Surface Texture of Thin Gallium Nitride Grown on Closed to Van Der Wall Layer of Molybdenum Disulfide

Iwan Susanto[1,2], Ing-Song Yu[1], Dianta Mustofa Kamal[2], Belyamin[2], Fuad Zainuri[2], Sulaksana Permana[2,3], Chi-Yu Tsai[1], Yen-Ten Ho[4], Ping-Yu Tsai[5]

[1]*Department of Materials Science and Engineering, National Dong Hwa University, Hualien 97401, Taiwan ROC*
[2]*Department of Mechanical Engineering, State Polytechnic of Jakarta, Depok 16424, Indonesia*
[3]*Center of Mineral Processing and Corrosion Research, Department of Metallurgy and Materials Engineering, University of Indonesia, 16424 Depok, Indonesia*
[4]*International College of Semiconductor Technology, National Chiao Tung University, Hsinchu 300, Taiwan ROC*
[5]*Department of Electronic Systems Research Division, Chung-Shan Institute of Science & Technology, Tao-Yan 325, Taiwan ROC*

Keywords: Gallium Nitride, Surface Texture, Molybdenum Disulfide, Molecular Beam Epitaxy

Abstract: A comprehensive analysis of surface texture of gallium nitride (GaN) films grown on the MoS_2 layer via plasma-assisted molecular beam epitaxy was performed. Scanning electron microscopy (SEM) was used to explore the surface morphology of GaN films. The smooth surface with attending the amount of Ga particle created on the GaN films. The great of Ga-N bonding elements more than 80 % explored by XPS core level (CL) 3d Ga was also obtained in the GaN films. Moreover, investigating the results of surface contour by atomic force microscopic (AFM) exhibited a smoother surface texture with RMS of 2.17 nm for scan area 3 x 3 µm. Finally, the higher growth temperature served by substrate could facilitate the smoother surface with the minimum of Ga metallic.

1 INTRODUCTION

Understanding the surface properties of GaN-based on semiconductor materials is important things to develop the technology for electronic and optoelectronic applications (Chen et al., 2019; Tian et al., 2019). Several studies of GaN have been devoting continually for applied to those fields like HEMTs, LEDs, sensors, solar cells, etc(Chapin et al., 2017; Chen et al., 2017; Aissat and Vilcot, 2019; Husna Hamza and Nirmal, 2020). In general, the GaN thin film grows on foreign material, since the creating of bulk GaN has not been effective in cost (Liu and Edgar, 2002; Yang et al., 2017). However, the growing GaN layer on those substrates could generate the defect structure in the interface up to the surface films due to residual stress (Kuwano et al., 2014; Mynbaeva et al., 2016). Several studies continue to be promoted to overcome the existing matter by growing the 2D transition-metal dichalcogenides (TMDs) layer above the layer that has the van der wall epitaxy (Ajayan, Kim and Banerjee, 2016). This layer does not have a strong bond to the substrate, so the residual stress will be released on the surface boundary, and the defects can be minimized as the film is cooled to room temperature.

Recently, MoS_2 including to TMDs has good properties to be applied for next-generation electronics and optoelectronics devices in the semiconductor materials (Choi et al., 2017). Even more interesting, the structure of its material is hexagonal with a close lattice-matched with GaN (Yamada et al., 1999; Susanto, C.-Y. Tsai, et al., 2019). Therefore, MoS_2 has an opportunity to be promising as a substrate for deposition the GaN film. So, the growth of GaN layers on the MoS_2 layer might produce high quality of GaN films which could promise for electronics and optoelectronic applications. Besides, the MoS_2 layer has a van der wall bonding that may facilitate to reduce the residual stress in the films. More interesting, the layer can be also transferred to a foreign substrate to attach the GaN layer for another device (Liu et al.,

Susanto, I., Yu, I., Kamal, D., Belyamin, ., Zainuri, F., Permana, S., Tsai, C., Ho, Y. and Tsai, P.
Surface Texture of Thin Gallium Nitride Grown on Closed to Van Der Wall Layer of Molybdenum Disulfide.
DOI: 10.5220/0009870400002905
In *Proceedings of the 8th Annual Southeast Asian International Seminar (ASAIS 2019)*, pages 22-26
ISBN: 978-989-758-468-8

2019). Until now, several studies have been conducted on growing MoS_2 layers on GaN materials (Wan et al., 2018; Zhang et al., 2018). However the growing layer of GaN films above the MoS_2 layer has not been observed completely.

