Surface Structure and Morphology of Gallium Nitride Thin Film Grown on Molybdenum Disulfide Layer by Molecular Beam Epitaxy

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Abstract: The layer of gallium nitride thin film was grown near to the surface of the molybdenum disulfide substrate by plasma-assisted molecule beam epitaxy (PA-MBE) system. In-situ RHEED and ex-situ characterization of AFM and SEM were used to exploit subsequently the surface character of GaN films. The results show that the RHEED pattern demonstrated the mix structure of polycrystalline and amorphous with 2-dimensional (2D) growth mode. The crystalline structure was influenced by the defect constructed in the GaN films. Meanwhile, the 3D AFM image served in detail the smooth surface with root mean square (RMS) of 3.87 nm. Further, the SEM image with an EDS pattern performed the fixture of morphology and surface composition. However, Ga cluster like particles presented on the surface of the GaN layer. The sufficient of the thermal energy with the crystalline structure provided by the substrate would be a promising approach for creating GaN film with greater structures and smoother surface.

1 INTRODUCTION

GaN semiconductor is an interesting material because it has several excellent properties like high electrons mobility, high conductivity and chemically stable (Kawashima et al., 1997; Hanada, 2009). According to this feature, GaN was utilized for some applications of optoelectronic devices and electronic components (Würtele et al., 2011; Su, Chen and Rajan, 2013; Joshin et al., 2014; Chen et al., 2017). Unfortunately, GaN layers are generally grown on other materials substrate, since the GaN bulk has been a high-cost material as subtract (Liu and Edgar, 2002). Several attempts have been done for growing GaN layers on other materials (Kukushkin et al., 2008). However, the lattice-mismatched with different thermal expansion coefficient rises the residual stress which could create defects in GaN film during the cooling process (Trampert, 2002; Poust et al., 2003). In general, the defects will be started from the surface boundary in the interface of two materials and afterward they propagate to the inside of the film up to the surface of GaN film (Trampert, 2002).

Several efforts have been strived for reducing the residual strain by growing the GaN layer on the close-lattice matched (Mánuel et al., 2010; Gupta et al., 2016) (Susanto, C.-Y. Tsai, et al., 2019). Recently, MoS_2 as an interesting semiconductor material applied for optoelectronic which is grown on GaN material (Wan et al., 2018; Zhang et al., 2018). Since the MoS_2 has been a lattice-matched with closed to GaN, it becomes a promising chance for growing high-quality GaN film layers. Moreover, GaN films are usually grown with a thick layer until 1.8 μm (Kimura et al., 2005), So that the

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defects were not seen on the surface of the film. On the other hand, observations of the GaN film surface near the substrate surface have also not been reported more clearly. It will be an interesting section to investigate the thin layer near to the surface substrate which has a potential area to generate serious defects at the surface boundary.

So, in this study, we investigated the surface structure and morphology of GaN grown near to the surface of the MoS_2 layer by molecular beam epitaxy technique. The surface of the substrate and GaN film was observed using in-situ and ex-situ characterization techniques. Observation of two surfaces is carried out using RHEED, AFM, and SEM. The results of the characterization will be presented in 2-dimensional (2D) and 3-dimensional (D) images. Structure and character of the surface will be analyzed using the results of RHEED monitoring. Whereas surface roughness will be monitored using AFM. Meanwhile, the morphology and composition of surface elements will be investigated by SEM.

2 EXPERIMENTAL METHOD

The GaN layer was grown on the MoS_2 substrate using the PA-MBE system. While, the substrate used to deposit the MoS_2 layer is a single crystal of c-plane sapphire by the PLD method (Ho et al., 2015). The deposited temperature was given at 800 C with a background pressure at 8 x 10-6 Torr. For GaN film, the growth temperature is determined at 600 C for 20 minutes with a substrate rotation speed of 10 rpm. All of the growth parameters have been done in our previous study (Susanto, C. Tsai, et al., 2019). Before the growth process of the GaN layer, the substrate is heated up to 600 for 40 minutes to clean contaminants on the surface. The growth of the GaN layer carried out using K-cell as a producer of Ga atoms at 800 C and facilitated by a nitrogen gun as a source of N atoms with a flow rate of 0.8 sccm at Rf power 500 Watt. The ratio flux of nitrogen and gallium (N/Ga) is 161 or N-rich conditions (Susanto et al., 2017). During the cleaning substrate and growth GaN film, the surface condition is monitored using RHEED. Finally, the GaN film products were then examined by AFM and SEM to investigate in detail the characteristics of surface condition.

