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Thermally Stable Isolation of AlGaN/GaN Transistors by Using Fe Ion Implantation

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1. Introduction

GaN based transistors are very promising for power switching applications owing to the high breakdown strength with high saturation electron velocity [1]. The lateral and compact device structure is advantageous for the monolithic integration as long as the devices are electrically isolated between each other. Ion implantation technique enables planar isolation which is preferred for future high density integration. However, the reported isolation using ion implantation onto GaN devices cannot maintain high resistivity at high temperatures over 800^{o}C commonly used in the GaN processing [2,3].

In this paper, we present thermally stable isolation of GaN devices by Fe ion implantation, which can be applicable to monolithic GaN-based ICs. The Fe ion is theoretically and experimentally confirmed to form deep levels even after high temperature annealing which fully recovers processing damage caused by the ion implantation.

2. Choice of ion species for isolation of GaN devices

In order to obtain thermally stable isolation by ion implantation, the choice of the ion is preferred to form deep levels by its substitution at the atomic sites of Ga or N since the processing damages causing the carrier traps should be easily recovered by thermal treatments. Here, we propose the use of Fe as the choice based on the following simulation results. The critical properties are the magnitude of the processing damage and the formed energy levels by the atomic substitution. The vacancy concentration corresponding to the damage are calculated for four candidate ions including Fe and other reported ones by TRIM simulator [4]. Fig.1 shows the calculated vacancy profile for various ions into GaN. The dose and acceleration energy is chosen so as to have the peak concentration of ions and the projected range to be 10^{19}cm^{-3} and 25nm, respectively. Fe and Ar create almost same amount of the vacancies while other ions do lower values. In this study, we calculate the energy levels by first-principles calculation for various ions in GaN. The calculation estimates the formation energy and the density of state of the ions at the various atomic sites in 2a×2a×2c ($Ga_{32}N_{32}$) supercell shown in Fig.2. Three possible atomic positions for the ions are examined and the most stable one is extracted for each ion to have the lowest formation energy. Then density of state is calculated for GaN with the impurity ions positioned at the most stable places. Fig.3 shows the results for GaN with Fe and Ar ions as examples of the calculation. Note that the Fe is preferred to stay the Ga site while the Ar is at rather interstitial place. The Fe in GaN forms a deep level at the midgap of GaN and no apparent level is formed for interstitial Ar. Although same level of the processing damage is formed by Fe and Ar, the energy level formed after full recovery of the processing damage should be significantly different.

3. Isolation characteristics of AlGaN/GaN structure

The thermal stability of the implanted isolation regions is examined for various ions into AlGaN/GaN as shown in Fig.4. The resistivity of the implanted regions is measured for before and after the annealing. The values for Fe remain high regardless the temperature, while these for Ar, B and N are decreased at high temperatures. Especially by the comparison of the results between Fe and Ar, it can be concluded that the implantation damage is fully recovered at 800^{o}C or more and the deep level becomes the origin of the high resistivity in Fe implanted GaN at higher annealing temperature. Changes of the resistivity at various temperatures are also measured for the implanted isolation regions to extract the activation energy as summarized in Fig.5. The activation energies from the Arrhenius plots are plotted as a function of the annealing temperature in Fig.6. The activation energy of the deep levels in Fe is abruptly changed from 0.70 eV to 0.35 eV, while that in Ar stays constant. The activation energy is reduced for the substitutional Fe from the damage-related levels. All of the results imply that the activated deep levels after recovering of the implantation damages are dominant for the isolation by Fe ions. The resultant isolation regions serve breakdown voltage of 900V even after annealing at 1200°C as shown in Fig.7.

4. Conclusions

We present thermally stable isolation of AlGaN/GaN transistors by using Fe ion implantation. Fe forms deep levels at Ga site, which is demonstrated through first-principles calculation. Post-implantation annealing over 800°C fully recovers the processing damage by the ion implantation and the activated deep levels become a dominant origin for the high resistivity. The presented isolation by Fe ions achieves breakdown voltage of isolation region over 900V, which is indispensable for monolithic integration of GaN-based power switching transistors.

Acknowledgment

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References

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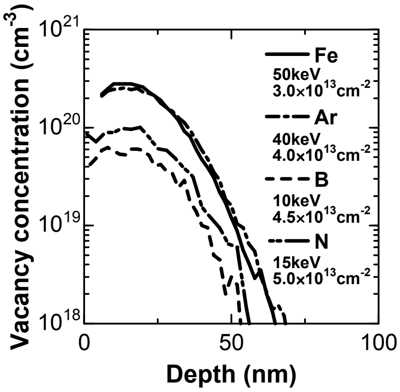

Fig. 1 Calculated depth profiles of vacancy concentration for various ions implanted into GaN. TRIM simulator is used for them and the condition of the ion implantation is chosen to have the peak concentration and the depth to be 10^{19}cm^{-3} and 25nm, respectively.

