘Optimization of the MOVPE growth of GaN on sapphire,’’ Mater. Sci. & Eng. B34 (1997) 147.
[22] T. Suski, P. Perilin, H. Teisseyre, M. Leszczynski, I. Grzegory, J. Jun, M. Bockowski and S. Porowski, ‘‘Mechanism of yellow luminescence in GaN,’’ Appl. Phys. Lett. 67 (1995) 2188.

[23] H. Tsuchiya, K. Sunaba, T. Suemasu and F. Hasegawa, ‘‘Growth of thick and pure cubic GaN on (001)GaAs by halide VPE,’’ J. Crystal Growth 198/199 (1999) 1056.
[24] H. Tsuchiya, K. Sunaba, M. Minami, T. Suemasu and F. Hasegwa, ‘‘Influence of As Autodoping from GaAs Substrates on Thick Cubic GaN Growth by Halide Vapor Phase Epitaxy,’’ Jpn. J. Appl. Phys. 37 (1998) L568.
[25] M. Ogawa, M. Funato, T. Ishido, S. Fujita and S. Fujita, ‘‘The Role of Growth Rates and Buffer Layer Structures for Quality Improvement of Cubic GaN Grown on GaAs,’’ Jpn. J. Appl. Phys. 39 (2000) L69.
[26] H. Tsuchiya, K. Sunaba, T. Suemasu and F. Hasegawa, ‘‘Growth condition dependence of GaN crystal structure on (001)GaAs by hydride vapor-phase epitaxy,’’ J. Crystal Growth 189/190 (1998) 395.
[27] J. Wu, H. Yaguchi, H. Nagasawa, Y. Yamaguchi, K. Onabe, Y. Shiraki and R. Ito, ‘‘Crystal Structure of GaN Grown on 3C-SiC Substrates by Metalorganic Vapor Phase Epitaxy,’’ Jpn. J. Appl. Phys. Part 1, 36 (1997) 4241.
[28] S. Miyoshi, K. Onabe, N. Ohkouchi, H. Yaguchi and R. Ito, ‘‘MOVPE growth of cubic GaN on GaAs using dimethylhydrazine,’’ J. Crystal Growth 124 (1992) 439.
[29] O. Brandt, H. Yang, J. R. Mullhauser, A. Trampert and K. H. Ploog, ‘‘Properties of cubic GaN grown by MBE,’’ Materials and Science and Engineering B43 (1997) 215.
[30] K. H. Ploog, O. Brandt, H. Yang and A. Trampert, ‘‘MBE growth and characteristics of cubic GaN,’’ Thin Solid Films 306 (1997) 231.
[31] H. Chen, Z. Q. Li, H. F. Liu, L. Wan, M. H. Zhang, Q. Huang, J. M. Zhou, Y. Luo, Y. J. Han, K. Tao and N. Yang, ‘‘Controllable cubic and hexagonal GaN growth on GaAs(001) substrates by molecular beam epitaxy,’’ J. Crystal Growth 210 (2000) 811.
[32] J. W. Mayer and S. S. Lau, Electronic Materials Science: For Integrated Circuits in Si and GaAs, (Macmillan Publishing Company, NEW YORK, 1990), Chap 6.