Development of PVD-AlN Buffer Process for GaN-on-Si

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Abstract

A magnetron sputtered AlN buffer layer process has been developed using a batch PVD system capable of substrate temperatures above 800C. Epitaxial growth has been demonstrated and the film is suitable as a template for subsequent GaN growth to be utilized for LED and high power Si devices.

INTRODUCTION

The "economies of scale" associated with increasing epitaxial growth substrate size can provide a clear cost advantage for LED manufacturers. Replacement of sapphire with Si is a viable alternative due to its low cost, proven scalability (silicon industry has already scaled up to 300mm diameter) and good thermal conductivity. However, replacing sapphire with Si still faces challenges. The lattice mismatch of ~17% and the thermal expansion mismatch (CTE 56%) can induce large residual stresses in the GaN epi-layer. [1, 2] In addition, it is well known that Si reacts with Ga under typical growth conditions, and the conventional GaN buffer layer technology developed for sapphire cannot be used.

There is no reaction between Si and AlN, making it a common choice for a buffer layer. While AlN buffer layers are often deposited in the same MOCVD system as the GaN, the typical precursor, tri-methyl aluminum (TMA), leads to more frequent preventative maintenance, is highly reactive, and can be a safety concern. [3, 4] A PVD buffer layer can provide a simpler, more cost effective alternative to the more complicated CVD chemistries.

EXPERIMENTAL

A PVD batch tool was designed to accommodate substrate sizes from 2-8". Substrate heating capability to over 800C allows for high quality epitaxial growth of AlN using DC or RF magnetron sputtering. PVD AlN films were deposited using 100-150mm <111> Si substrates up to 1mm thick. In-situ pre-treatment was used to remove native oxide before the AlN deposition. Deposition times were approximately 3min. A 10kW power supply was used for sputtering in an argon and nitrogen environment. Typical process pressures were 2mT and ranged from 1-5mT.

1 μm MOCVD GaN was deposited on several PVD AlN samples in order to characterize film quality and assess Si meltback and film cracking.

RESULTS AND DISCUSSUION

PVD AlN:

Film quality was evaluated using XRD and TEM. Surface roughness was quantified using AFM. XRD rocking curve FWHM (Full Width Half Maximum) values of <1600 arcsec for the 002 peak and <2600 arcsec for the 102 peak were obtained for films approximately 150nm thick. TEM measurements confirmed column-like structures growing epitaxially on the Si. Surface roughness from <1nm to several nm has been measured by AFM. In figure 1 the AFM of 160nm of PVD AlN is shown. Films were deposited with different Si surface pre-treatments. The PVD AlN films were deposited in tensile stress, typically observed on Si. Film stress was typically <800MPa and lead to approximately 12µm bow after deposition. Film properties are summarized in Table1. In Figure 2 several TEM micrographs are shown. On the left, a Moiré fringing associated with the epitaxial growth of the AlN is evidenced in the high resolution TEM. Domain epitaxial growth of the AlN film on Si is also confirmed by the Fourier Filtered TEM. The 5:4 lattice matching of the AlN/Si lattice planes can easily be seen with this technique. The interface is demarcated by “T”.

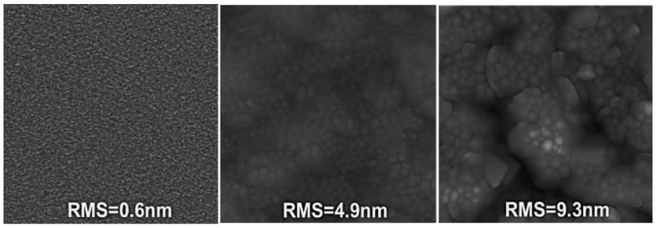

Figure 1: AFM of PVD AlN with various surface pre-treatments

Table 1: Film Property Summary

Parameter	Units	Result	
XRD Film Quality	ω FWHM, arcsec	(002)	(102)
		1500-1800	2900-3700
Deposition Rate	nm/min	>20	
Thickness NU	% 3σ	7-9	
Surface Roughness	RMS, nm	<1	
Film Stress	MPa	<800	
Bow	mm	<12	
Lattice Mismatch	AlN/Si, %	5.7	