3 RESULT AND DISCUSSION

Figure 1 shows the RHEED pattern on the surface of MoS_2 during the hot cleaning process. The foggy pattern is shown by RHEED in Figure 1(a) before hot cleaning. This pattern explains that the structure formed of the MoS_2 layer is amorphous. After the hot cleaning, a bright streak pattern is displayed by RHEED in Figure 1 (b). This pattern explains that the surface structure constructed on the MoS_2 layer is a crystalline structure. So, based on the cleaning results by the heating process, the surface structure is changed from amorphous to crystalline. This process was found to be effective in removing contaminants that covered the surface of the MoS_2 layer and improving the surface structure of the substrate. Besides, the striped pattern explains that the surface layer is 2-dimensional. Meanwhile, the bright intensity of the streak pattern shown explains the crystal structure formed in the MoS_2 layer. The stronger intensity of the pattern indicates the crystallinity structure formed. Further, the RHEED pattern in Figure 1 (c) displays the surface of the GaN film growing on the MoS_2 layer. The dots connected with a ring in the RHEED pattern show the surface structure of the layer which is a polycrystalline structure. This structure leads to be constructed low mobilization of atoms caused by the lack of heat energy provided by the substrate results in the creation of Ga droplets or clusters due to low desorption and diffusion of atoms (Susanto et al., 2017). Moreover, the substrate's surface character related to the different orientation was also responsible for creating the structure. While the weak intensity pattern correlates with the polycrystalline mixed with an amorphous structure. In addition, the single crystal of GaN films was not constructed on the epitaxial structure. It indicates that the defect was formed on the layer and influencing the crystalline structure. The result is consistent with the surface morphology on the GaN film shown in the AFM image in Figure 1(d). The peaks and valleys pattern on the surface illustrates the surface character of the GaN film formed. The RMS total of surface roughness constructed on GaN film is 3.87 nm, in which the height peak is 118.93 nm and the depth valley is 15.99 nm. The presence of peaks could be due to the accumulation of Ga atoms which generate Ga clusters during the growth process. The formation of valleys is created due to the low mobilization of Ga and N atoms during growth as well. The minimum of atoms mobilization corresponds to less desorption influenced by the insufficiency of thermal energy (Susanto, Kan and Yu, 2017).

Furthermore, the morphology and composition element of the surface film was presented more clearly in Figure 2. The GaN film with some light particles has completely covered the substrate. The smooth surface corresponded to 2D layers has deposited on the MoS_2 layer. However, there are also Ga clusters like a particle with a brighter color attend on the surface of the GaN film. The clusters pattern is believed to be the peaks demonstrated in the AFM image in figure 1 (d). To ensure these particles are Ga clusters, the observations are targeted more focus at particles in spectrum 3 using the EDS test shown in Figure 2(a). The result of the spectrum 3 observations is shown in Figure 2 (b). The peaks on the image are the elements constructed from such as the films and substrate. The high peak corresponds to the quality of the elements, while the area of peaks relates to the number of elements. Moreover, the number of elements namely Al, O, S, C, and Ga is tabulated inset in Figure 2(b). The presenting of Al, O and S elements could become from the substrate material, while the Ga element attends from Ga films. Based on the surface morphology and composition element results, it clears that the GaN film has grown well on the MoS_2 layer without the pits defect on the surface.

