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Dielectrics for GaN Based MIS-Diodes

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ABSTRACT

GaN MIS diodes were demonstrated utilizing AlN and $Ga_2O_3(Gd_2O_3)$ as insulators. A 345 Å of AlN was grown on the MOCVD grown n-GaN in a MOMBE system using trimethylamine alane as Al precursor and nitrogen generated from a wavemat ECR N_2 plasma. For the $Ga_2O_3(Gd_2O_3)$ growth, a multi-MBE chamber was used and a 195 Å oxide is E-beam evaporated from a single crystal source of $Ga_5Gd_3O_{12}$. The forward breakdown voltage of AlN and Ga_2O_3(Gd_2O_3) diodes are 5V and 6V, respectively, which are significantly improved from ~1.2 V of schottky contact . From the C-V measurements, both kinds of diodes showed good charge modulation from accumulation to depletion at different frequencies. The insulator/GaN interface roughness and the thickness of the insulator were measured with x-ray reflectivity.

INTRODUCTION

Silicon bipolar junction transistors and GaAs metal field effect transistors have been quite successful in the area of high speed power applications because of their combination of high saturation velocity and moderately large bandgaps[1,2]. As power requirements continue to increase, however, performance is becoming limited by device breakdown, suggesting larger bandgap materials are required. Recently, the group III nitrides have received a great deal of attention as wide bandgap alternatives to the more extensively investigated SiC material[3,4]. These materials are expected to be excellent candidates for use in high temperature and high power applications because of their saturation velocities in addition to the larger bandgaps.

A number of GaN field effect transistors (FETs) and AlGaN/GaN heterostructure FETs have been reported, showing excellent device breakdown characteristics[5,6]. However, the conventional low resistance n^+-cap layer structure for the GaAs technology cannot be applied in the nitride based material system to reduce the parasitic resistances, owing to no adequate gate recess technology available. The III-nitrides are chemically very stable and few wet etching recipes exist. GaN may be etched by molten KOH or NaOH at ≥400°C, while laser enhanced HCl or KOH solutions produce etch rates of a

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few hundreds angstroms per minute at room temperature[7]. Virtually all of the nitride devices reported to date have employed dry etching for pattern transfer and ion bombardment induced low gate breakdown voltage were observed[8,9]. Both of these problems may be overcome by using a MOSFET approach.

Recently, interface properties of $Ga_2O_3(Gd_2O_3)$/GaAs structures fabricated using *in-situ* multiple-chamber molecular beam epitaxy have been investigated. The oxide films were deposited on clean, atomically ordered (100) GaAs surfaces at ~550 °C by electron-beam evaporation using a $Gd_3Ga_5O_{12}$ single-crystal source. A mid-gap surface state density of 2×10^{10} $cm^{-2}eV^{-1}$ was obtained[10]. Both n- and p-GaAs based enhancement-mode MOSFETs were also demonstrated[11].

Aluminum nitride has been proposed as a potential replacement for silicon dioxide in high temperature MIS based silicon carbide device applications. AlN is a wide bandgap semiconductor (6.2 eV) but if made undoped, its properties are most like those of an insulator. A high relative dielectric constant (8-9) alleviates the problem of high fields in the dielectric in high voltage applications. The breakdown electric field, however, is not yet fully determined. Moreover, the thermal conductivity of AlN is high, making this material a potential high temperature stable gate dielectric. One difficulty associated with this material may be its tendency to deposit as a polycrystalline layer rather than an amorphous one.

In this work, first we employed the similar deposition technology of Ga_2O_3(Gd_2O_3) on GaAs for the GaN based material system. We also used MOMBE system to grow the aluminum nitride for the alternative diode insulator. The MIS diodes using these two insulators were then fabricated and characterized with I-V and C-V measurements. The dielectric thickness and interface roughness were measured with x-ray reflectivity[12,13].

EXPERIMENTAL

The GaN layer structure was grown on c-Al_2O_3 substrates prepared initially by $HCl/HNO_3/H_2O$ cleaning and an in-situ H_2 bake at 1070 °C. A GaN buffer <300 Å thick was grown at 500°C using trimethylgallium and ammonia, and crystallized by ramping the temperature to 1040°C. The same precursors were again used to grow ~3 μm of undoped GaN ($n < 1 \times 10^{16}$ cm^{-3}) and a 2000 Å Si-doped ($n = 2 \times 10^{17}$ cm^{-3}) active layer[14].

The diode fabrication started with ohmic contact formation by depositing In on the edge of the GaN samples by using shadow mask and heat up to 500 °C. Then, the samples were transferred to growth chamber for insulator growth. For the $Ga_2O_3(Gd_2O_3)$ growth, the sample was loaded into a solid source MBE chamber and the native oxides of GaN were thermally desorbed at a substrate temperatures of 600 °C. After oxide desorption, the wafer was transferred under vacuum (10^{-10} torr) into a second chamber and the $Ga_2O_3(Gd_2O_3)$ was deposited on the GaN using e-beam evaporation at a substrate temperature of 550 °C[15].

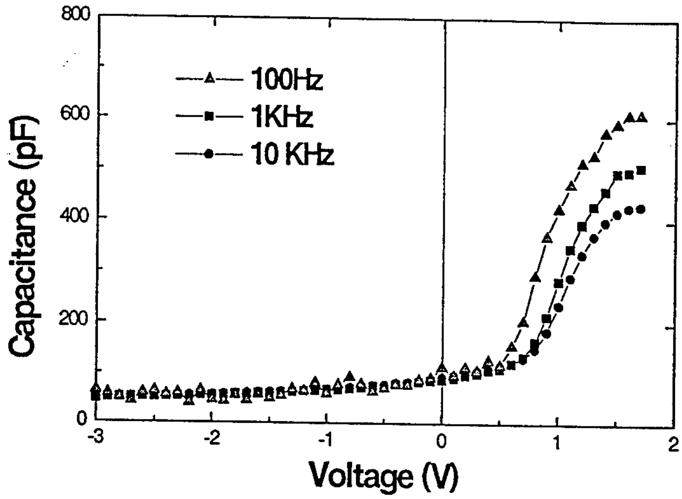

Fig. 2. A C-V characteristics of a $Ga_2O_3(Gd_2O_3)$/GaN diode measured at different frequencies.