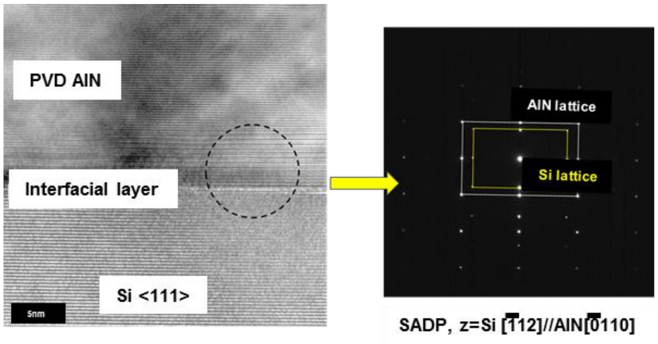

Figure 2: High Resolution, Fourier Filtered, Diffraction TEM Micrographs

MOCD GAN:

XRD rocking curve FWHM values obtained for the GaN films were <480 arcsec and <660 arcsec for the 002 and 102 peaks, respectively. Roughness was ~0.3nm (RMS). Defect density was estimated from XRD and TEM and is <1 x10^9 /cm^2. In the TEM of Figure 3, the typical dislocation defects associated with GaN growth have been identified. Screw type or threading defects were estimated to be 7 x10^8/cm^2. A 4% lattice mismatch between GaN and AlN was calculated from the diffraction pattern in Figure 4.

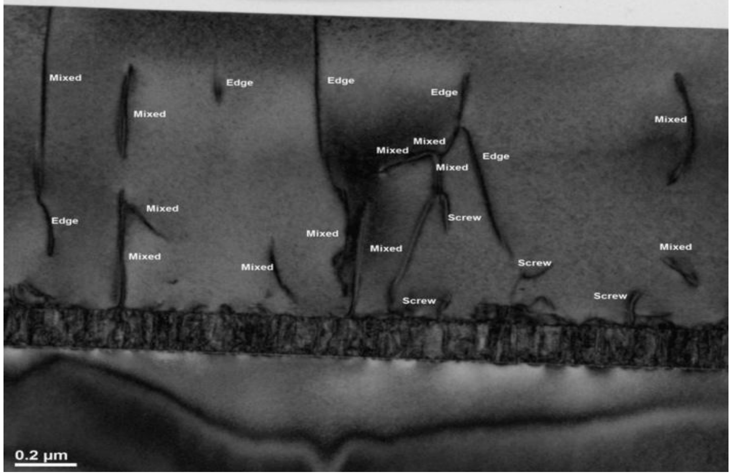

Figure 3: TEM of 1µm GaN on PVD Buffer. Threading defect density equals 7 x10^8/cm^2

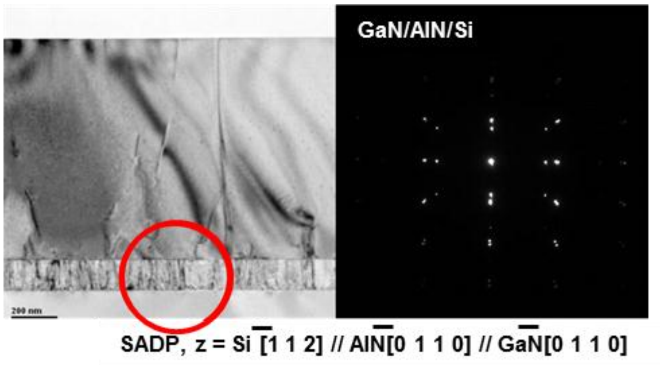

Figure 4: TEM and Diffraction Pattern of 1μm GaN on PVD AlN Buffer

CONCLUSIONS

A PVD AlN buffer layer process was developed for Si substrates up to 8” in size. Epitaxial growth with high quality films has been demonstrated. MOCVD GaN deposited on the AlN leads to low defect density films with (002) and (102) ω FWHM <700 arcsec for thickness of 1μm.

ACKNOWLEDGEMENT

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REFERENCES

[1] Nikishin S A et al 1999 *Appl. Phys. Lett.* **75** 2073.

[2] Strite S et al 1992 *J. Vac. Sci. Technol.* B **10** 1237.

[3] Choy K L 2003 *Progress in Matl. Sci.* **48** 57.

[4] Razeghi M *Technology of Quantum Devices* (New York: Springer 2010), 17.

ACRONYMS

PVD: Physical Vapor Deposition
AlN: Aluminum Nitride
GaN: Gallium Nitride
CTE: Coefficient of Thermal Expansion
MOCVD: Metal-Organic Chemical Vapor Deposition
XRD: X-ray Diffractometry
TEM: Transmission Electron Microscopy
AFM: Atomic Force Microscopy