In this report, we investigate surface conditions related to morphology, composition, and roughness of Ga thin film grown on MoS_2 layer which has vdW bonding using molecular beam epitaxy. The surface texture was further observed in detail trough both the 2D scan area and the contour profile of AFM. Meanwhile, the surface composition related to boding element was examined absolutely with XPS spectra. Finally, the surface condition accordance with surface roughness for substrate and GaN films was analyzed and served according to both AFM images and de-convoluted of 3d Ga in the fitting curve.

2 EXPERIMENTAL METHOD

In the experiment procedure, we grew GaN film on 2D MoS2 layer by PA-MBE method. The growth temperature was carried out for 20 minutes at 600 C with a 10 rpm rotation speed of the substrate (Susanto et al., 2019). During the growth of the GaN layer, the thermal cleaning process was done at 600 C for 40 minutes to trough out the contaminants on the surface substrate. Further, the deposition both of Ga and N atoms used K-cell at 800 C and nitrogen gun with a flow rate of 0.8 sccm at Rf power 500 Watt, respectively. Thus, the growth of GaN film was carried out in N-rich condition with a flux ratio of N/Ga at 161 (Susanto et al., 2017). Other hand, MoS_2 layer used for growing GaN was a single crystal of c-plane sapphire deposited by the PLD system (Ho et al., 2015). The deposited temperature was served at 800 C with 8 x 10-6 Torr of a background pressure. Finally, the ex-situ characterizations of SEM and XPS spectra were performed to investigate the morphology and surface composition of GaN films. While the AFM was execute to observe in detail surface texture related to the roughness both of MoS_2 substrate and GaN films.

3 RESULT AND DISCUSSION

Morphology and surface composition of GaN films served by SEM image and XPS fitting curve was presented completely in Figure 1. The GaN films grew and covered throughout on the surface of the MoS_2 layer Figure 1(a). The morphology of GaN films seems smooth with a large flat area indicating that GaN was grown epitaxial by the 2D mode layer. However, several Ga particles spread irregularly on the surface with size in the range up to 150 nm. Attending the particles associated with low growth temperature on the system. The low heat energy provided by the substrate might be caused the atoms are not sufficiently mobile to reach the favourable sites at the step edges (Susanto, Kan and Yu, 2017). They are incorporated at random position and accumulated to construct the cluster on the surface. In Ga-rich growth condition, the particle can be even bigger formed like the droplets on the surface. By the less energy desorption, both Ga and N atoms became retarded to mobilize in creating 2D layer epitaxy. Further, the composition of Ga cluster related to Ga metallic bonding will be inspected carefully by the XPS measurement.

In Figure 1(b), the XPS result was demonstrated the semi-quantitative analysis by the peak fitting of XPS spectra. The surface composition of GaN film was displayed in detail by de-convoluted Ga-3d core level spectra. The peak positions of bonding elements were located at 18.25, 20.05, and 23.50 eV for Ga-Ga, Ga-N and O-O, respectively (Yu et al., 2014; Mishra et al., 2015). Meanwhile, the percentages of those bonding elements were 8.8, 81.0 and 10.2 %, serially. According to the results, GaN bonding has been constructed on the surface of the MoS2 layer with great composition related to a higher percentage of 80 %. However, the presenting of Ga-Ga bonding was formed due to the accumulation of Ga atoms, deposited on the surface of GaN films. The result was consistent with the SEM result in Figure 1(a) that the Ga-Ga related with Ga particles was come on the surface GaN films(Susanto et al., 2017; Susanto, Kan and Yu, 2017). Unfortunately, there is an O-O bonding element also detected in higher binding energy. It could be related to oxygen absorbed on the GaN surface as was contacted to the air. Furthermore, the surface features correspond with morphology and roughness condition will be observed clearly by AFM.