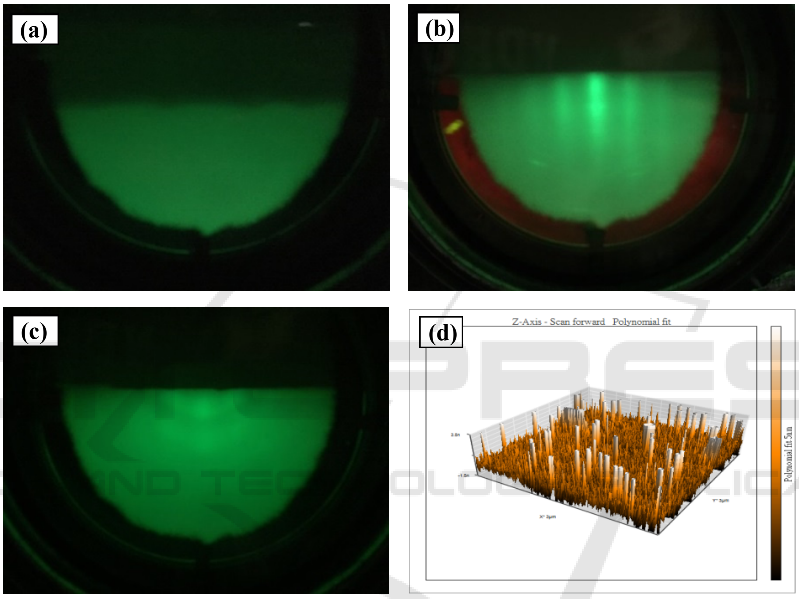

Figure 1: RHEED patterns (a) MoS_2/Sapphire, (b) MoS_2/Sapphire after nitridation, (c) GaN films, and (d) 3-dimensional (3D) AFM GaN film surfaces with a volume of 3 µm x 3 µm x 5nm.

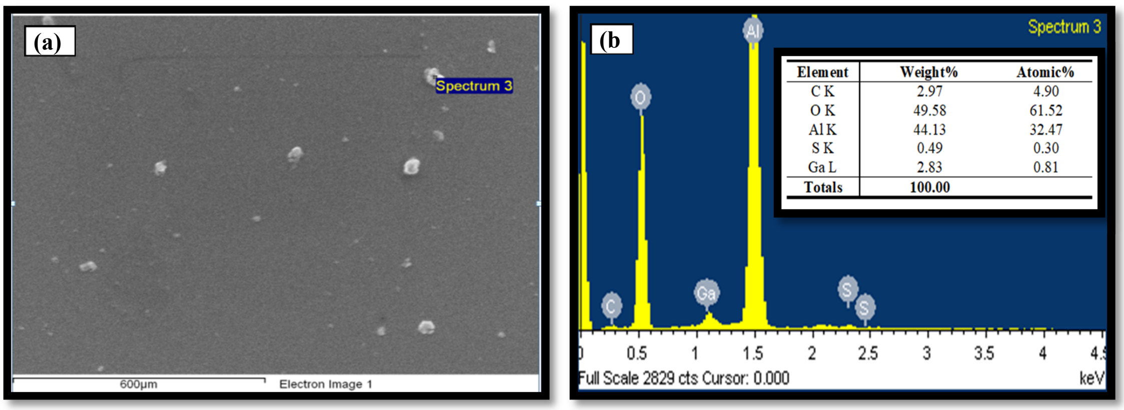

Figure 2. SEM and EDS images of GaN film surface

4 CONCLUSIONS

The GaN layer has been successfully grown near the surface of the MoS_2 layer with the PA-MBE technique. The surface substrate of the MoS_2 layer was covered throughout with GaN films. The structure formed on the GaN film was either polycrystalline closed-amorphous or a mixture structures of polycrystalline and amorphous. The defect influenced the crystalline structure of GaN films. While the surface contour formed was in 2D mode with a roughness of RMS 3.87. The smooth layer of GaN film with presenting the Ga cluster also constructed on the MoS_2 layer. The low heat energy provided by the substrate was responsible to construct the Ga cluster on the surface of GaN films. In addition, the mixture of structures formed is also believed to be formed due to low mobilization and desorption of atoms during the growth epitaxy.

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