From Fig. 3, the thickness of the $Ga_2O_3(Gd_2O_3)$ and the root mean square roughness of the $Ga_2O_3(Gd_2O_3)$/GaN interface were estimated to be 195 Å and 3 Å, respectively. The slope of the x-ray reflectivity is a function of the oxide thickness and the roughness of the $Ga_2O_3(Gd_2O_3)$/GaN interface as well as the air/$Ga_2O_3(Gd_2O_3)$ interface will determine the widths of oscillation periods. With the 195 Å thick $Ga_2O_3(Gd_2O_3)$ and the 6 V forward breakdown, the breakdown field of the oxide is >12 MV/cm. The atomic level (3 Å) smoothness for the $Ga_2O_3(Gd_2O_3)$/GaN interface can provide a high carrier mobility for MISFET.

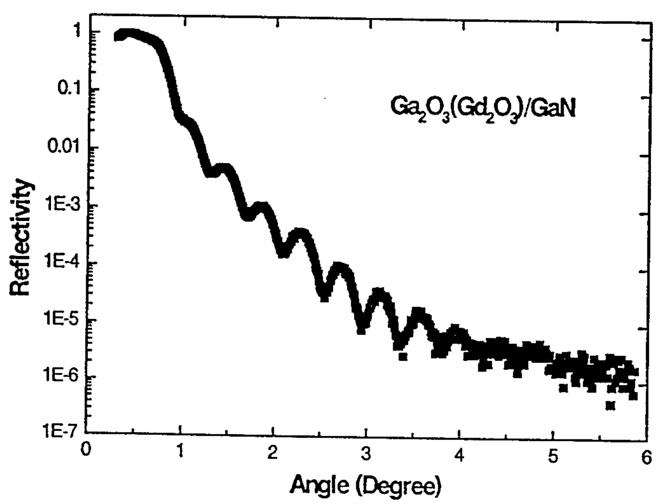

Fig. 3. X-ray reflectivity of the $Ga_2O_3(Gd_2O_3)$/GaN diode sample.

The x-ray reflectivity data for the AlN/GaN diode sample is illustrated in Fig. 6. The thickness of the AlN and the root mean square roughness of the AlN/GaN interface were determined to be 345 Å and 20 Å, respectively. The 20 Å roughness of the AlN/GaN interface may be due to the inter-diffusion between Al and Ga, however, more detailed study is needed to confirm this. With the 345 Å thick AlN and the 5 V forward breakdown, the breakdown field of the oxide is around 1.4 MV/cm. The lower breakdown field may be caused by the rough AlN/GaN interface or the crystalline of AlN.

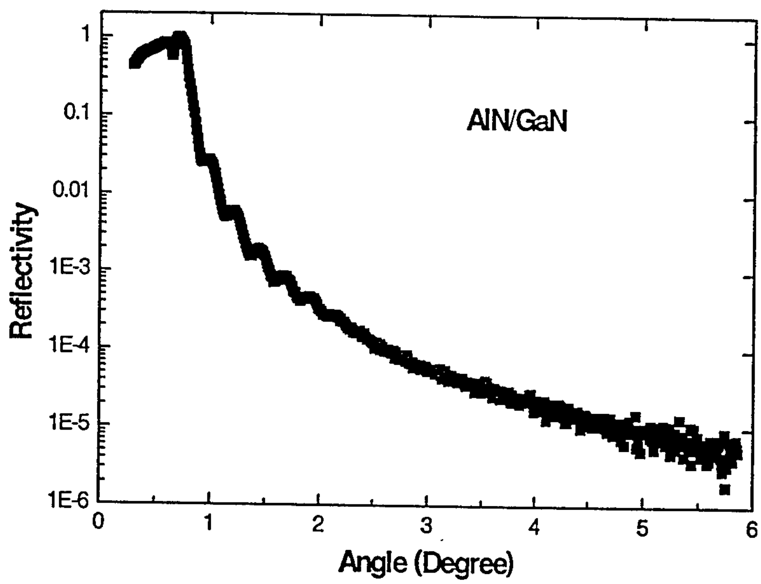

Fig. 3. X-ray reflectivity of the $Ga_2O_3(Gd_2O_3)$/GaN diode sample.

CONCLUSIONS and SUMMARY

GaN MIS diodes were demonstrated using MOMBE grown AlN and MBE evaporated $Ga_2O_3(Gd_2O_3)$ as the insulators. The breakdown fields of AlN and $Ga_2O_3($ $Gd_2O_3)$ diodes are 1.4 MV/cm and 12 MV/cm, respectively. From the C-V measurement, both kinds of diodes show good charge modulation from accumulation to depletion at different frequencies. The extremely smooth $Ga_2O_3(Gd_2O_3)$/GaN interface was achieved and the rms of the interface roughness is 3 Å which is down to the atomic range. However, the rms roughness AlN/GaN interface is around 20 Å which may be caused by inter-diffusion by Al and Ga, more detail study is needed to confirm this. For future studies, the surface cleaning (*in-situ* or *ex-situ*) wet/dry processes, including thermal oxide desorption, ozone cleaning or HF vapor, and thermal stability of the diodes are the key for the realization of the GaN based MISFET technology.

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