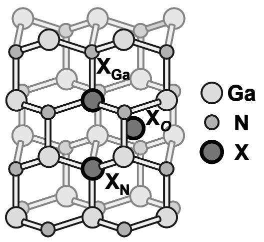

Fig. 2 Atomic configuration of supercell of GaN used for first-principles calculation. The Xs are the possible positions of implanted ions to be calculated.

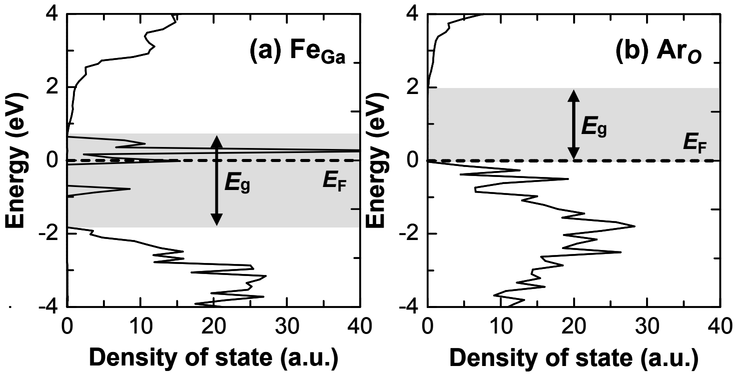

Fig. 3 Calculated density of state for (a) Fe-implanted GaN, (b) Ar-implanted GaN. Fe is placed at Ga site while Ar is placed at the interstitial position.

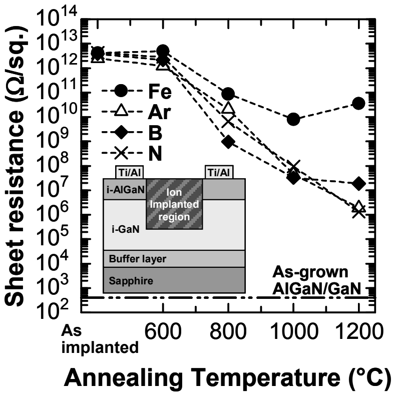

Fig. 4 Sheet resistance of implanted region formed by ion implantations plotted as function of post-annealing temperature. The inserted figure shows the schematic cross section of the characterized device structure.

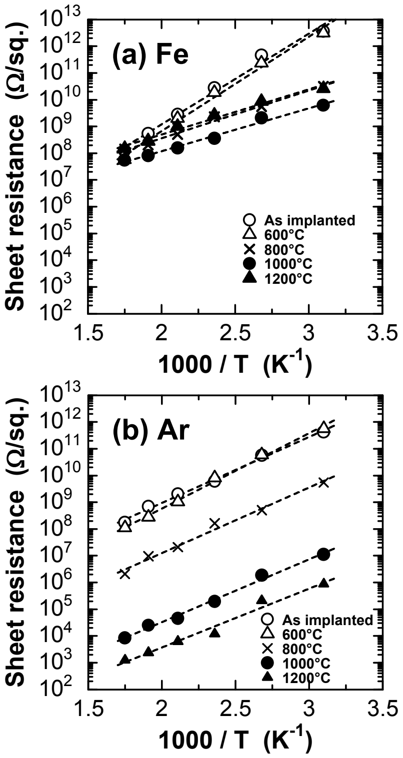

Fig. 5 Measured sheet resistance at various temperatures for the samples which are annealed at various temperatures after ion implantation. (a), (b) are for Fe and Ar ions, respectively.

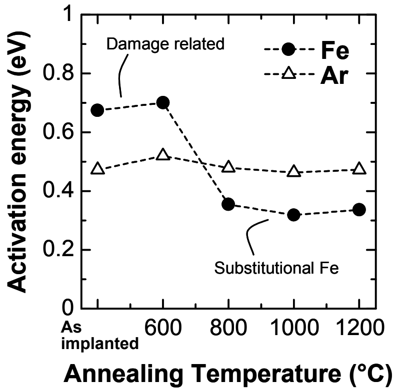

Fig. 6 Activation energy of sheet resistance plotted as a function of the post-annealing temperature for Fe and Ar ions into AlGaN/GaN.

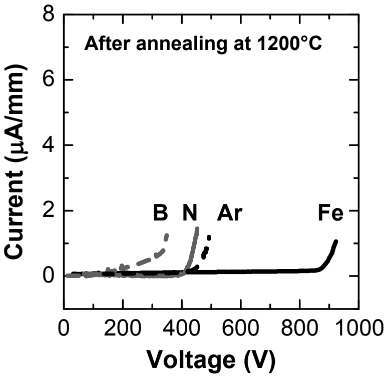

Fig. 7 Isolation characteristics of the ion-implanted isolation regions after annealing at 1200^{o}C.