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Synthesis and Characterization of GaN Nanocrystalline Thin Films on Various Substrates by RF Magnetron Sputtering

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Gallium nitride (GaN) nanocrystalline (NC) thin films (TH) were deposited on different surfaces of material as substrates; quartz, glass as well as fluorine-doped tin oxide (FTO) using radio frequency (RF) reactive magnetron sputtering method. The effects of substrate type on structural and morphological properties of GaN-NCTH were studied. X-ray diffraction analyses and field-emission scanning electron microscopy (FESEM) images showed that the GaN particles have covered all surfaces of the substrates with a smooth arrangement. The root mean square (RMS) surface roughness was 30.8, 1.45 and 1.46 nm for the GaN-NCTH deposited on FTO, glass and quartz substrates, respectively. Based on the GaN-NCTH prepared onto glass substrate, the optical bandgap was calculated to be 3.38 eV.

Keywords: GaN nanocrystalline; RF sputtering; thin film; Epitaxial growth.

1. INTRODUCTION

GaN is a semiconducting material with a wide and direct bandgap of 3.4 eV, superior optical characteristics and good thermal constancy with binding energy of excitation of 26 MeV, [1, 2]. GaN as a Bulk is troublesome to prepare owing to its excessive deposition states and complicated methods. Fortunately, with the extension and development of synthesis methods, GaN substrates with variety dimensions are now mercantile obtainable [3]. The epitaxial growth of GaN on various substrates for device fabrication is a modern and typical technology that reduces the cost and dimensions of GaN in bulk form.

The heteroepilayers of GaN are commonly displayed with a large ratio of defects containing a high value of n-type carriers and threading disruption [4-7]. Many preparation methods including chemical bath deposition techniques are high in expenditure for growing

GaN-NCTH and extremely beneficial in nanomaterials fabrication. Nevertheless, the precursors used in previous studies were high cost and not easily obtainable. On the other hand, the ideality and efficiency of the grown films prepared by chemical solution methods were not equal to those of other methods in characterizing the optical properties and surface morphology [8]. So, in this work, a simple method was explored to obtain a high efficiency of GaN-NCTH by the RF sputtering method. In this context, a successful preparation of epitaxial GaN-NCTH onto glass, FTO and quartz substrates by this method was reported.

2. EXPERIMENTAL PROCEDURE

GaN-NCTH was prepared via radio frequency (RF) reactive magnetron sputtering on FTO, glass and quartz substrates. The growth time was recorded to be 80 minutes to produce thin GaN-NCTH with a thickness of 200 nm ± 5 nm. A disk of GaN (99.99% purity with 3 in diameter) was used as a target. Meanwhile, argon and nitrogen with high purity (99.99%) were used as sputtering gas at a steady ratio of 5%. All procedure details on cleaning method of the substrates, vacuum of preparation chamber and other conditions such as pressure, RF power, deposition temperature as well as characterization instruments, operation conditions of tools and setting parameters used in this study have been briefly described in the previous work [9, 10].

3. RESULTS AND DISCUSSION

Figure 1 displays the FESEM images of GaN-NCTH grown on FTO, glass and quartz substrates with two magnification images (50.000 and 300.000 x). It was apparent that the deposited GaN-NCTHs have homogeneously covered the whole surface of the substrate without any crack. However, GaN-NCTH on FTO substrate appeared aggregated to form large grains, whereas the TH deposited on quartz and glass substrates showed a smooth arrangement of GaN particles on the surface with a very flat surface and a very small aggregation to form tiny grains.

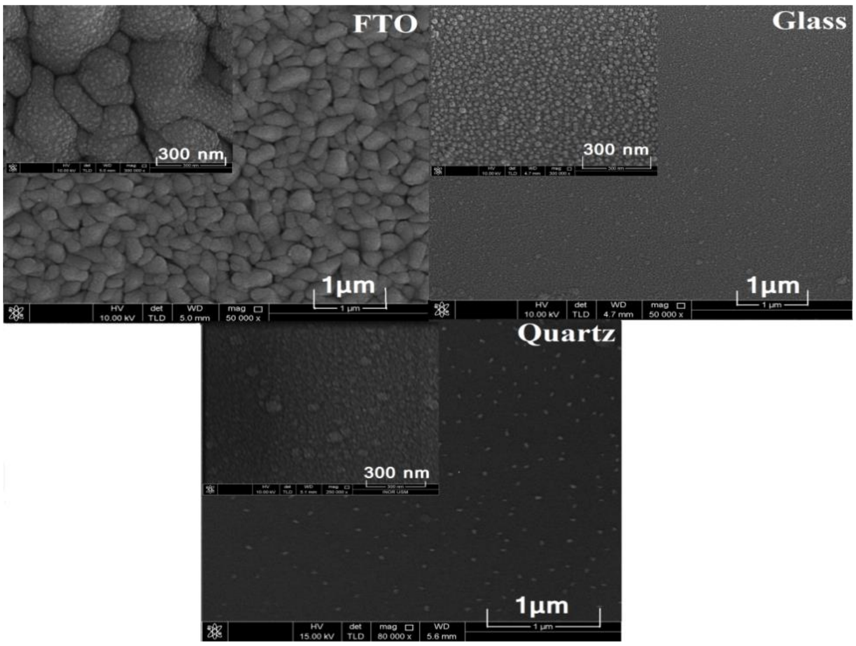

Figure. 1: FESEM images of GaN-NCTHs prepared on different substrates.