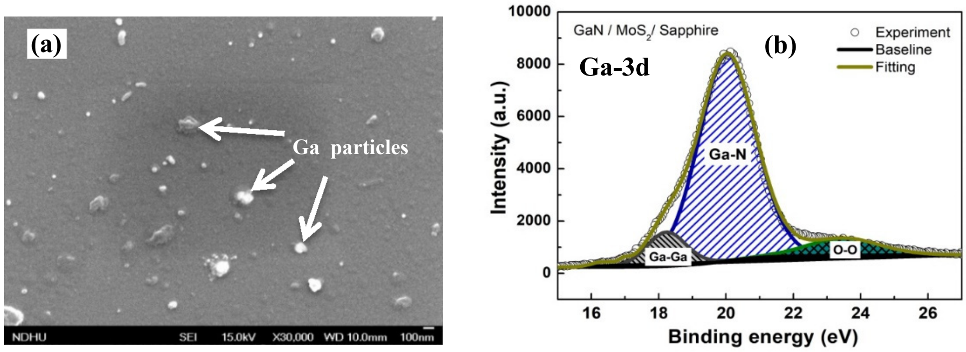

Figure 1. (a) SEM images and (b) De-convoluted Ga-3d XPS spectra for the surface composition of the GaN films

Detail of surface morphology of MoS_2 layers and GaN films was exhibited clearly by AFM observation in Figure 2 (a, c) and (b, d), serially. By the scan area of 3 x 3 µm, the bright area likes particles and the dark relates with thick striped demonstrating the character both of surface feature. The bright areas describe the pattern of rising surface peaks, and dark areas illustrate the valleys formed on the surface. The broader area of dark and bright regions with a root mean square (RMS) of 3.01 nm was exhibited on the surface of MoS_2 in Figure 2(a). After deposition of GaN films, the reduction of those areas with RMS of 2.17 nm was demonstrated on Figure 2(b). The reduction in the size of these two regions represented that decline peak and valley formed on the film's surface. The narrowing of both areas could describe that a smoother surface has constructed on the GaN films.

Moreover, the line roughness will be confirmed more clearly with one dimension of contour scan in Figure 2(c), (d) demonstrating the profile of the valley and peaks feature. They can be compared to the results from the striped scan in Figure 2 (c) and (d). There are several grooves with a smaller curve in Figure 2(c) than in Figure 1(d). The curve relates to the peak formed on the surface layer, while the groove correlates with the valley constructed on the surface as well. The high peak and the deep of the valley for both surface contours is 0.51 nm and 0.31 nm for MoS_2 layer, and 1.11 nm and 0.73 nm for GaN films, respectively. Based on the AFM results, the surface of GaN film was smoother than the MoS_2 layer even though the peak and valley GaN films higher and deeper than the MoS_2 layer. It could be come due to the line roughness of the GaN film taken in the highest and the deepest area.

