Characterization on Surface Morphology of GaN Layer Deposited on 2D MoS_2 Developed by CVD System

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Abstract: A few layers of GaN was deposited epitaxial on the MoS_2 layers by PA-MBE technique. A smooth surface with mixed like-flakes of MoS_2 is provided by the development of CVD system. It is grown on the c-sapphire substrate with a few layers. Further, surface morphology both of MoS_2 substrate and GaN layer was investigated in detail by the AFM and FE-SEM characterization. The results demonstrated that the surface morphology of the constructing GaN layer was smoother than MoS_2 layer. The surface texture was obtained throughout the decreasing of area roughness up to 1.44 nm and root mean square (RMS) of 2.40 nm. However, thin GaN layers covering the MoS_2 surface was in the less content of atomic with a weight Ga element. It takes longer growth time and more flux to obtain a flat morphological surface with high smoothness.

1 INTRODUCTION

GaN included on the group III-IV semiconductor materials has excellent properties such as high conductivity, high electrons mobility, very hard material, chemically and mechanically stable (Kawashima et al., 1997; Hanada, 2009). In accordance with those properties, GaN is used extensively for application in optoelectronic, electronic components, high-power and high-frequency devices (Chen et al., 2017; Su, Chen and Rajan, 2013; Würtele et al., 2011; Joshin et al., 2014). However, since a high-cost of the GaN bulk (Liu and Edgar, 2002), GaN layers are developed to be grown on other materials substrate. Several materials are attempted for providing GaN layers as a substrate (Kukushkin et al., 2008). Unfortunately, distinguish thermal expansion coefficient and the lattice-mismatched might build the residual strain initiated the defect as decreasing the temperature from manufacturing (Trampert, 2002; Poust et al., 2003). The beginning of the damage raised from the interface and then spread it toward the surface of layer (Trampert, 2002; Fachruddin et al., 2020), which degrade the quality structure and reduction for long-term application.

Recently, several studies have been devoted for increasing the GaN quality by growing it near lattice matched (Susanto et al., 2019; Gupta et al., 2016; and Mánuel et al., 2010). 2D MoS_2 layers was a hot topic when they were grown on GaN material as semiconductor material for optoelectronic application (Wan et al., 2018; Zhang et al., 2018). Moreover, MoS_2 has a lattice-matched with GaN which promises for the high-quality growing of GaN layers. As thick layers of GaN films were grown up to it's thick of 1.8 μm (Kimura et al., 2005), the defects are not attended on the film's surface. Besides, an investigation of the surface morphology of the GaN layer near the substrate has not been studied in detail. It could be an exciting part to observe it.

In this report, the morphology of GaN films will be characterized to get a deep understanding of the contour and texture of surface condition. A few

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epitaxial growth parameters will be used to deposit the impinging Ga and N atom on the 2D MoS_2 layer. The characterization results will be presented and analyzed based on both of 2-dimensional (2D) images and quantitative data observation of AFM and SEM technique.

2 EXPERIMENTAL METHOD

The growing GaN films on 2D MoS_2 layers are prepared by MBE technique. The growth GaN was controlled at 600 °C for 20 minutes. The thermal cleaning is given for 40 minutes and free-nitridation of 10 minutes before the epitaxial growth. The imaging atom of Ga flux is provided by K-cell at 800 °C, while Radiofrequency of Nitrogen Gun supplied N flux at 500 W. The flow rate was provided in sccm of 0.8 for N6 gas. Furthermore, the background pressure was built at 8 x 10-6 Torr. The 2D MoS_2 layer substrate was exploited by the CVD method, deposited on the single crystal of c-sapphire. Finally, the ex-situ characterization was employed using AFM and FE-SEM machine for investigating the surface morphology.

