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Reduction of Impurity Incorporation into MOVPE-grown GaN films on $ScAlMgO_4$ Substrate

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Abstract

The influence of the impurity incorporation on the electron concentration and Hall mobility of GaN films grown on $ScAlMgO_4$ (SCAM) substrates by metalorganic vaper phase epitaxy was investigated. Hall measurements revealed huge drop of their characteristics in Si-doped GaN on an SCAM substrate compared with that on a sapphire substrate. Secondary ion mass spectrometry (SIMS) measurements showed that both atoms of Sc and Mg were incorporated into GaN films grown on an SCAM substrate. An AlN insertion layer between a GaN film and an SCAM substrate, and the SiO_2 coating on both backside and side walls of an SCAM substrate introduced for suppressing the impurity incorporation can improve the electron concentration and Hall mobility to the same level as those of a GaN film grown on a sapphire substrate. SIMS measurements clarified that an AlN insertion layer was effective for reducing the Mg incorporation, and SiO_2 coating on both a backside and sidewalls of an SCAM substrate was effective for reducing the incorporation of both atoms of Sc and Mg.

1. Introduction

The nitride semiconductor has been widely used for commercially available LEDs due to its widely tunable band-gap from ultraviolet to infrared. Neither a native GaN substrate nor a free-standing one can be available for LEDs fabricated with low cost because they are too expensive. Instead of them, *c*-plane sapphire substrates with large lattice mismatch of 14% to GaN have been mainly used. This mismatch leads to generating large number of misfit dislocations which acts as non-radiative recombination centers. To achieve LEDs with high efficiency, the introduction of a new substrate with small lattice mismatch is indispensable. As a solution of this issue, a $ScAlMgO_4$ (SCAM) substrate with small lattice mismatch of –1.8% to GaN has been proposed [1]. An SCAM crystal has been grown by Czochralski method which is suitable for mass production. GaN films grown on SCAM substrates by metalorganic vaper phase epitaxy (MOVPE) have been recently studied [2, 3]. Still now, SCAM has some difficulties in the usage as a substrate for GaN devices. It has been reported that a GaN film grown on an SCAM substrate exhibits higher resistivity than that on a sapphire substrate [4]. This is presumably due to impurities originated from an SCAM substrate, especially Mg which acts as a compensator for GaN. Sc was also reported to drastically reduce Hall mobility [5]. Those impurities are considered to be incorporated into GaN films by diffusion from the interface between GaN films and SCAM substrates or by diffusion through the vapor phase due to the decomposition of a back-surface and side-walls of an SCAM substrate. In this paper, the reduction of the impurity incorporation into a GaN film grown on an SCAM substrate by introducing the impurity suppression structures is described. The mechanism of the impurity incorporation is also discussed.

2. Experiments

All the samples were grown by MOVPE on cleaved *c*-plane SCAM substrates. The SCAM substrates were cleaned by an organic solvent and rinsed by purified water. The hydrogen cleaning was performed prior to the GaN growth at the surface temperature of 1070ºC for 8 min. Then a thin GaN layer was grown at low temperature of 600ºC and a 1.8-µm-thick undoped GaN template was grown at 1070ºC. This undoped layer was highly resistive. For Hall measurements, a 1.8-µm-thick Si-doped GaN was grown on the undoped layer.

To investigate the mechanism of the impurity incorporation from the interface, the Si-doped GaN was grown on a thin AlN layer via a 600-nm-thick GaN film using a GaN template on an SCAM substrate. An AlN layer is known to work as a diffusion stopper for Mg [6]. The temperature for the AlN layer was 600ºC. To suppress the decomposition of the back surface and the side walls of an SCAM substrate, the back surface and the side walls were coated with about a 1-µm-thick SiO_2 film formed by RF spattering. Hall effect measurements were performed to investigate the electrical properties under 3.0 kgauss at room temperature by Van der Pauw method. To measure the concentration of Mg atoms, the secondary ion mass spectrometry (SIMS) measurements were performed by CAMECA IMS-7f using Cs^+ as a primary Ion.

3. Result and discussion

As a reuslt of Hall measurements, all the samples showed n-type conduction. Figure 1 shows their Hall mobility and electron concentration, accompanied with these electrical characteristics simulated at various electron compensation ratios [7]. Both Hall mobility and electron concentration of GaN directly grown on an SCAM substrate decreased, compared with those for GaN grown on a sapphire substrate. The compensation ratio was estimated as high as 90% from

Fig. 1. This high compensation ratio is considered to be the effect of impurities incorporated from an SCAM substrate. For GaN with an AlN insertion layer, both the Hall mobility and the electron concentration increased. These increases in electrical characteristics indicate the reduction of the impurity incorporation by diffusion or segregation from the interface between SCAM and GaN. By introducing both an AlN insertion layer and an SiO_2 coating film, both electrical characteristics were improved farther more. The compensation ratio was recoverd to the level of GaN grown on sapphire. This result indicates that impurities from the back side and the side walls of an SCAM substrate are incorporated into GaN through the vapor phase. Therefore the mechanism of the impurity incorporation was found to be both the diffusions through GaN and from vapor phase.