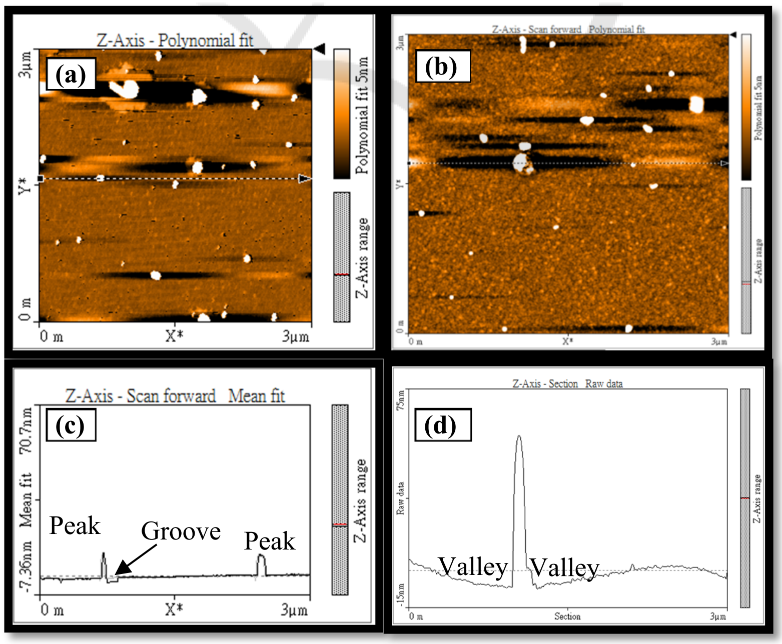

Figure 2. (a) 2D AFM images of the surface of MoS_2/Sapphire and (b) GaN films with scan area 3 x 3 µm, while (c) scan profile contour as long 3 µm on MoS_2/Sapphire and (d) for GaN films.

4 CONCLUSIONS

In conclusion, we are successful to deposit the GaN films on the MoS_2 layer by the MBE system. The surface texture of the GaN films formed was a smooth surface with a large flat area correlated with the 2D mode layer. The great of Ga-N bonding created on the surface with less Ga-Ga and O-O was obtained higher than 80 %. The reduction of surface roughness was initiated by the GaN layer covered the substrate. The RMS of GaN film with scan area 3 x 3 µm was archived at 2.17 nm. The diminution of peak size and groove related to the valley was also demonstrated on the contour of the scan profile. However, attending several Ga particles spread irregularly on the surface with size in the range up to 150 nm that was constructed due to low growth temperature provided by the system. Further, the higher growth temperature served by substrate could facilitate the smoother surface of GaN film with the minimum of Ga metallic.

ACKNOWLEDGMENTS

All authors would like to thank to Ministry of Research and Technology / Research Council and National Innovation Republic of Indonesia (BRIN) and also Ministry of Science and Technology, Taiwan for financially supporting this study (MOST 107-2221-E-259- 001-MY2 and 107-3017-F-009-002).

REFERENCES

Aissat, A. and Vilcot, J. P. (2019) 'Development of InxGa1-xN/GaN axial multiple quantum well nanowire for solar cell applications', Optik. Elsevier GmbH., p. 163844. doi: 10.1016/j.ijleo.2019.163844.

Ajayan, P., Kim, P. and Banerjee, K. (2016) 'Two-dimensional van der Waals materials', Physics Today, 69(9), pp. 38–44. doi: 10.1063/PT.3.3297.

Chapin, C. A. et al. (2017) 'InAlN/GaN high electron mobility micro-pressure sensors for high-temperature environments', Sensors and Actuators, A: Physical. Elsevier B.V., 263, pp. 216–223. doi: 10.1016/j.sna.2017.06.009.

Chen, Y. et al. (2017) 'High efficiency GaN LEDs with submicron-scale 2D periodic structures directly fabricated by laser interference ablation', Optics and Laser Technology. Elsevier, 90(August 2016), pp. 211–215. doi: 10.1016/j.optlastec.2016.08.019.

Chen, Y. et al. (2019) 'GaN in different dimensionalities: Properties, synthesis, and applications', Materials Science and Engineering R: Reports, 138(January), pp. 60–84. doi: 10.1016/j.mser.2019.04.001.

Choi, W. et al. (2017) 'Recent development of two-dimensional transition metal dichalcogenides and their applications', Biochemical Pharmacology. The Author(s), 20(3), pp. 116–130. doi: 10.1016/j.mattod.2016.10.002.

Ho, Y. T. et al. (2015) 'Layered MoS_2 grown on c - sapphire by pulsed laser deposition', Physica Status Solidi - Rapid Research Letters, 9(3), pp. 187–191. doi: 10.1002/pssr.201409561.

Husna Hamza, K. and Nirmal, D. (2020) 'A review of GaN HEMT broadband power amplifiers', AEU - International Journal of Electronics and Communications. Elsevier GmbH, p. 153040. doi: 10.1016/j.aeue.2019.153040.

Kuwano, N. et al. (2014) 'Behavior of defects in a-plane GaN films grown by low-angle-incidence microchannel epitaxy (LAIMCE)', Journal of Crystal Growth. Elsevier, 401, pp. 409–413. doi: 10.1016/j.jcrysgro.2013.11.032.