3 RESULT AND DISCUSSION

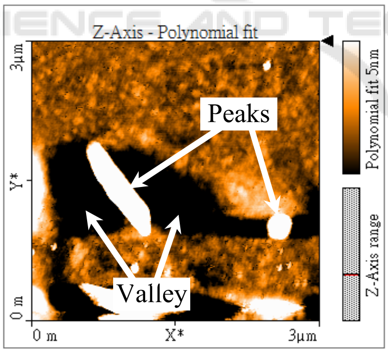


Figure 1. AFM image of 2D MoS_2 layer deposited on the sapphire substrate

Fig 1 displays the surface morphology of MoS_2 layer grown on the sapphire. The surface texture 2D MoS_2 layer was observed with 3 x 3 µm of scan area. The bright color was related to peak of MoS_2 on the surface, while the dark color was associate with the valley of the surface. The difference both of the colors elucidate the surface condition formed on the MoS_2 layer. The MoS_2 like-steps with the bright color, and the dark area formed was associated with the surface contour of the MoS_2 layer during the deposition process using the CVD system. The area roughness of MoS_2 surface is achieved to be 2.17 nm and the root mean square is obtained about 4.19 nm. The high peak value and the deep valley are 25.14 nm, and 31.99 nm, serially. Based on the characterization using the AFM method, the texture of the MoS_2 layer is established with smoother of surface condition.

Since the growth epitaxial, the morphology of GaN layers on 2D MoS_2 has entirely demonstrated in Fig 2. The surface texture GaN layer was observed with a scan area of 3x3 µm in Fig 2(a). The bright color was related to peak of GaN on the surface, while the dark color was associate with the valley of the surface in Fig 2(b). The surface texture was more apparent as they were demonstrated using the 3-dimension profile shown in Fig 2(c). The distinct colors seem with a low degradation value, suggesting the smooth surface formed on the GaN layer. However, attending the protrusions, GaN like-steps on the surface in Fig 2(a) could be increasing the surface roughness on GaN layer. The GaN like-steps formed was initiated with the surface contour of the MoS_2 layer exhibited on Fig 1. As the impinging Ga and N atoms on the MoS_2 layer, the GaN layer grew epitaxial following the substrate's texture. So, in the short growth time, the GaN layer formed based on the substrate surface pattern (Susanto et al., 2019). Furthermore, the area roughness on the surface GaN has reached up to 1.44 nm and the root mean square is 2.40 nm. The highest peak value is up to 21.07 nm and the deep valley is until 15.01 nm. According to the AFM images, the surface GaN layer constructed with smoother than the MoS_2 surface. The smoother of surface morphology as indicated by decreasing the area roughness and root mean square up to 33.6 % and 44.7 %, respectively.

Fig 3 exhibit the FE-SEM images and EDS observation of the surface morphology and element composition on the GaN layer. By the magnitude of 15,000 displayed in Fig 3(a), the surface GaN layer's condition looks smooth, indicating that it has grown on the MoS_2 layer. However, the GaN like-flakes were still visible on the surface, which is in tune to the AFM images in Fig 2. Observation using the spot scans in spectrum one on Fig 3(b) was carried out to identify the GaN layer. Fig 3 show Ga element detected in spectrum 1 with less content, suggesting that the few GaN layers have grown on the MoS_2 flakes. All elements related to substrate layers were tabulated more detail in Table 1. GaN layers have successfully covered all of surface MoS_2 layer even in the less content of percentage atomic with a percentage weight Ga element.