Figure 2 displays three dimensions AFM images of the surface morphology of GaN-NCTHs grown on various substrates. The surface roughness of the GaN-NCTHs was calculated by investigating the AFM images using NanoScope Analysis program. Evidently, it was seen that the type of substrate had affected surface roughness. The RMS values of GaN-NCTHs grown on FTO, glass and quartz substrates were 30.8, 1.45 and 1.46 nm, respectively. In the meantime, the prepared GaN-NCTHs on glass and quartz displayed a smoother surface morphology compared to that deposited on FTO substrate. The large and rough surface area of GaN-NCTH on FTO substrate may have improved the photo-scattering activity and increase light absorption [11,12]. Subsequently, the RF sputtering technique can be used to prepare GaN-NCTH with high quality and least defects for future applications in the field of optoelectronic nanodevice. Moreover, the EDX analyses of all GaN-NCTHs showed the existing of Ga and N atoms in the films, thus supporting the synthesis of GaN-NC. Furthermore, Figure 3 exhibits that the ratio of Ga to N was changed with the substrate type. The Ga to N ratios of GaN-NCTHs grown on various substrates are recorded in Table 1.

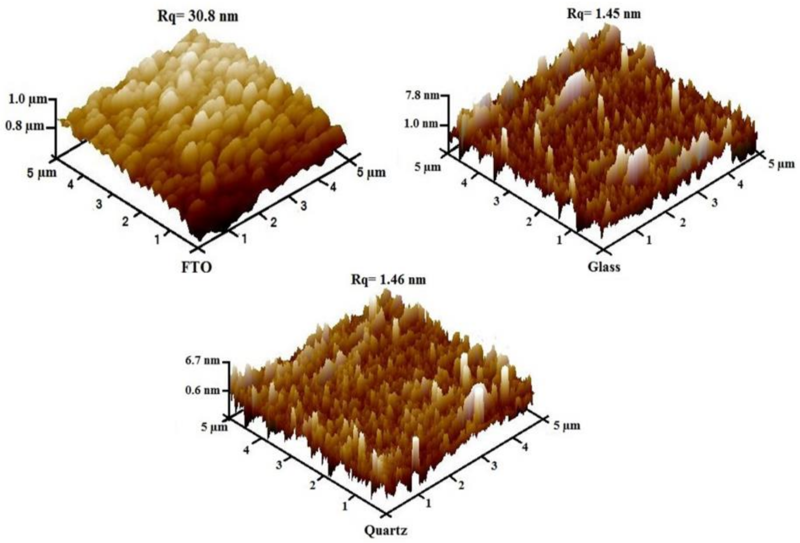

Figure. 2: AFM images (3D) of GaN-NCTHs prepared on different substrates.

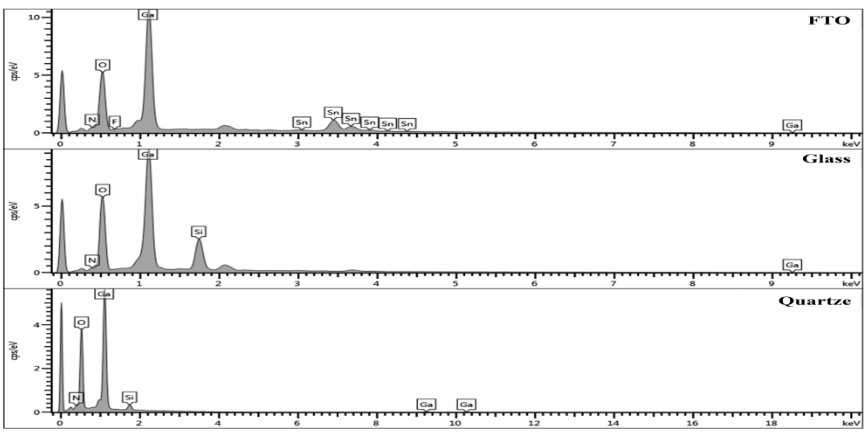

Figure. 3: EDX spectra of GaN-NCTHs grown on various substrates.

Table 1: EDX analysis results for the GaN-NCTHs grown on various substrates.

Substrate	Ga		N		Si		O	
	weight %	Atom %	weight %	Atom %	weight %	Atom %	weight %	Atom %
FTO	51.53	31.53	26.35	9.47	0	0	22.12	59
Glass	55.21	24.52	1.81	4	14.1	15.56	28.88	55.92
Quartz	57.05	23.54	3.57	7.33	2.16	2.21	37.22	66.92

These values displayed a best stoichiometry compared to the other two samples for the sample prepared on FTO substrate. On the other hand, results showed that this sample has 51.53 wt.% Ga and 26.35wt.% N as well as the signal of Si in other samples that comes from the substrate. However, the presence of O atom maybe because of the surface contamination growing from substrate through deposition operation [4].