To further reduce the impurity incorporation, another coating material was also investigated. An SiO_xN_y film as thin as 40 nm was formed by the RF sputtering process. A Si-doped GaN film grown on an SCAM substrate coated with an SiO_xN_y film showed the electron compensation ratio as low as 60 %. This result is comparable with the result on a sapphire substrate. The low electron-compensation ratio is considered to be the result of highly dense SiO_xN_y compared with SiO_2.

The impurities and those origins inside a GaN film grown on an SCAM substrate were identified with the SIMS measurement. A GaN film was grown on an SCAM substrate with both an SiO_2 film and an AlN insertion layer which act as the impurity suppression structures. Figure 2 shows both the depth profiles of the Mg concetration and the Sc secondary ion intensity measured by SIMS using Cs^+ ions as primary ions. Without any impurity suppression stuctures, the Sc secondary ion intensity decreased with increasing the distance from the SCAM substrate, which indicates that a main pass of the Sc incorporation is the diffusion through the interface between the GaN film and the SCAM substrate. In contrast, the Mg concentration was almost constant at 1×10^{18} atoms/cm^3. This result indicates that the diffusion through the vapor phase is a main pass of Mg incorporation. From the comaprison of the electron concentration determined by Hall measurement with the Mg concentration determined by SIMS, the electron concentration was also found to be compensated by the incorporated Mg impurities which acted as acceptors.

For the sample coated with an SiO_2 film and insereted an AlN layer, both the Sc secondary ion intensity and the Mg concentration between a substrate and an AlN layer were lower than those for a sample without any suppression structures. This result suggests that the SiO_2 coating was effective for the incorporation of both Sc and Mg.

By comparing the impurity concentration between the regions above and below an AlN insertion layer, the Sc intensity over an AlN layer decreased by about two orders of magnitude although the concentration of Mg was constant in both regions. This result means that AlN was effective only for Sc incorporation.

4. Conclusions

The supression method for the impurity incorporation into a GaN film grown on an SCAM substrate was investigated. The electrron concentration and the Hall mobility in an Si-doped GaN film grown on an SCAM substrate were found to be low, compared with those on a sapphire substrate. By inserting an AlN layer between an Si-doped GaN and an SCAM substrate, and by coating with an SiO_2 filmr on both a back surface and side walls of an SCAM substrate, the electron compensation ratio was improved to be the same as one of a GaN film grown on a sapphire substrate. The SIMS measurement clarified that the incorporated impurities were Mg and Sc. The insertion of an AlN layer was found to be effective for suppressing the Mg incorporation, while coating both a backside and side walls of a substrate was also effective for the incorportion of both Sc and Mg. The higher electron compensation ratio was achieved by introducing the SiO_xN_y coating on both a backside and side walls of an SCAM substrate. These techiniques developed and the knowledge obtained in this paper will open a window for an SCAM substrate to fabricate high-peroformance devices.

References

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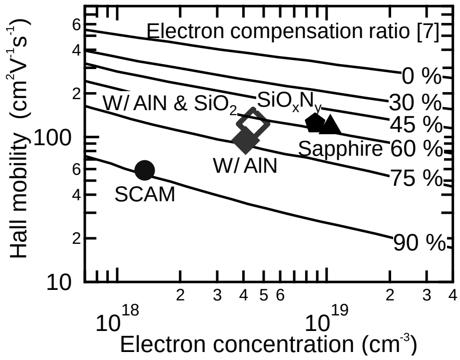

Fig. 1 Result of Hall measurement of Si-doped GaN with various sample structures.

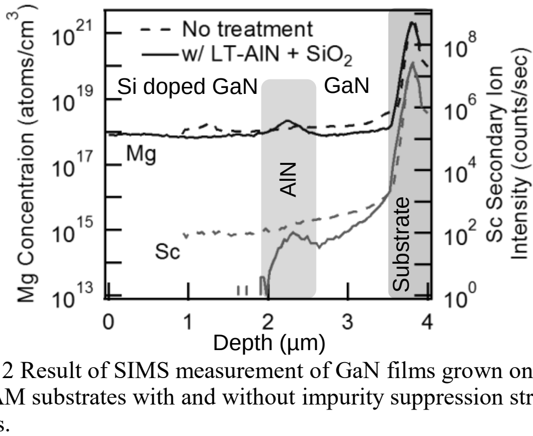

Fig. 2 Result of SIMS measurement of GaN films grown on both SCAM substrates with and without impurity suppression structures.