Liu, L. and Edgar, J. H. (2002) 'Substrates for gallium nitride epitaxy', Materials Science and Engineering: R: Reports, 37(3), pp. 61–127. doi: 10.1016/S0927-796X(02)00008-6.

Liu, Y. et al. (2019) 'Transferable GaN Films on Graphene/SiC by van der Waals Epitaxy for Flexible Devices', Physica Status Solidi (A) Applications and Materials Science, 216(11), pp. 1–6. doi: 10.1002/pssa.201801027.

Mishra, M. et al. (2015) 'Pit assisted oxygen chemisorption on GaN surfaces', Physical Chemistry Chemical Physics. Royal Society of Chemistry, 17(23), pp. 15201–15208. doi: 10.1039/c5cp00540j.

Mynbaeva, M. G. et al. (2016) 'TEM study of defect structure of GaN epitaxial films grown on GaN/Al_2O_3 substrates with buried column pattern', Journal of Crystal Growth. Elsevier, 445, pp. 30–36. doi: 10.1016/j.jcrysgro.2016.04.011.

Susanto, I. et al. (2017) 'Effects of N/Ga flux ratio on GaN films grown on 4H-SiC substrate with 4° miscutting orientation by plasma-assisted molecular beam epitaxy', Journal of Alloys and Compounds. Elsevier B.V, 710, pp. 800–808. doi: 10.1016/j.jallcom.2017.03.320.

Susanto, I. et al. (2019) 'Morphology and surface stability of GaN thin film grown on the short growth time by Plasma Assisted Molecular Beam Epitaxy', J. Phs : Conference Seriese, 1364(012067). doi: 10.1088/1742-6596/1364/1/012067.

Susanto, I., Kan, K. and Yu, I. (2017) 'Temperature effects for GaN fi lms grown on 4H-SiC substrate with 4 miscutting orientation by plasma-assisted molecular beam epitaxy', Journal of Alloys and Compounds. Elsevier B.V, 723, pp. 21–29. doi: 10.1016/j.jallcom.2017.06.224.

Susanto, I., Tsai, C.-Y., et al. (2019) 'The influence of 2D MoS_2 layers on the growth of GaN films by plasma-assisted molecular beam epitaxy', Applied Surface

Science, 496(July), p. 143616. doi: 10.1016/j.apsusc.2019.143616.

Tian, J. et al. (2019) 'Optoelectronic properties of two-dimensional GaN adsorbed with H, N and O: A first-principle study', Physics Letters, Section A: General, Atomic and Solid State Physics. Elsevier B.V., 383(24), pp. 3018–3024. doi: 10.1016/j.physleta.2019.06.007.

Wan, Y. et al. (2018) 'Epitaxial Single-Layer MoS_2 on GaN with Enhanced Valley Helicity', Advanced Materials. doi: 10.1002/adma.201703888.

Yamada, a. et al. (1999) 'Molecular beam epitaxy of GaN on a substrate of MoS_2 layered compound', Applied Physics A: Materials Science & Processing, 69(1), pp. 89–92. doi: 10.1007/s003390050976.

Yang, Z. P. et al. (2017) 'Effects of substrate and annealing on GaN films grown by plasma-assisted molecular beam epitaxy', Surface and Coatings Technology. Elsevier B.V., 320, pp. 548–553. doi: 10.1016/j.surfcoat.2016.11.019.

Yu, I.-S. et al. (2014) 'Characterization and density control of GaN nanodots on Si (111) by droplet epitaxy using plasma-assisted molecular beam epitaxy.', Nanoscale research letters, 9(1), p. 682. doi: 10.1186/1556-276X-9-682.

Zhang, Z. et al. (2018) 'Interface Engineering of Monolayer MoS_2/GaN Hybrid Heterostructure: Modified Band Alignment for Photocatalytic Water Splitting Application by Nitridation Treatment', ACS Applied Materials and Interfaces. doi: 10.1021/acsami.8b01286.