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Optoelectronic properties of improved gan semiconductor on si(111)using growth approaches and different interlayer's

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Abstract: The crystalline quality of wider direct band gap semiconductor (3.4 eV)hexagonal GaN (h-GaN)epilayer grown on Si(111)is evaluated by using different growth approaches and interlayer's. The investigations of GaN epilayer crystal quality for the template of converted porous GaN layer formed by novel nitridation process of thin (2 and 0.5µm)GaAs layer on Si(111)and on C^+ ion implanted very thin SiC layer formed on Si(111)and grown ambient effect are made. Epilayer grown on thinner non-isoelectronic converted SiC templates is found to broaden its PL line width whereas epilayer grown on porously converted GaN layer fromed from iso- electronic GaAs (111)layer on Si(111)is found narrow line width. H_2 ambient grown film better crystalline quality and higher PL Ex. peak energy is found as compared to N_2 ambient grown film. Low temperature PL measurement, similarity between defect related donor-acceptor peaks (DAP)to defect related yellow band luminescence at the room temperature PL measurement is also found. Grown epilayer different characterization reveals better crystalline quality h-GaN is achieved by using thin iso-electronic GaAS interlayer on Si(111)with H_2 grown ambient.

Keywords: Wide Band Gap, UV Detector, RF Power Electronics, Optoelectronics, Photoluminescence, H-Gan, Iso-Electronic, Ohmic Contact

1. Introduction

As a direct wide band gap and intense luminescence intensity semiconducting material, GaN is promising for RF power electronics, UV detectors, laser diode (LDs), light emitting diode (LEDs)and its integration with InN can covered almost whole solar spectrum for Solar Photovoltaic application [1-3]. As well-known matured semiconductor technological application of Si; GaN epitaxy on Si is highly desirable for optoelectronic devices application due to its reduction of ohmic contact resistance. In conventional growth process due to stress and for poor wetting property of GaN on Si, poor quality of epilayer is found to be grown [4-5]. As III-V semiconductor materials, GaAs iso-electronic structure is compatible with III-N materials and considering coincidence site lattice (CLS)relationship between GaAs and GaN, GaAs is promising substrate for GaN epitaxy [5]. Much higher electro negativity of N and shared Ga atom is suitable for GaN epitaxy on GaAs. GaAs is also suitable to act as a low yield stress compound semiconductor. Also, in case of performance aspects sapphire is less attractive than Si for laser diode (LDs)and light emitting diode (LEDs)and for the integration of GaN [1]. Due to poor thermal conductivity of sapphire, it prevents dissipation of heat for high power and high current operating devices [6]. But for better quality device fabrication, impact of higher residual stress or cracking in the epilayer for GaN epitaxy on Si is a detrimental [7].

2. Experimental

GaN on Si(111)is deposited using MBE grown GaAs layer as nucleation layer of GaN and C^+ implanted SiC layer is used as nucleation layer for GaN on Si(111)in MOVPE process [8-9]. For hetro-epitaxy, buffer layer acts as a wetting layer for improvement of epitaxial layer quality. Porous/intermittent converted layer (CL)is formed from conversion of cleavage GaAs surface into GaN by inter diffusion of N→As [10]. Then h-GaN epitaxy is made on Si by using converted GaAs layer by formation of low temperature GaN coating layer prior to nitridation of GaAs surface [8]. Due to the variation of lattice bond length and atomic radii of As and N atoms the converted GaN layer is formed defective and porous. SiC interlayer formed by C^+ ion implantation on Si(111)also thought to be defective between crystalline SiC template and Si substrate [11] . So such interface defects and porous interface layer appears effectively to reduce epilayer residual thermal stress during post growth cooling [9].

3. Result and Discussion

In case of epilayer growth in novel approach using low temperature GaN cap layer on GaAs and due to nitridation during ramping substrate temperature, the GaAs layer much decomposition at high temperature was found to form poor crystalline porous GaN interlayer as it is shown in Fig.1a. Due to conversion of GaAs through the GaN cap layer (appears to suppress sufficient nitridation), such porous and poor crystalline structure is found to be formed.