3.2. Structural analysis and energy gap

Figure 4 exhibits XRD graphs of GaN-NCTHs prepared on various substrates. All prepared films demonstrated different peaks that are in line with the criterion value of bulk GaN having a hexagonal structure (JCPDS card no. 50-0792) as earlier investigated for GaN-NC [13-15]. The XRD Peaks of the samples grown on FTO and quartz substrates were noted as (100), (004), (202) and (100), (002), (004), respectively. In addition, the six detected peaks with higher intensity were seen belonged to FTO substrate (JCPDS card no. 30-1375). Dominant peaks were observed in Figure 4 and indexed as (100), (102), (110) and (200), (201) for GaN-NC grown on glass substrates. Meanwhile, the lattice constants (L.C) a and c, strain (ζ_a, ζ_c), size of crystalline (D) and lattice mismatch (d) were obtained from the highest peak namely (100) using famous equations [16, 17] as listed in Table 2.

Table 2: Structural parameters of GaN-NCTHs prepared on different substrates.

Substrate	Lattice Constant		Strain (ζ_a) (%)	Strain (ζ_c) (%)	Crystalline Size D (nm)	Lattice Mismatch d (%)
	a	c				
FTO	3.184	5.177	-0.15	-0.15	6.11	-0.077
Glass	3.240	5.136	1.59	-0.94	10.37	1.2
Quartz	3.162	5.182	-0.84	-0.05	7.21	-0.667

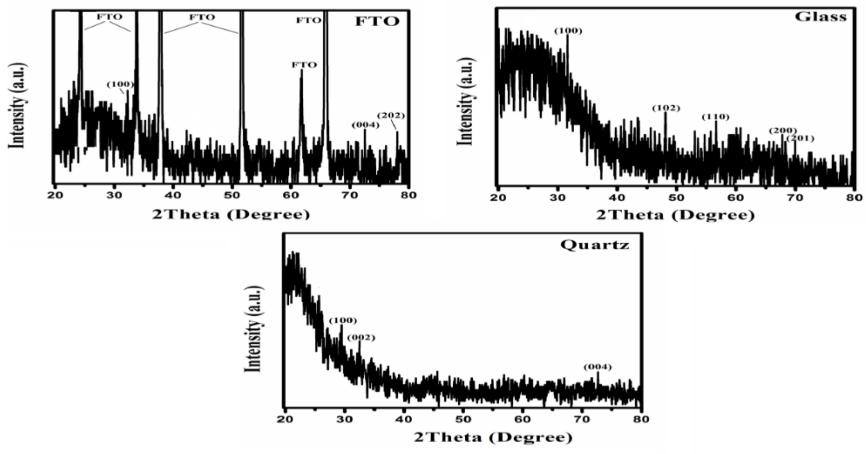

Figure. 4: XRD graphs of GaN-NCTHs prepared on a variety of substrates.

The optical energy gap was calculated (Fig. 5) by drawing the intercept of tangent to the curve in the $(\alpha hv)^2$ versus hv schemes according to the standard formulae [9, 18]. The energy gap of GaN-NCTHs prepared on glass substrate was 3.38 eV, which was very close to the value earlier reported [19-21].

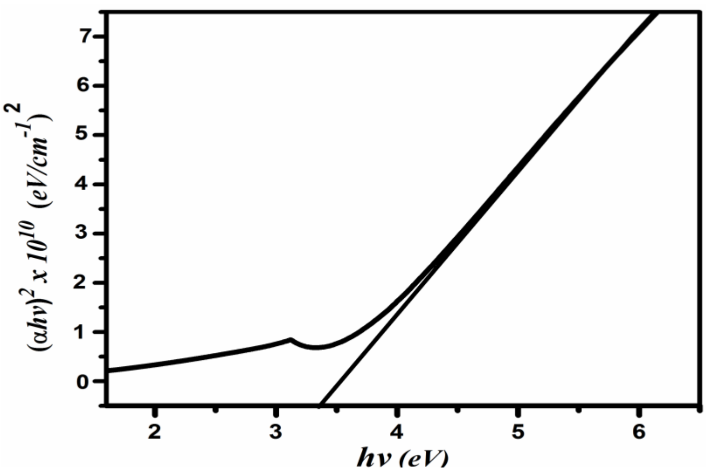

Figure. 5: A plot of $(\alpha\, hv)^2$ versus (hv) of GaN-NCTHs prepared onto glass substrates.

4. CONCLUSION

In summary, the GaN-NCTHs with hexagonal structure have been grown at room temperature by the RF sputtering method with a low thickness on various substrates. All results in this study showed that the types of substrate affected the structural and morphological properties of the prepared samples. Furthermore, the energy gap has been calculated for sample grown on glass substrate and found to be equal to 3.38 eV.

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