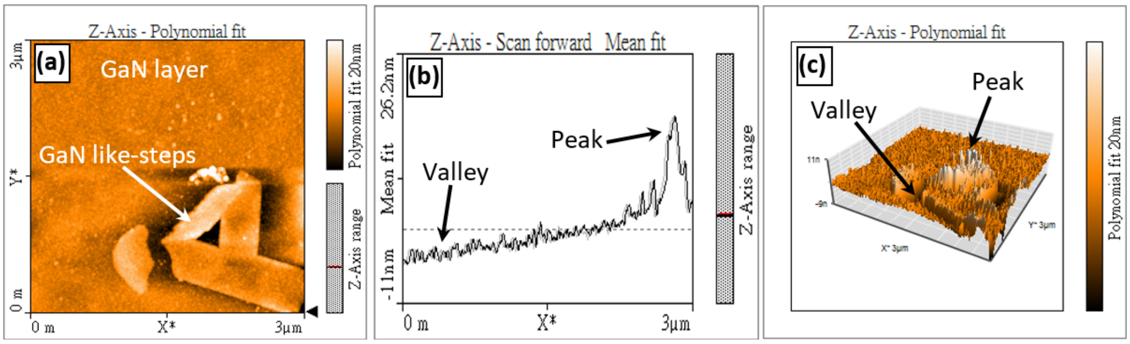
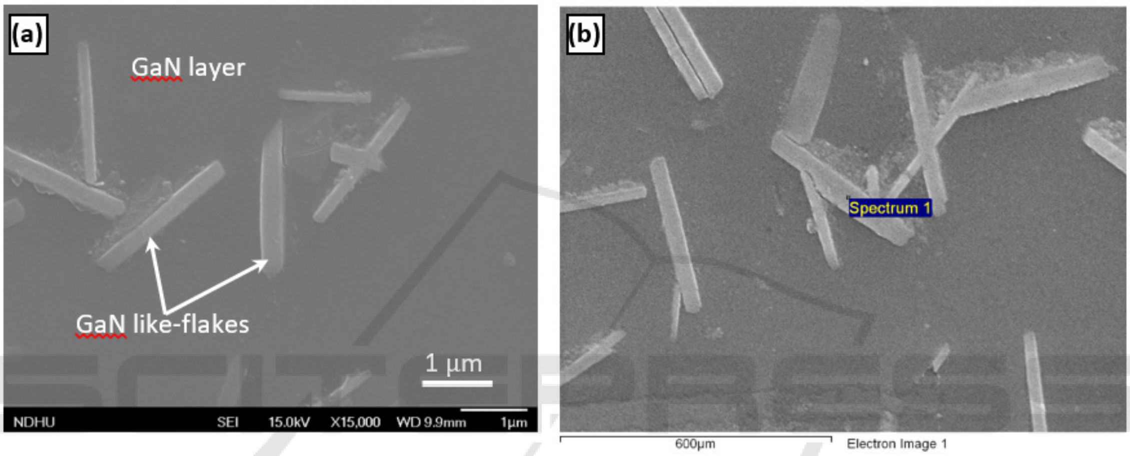


Figure 2. AFM images of surface GaN layer observed; (a) Scan area profile of 3x3 µm, (b) line-profile through of 3 µm, and (c) 3-dimension profile with a deep of 20 nm



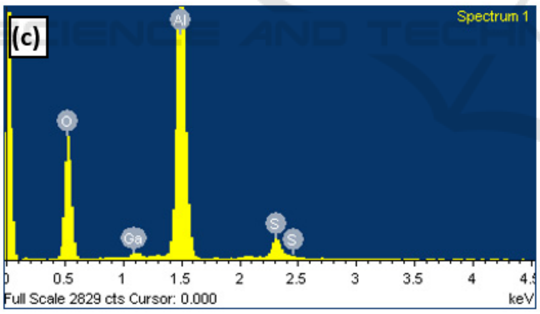


Table 1. Element contents

Element	Weight%	Atomic%
O K	44.73	58.46
Al K	49.13	38.08
S K	4.61	3.01
Ga L	1.52	0.46

Figure 3. SEM images of surface morphology GaN layers (a, b), and (c) EDS of scan-spot on the surface GaN like-flakes

4 CONCLUSIONS

The characterization of surface morphology on the GaN layer deposited on 2D MoS_2 layer by PA-MBE system was successfully done using AFM and FE-SEM technique. The surface texture of MoS_2 layers was observed in detail for initial surface condition of the substrate. Besides part for MoS_2 plat-layers, attending MoS_2 like-flakes leads to establishing the texture of GaN layers epitaxial. A less content of atomic and weight Ga also covered the surface of MoS_2 plat-layers. Even though the epitaxial was employed in the short growth time, the decreasing of the area roughness and root mean square attained the smoother surface of the GaN layer. Thicker GaN films should be employed by providing a higher Ga and N fluxes with longer growth time.

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