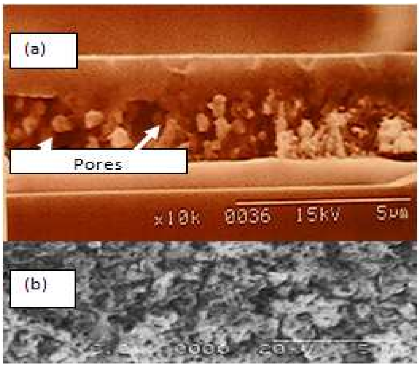

Fig. 1. *SEM cross-sectional view of GaN layer grown on 2μm porous GaN (a)and interlayer surface after KOH etching of GaN layer (b).*

Etching of cap layer shows many pores in the surface as it is shown in Fig.1.b. This porous and poly type surface below the GaN cap layer appears to be effective to reduce epilayer thermal stress and cracks. h-GaN growth direction is the direction of out of plane lattice constant c, which usually contracts or dilates for biaxial strain. Room temperature X-Ray diffraction pattern (XRD)comprises the stress of GaN layer due to growth and the thermal stress. In below Fig. 2 shows the growth ambient effect on a variation of epilayer out of plane lattice strain. In case of GaN epilayer grown on Si(111)in hydrogen gaseous (H_2)ambient, out of plane lattice strain is found to be decreased in compare to the epilayer grown in nitrogen gaseous N_2 ambient. For N_2 ambient growth strategies, due to higher nitrogen vapor pressure spontaneous GaN composition occurs and the growth seems to be enhanced along c plane of h-GaN. So such growth property may be related for the variation of lattice strain and polarity. It may be due to polarity/ polarization effect. By calculating the GaN(004)plane scattering result out of plane lattice constant is found to be 5.185 (near stress free)and 5.18 nm for H_2 and N_2 ambient grown epilayer respectively.

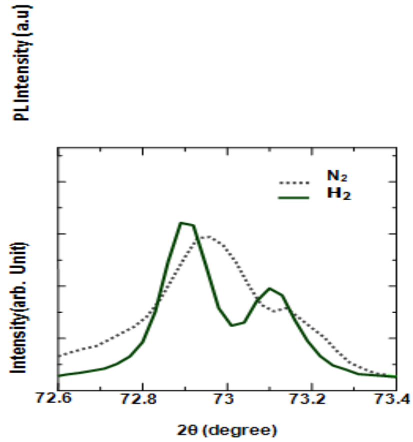

Figure. 2. *θ-2θ X-Ray diffraction pattern of hexagonal-GaN (004)plane.*

Figure 3, shows the PL excitonic peak energy level for H_2 and N_2 ambient grown film. Using thin interlayer on Si substrate, the epilayer of crystalline quality is found to be improved significantly as compared to the epilayer grown on Si substrate. The H_2 grown ambient is found to improve the epilayer excitonic peak energy though significant line width improvement is not observed. The epilayer grown by H_2 ambient is found to the PL energy level similar to Ga polarity GaN grown on Al_2O_3 [9]. KOH wet etching also revealed it.

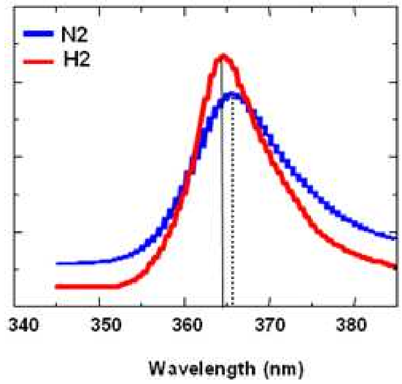

Figure 3. *Near band edge (NBE)Photo-luminescence (PL)peak of h-GaN.*

The epilayer PL line width improvement by using iso-electronic crystalline structure interlayer is observed precisely. The epilayer grown on SiC interface layer surface was found wider PL FWHM value as compared to the epilayer grown on converted GaN interlayer from GaAs. Though both cases (SiC and GaAs interlayer)the large inversion domain seems to be related to be broadened the PL line width as compared to GaN epilayer grown on sapphire, but due to iso-electronic crystalline structure of GaAs and GaN in certain cleavage direction, the epilayer such improvement is observed as it is shown in Fig.4.

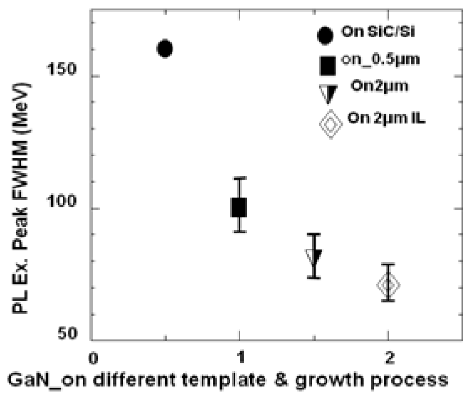

Figure 4. *Near band edge (NBE)Photo-luminescence (PL)peak full width at half maximum (FWHM) of h-GaN.*

So it appears that apart from the Si substrate epilayer electronic structure of GaAs surface on Si and eventually its converted into GaN is most possible reason to improve it significantly.

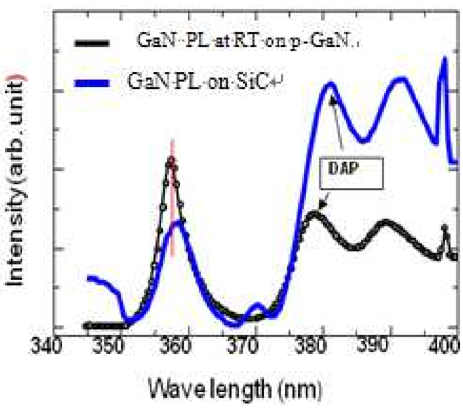

Figure 6. *Low temperature (25°C) photo-luminescence assessment of h-GaN.*

Room temperature (RT)PL measurement, it is shown that GaN epilayer grown on converted GaN interlayer possesses intense GaN near band edge peak and low yellow band related peak[8]. But GaN grown on very thin converted SiC interlayer is very high yellow band related peak. From low temperature PL measurement a co-relation between the defects related yellow band emission intensity to DAP recombination related peak intensity is found. Extensive near bandage excitonic peak energy with low level of defect related yellow band emission sample shows low DAP related peak as compare to the sample shown higher defect related yellow band emission as well as higher DAP related peak at room temperature and low temperature PL measurement respectively. This measurement shows higher DAP recombination related peak intensity at low temperature PL measurement. So from this characterization it is also revealed that acceptor related V_{Ga} -O_N or V_{Ga}-Si_{Ga}, complex point defects may be related to the yellow band emission for n-type GaN and it is found form DAP recombination. Excitonic emission intensity of GaN epilayer on porously converted layer is found very intense with low impurity or defect related DAP recombination peak.

Due to piezoelectric property of h-GaN, E_2 (high)phonon frequency of Raman scattering analysis is highly sensitive to the lattice out of plane lattice constant and it frequency is varied for Biaxial strain. GaN epilayer grown hetro-epitaxially on Si substrate is not found to increase its E_2 (high)phonon frequency with growth H_2 ambient. h-GaN E_2(high)peak for the epilayers grown on SiC and porously converted GaN interlayer is found to increase with respect to GaN grown directly on Si. It appears from Raman scattering analysis that the epilayer out of plane lattice strain variation of different growth approach samples grown at 1000℃ is mainly due to the interface layer structural property. Our Ga polarity domain epilayer E_2 (high)phonon frequency revealed it.

From Raman scattering analysis for A_1(LO)peak position is measured. Low PL Ex. peak energy film average higher carrier concentration related shift of A_1(LO)to higher Cm^{-1} is found. From PL and Raman scattering analysis, it appears that epilayer crystalline quality is poor for N_2 ambient grown film and due to excess carriers; low Ex. peak energy is found. So space-charge scattering of carriers due to inhomogeneous impurities and/or local defects seems to cause red shift of the PL near band energy (NBE)[12] and it is not due to the stress of the epilayer.

4. Conclusion

As a promising wideband gap semiconductor for optical communication and devices as well, GaN semiconductor properties on Si(111)is addressed properly in this research work. The GaN epliyer stress and cracks minimization technique is investigated for its promising integration with Si(111). Thermal stress reduction due to porous layer formation between Si and GaN is revealed. Depending on pre-epilayer growth process or template formation and growth ambient, the out of plane lattice strain and epilayer crystalline property is investigated properly. The GaN epilayer grown on Si(111)substrate using porous interface layer is found better crystalline quality compared to the epilayer grown on SiC interlayer formed by C^+ ion implantation on Si(111). Interlayer iso-electronic structure was found to be a promising factor to improve the epilayer crystalline and optical properties as well. The epilayer grown by H_2 ambient was found to the PL NBE level similar to Ga polarity GaN grown on Al_2O_3.

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