Comparison of GaN-based Betavoltaics Fabricated on Different Epitaxial Structures

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1. Introduction

Betavoltaics based on radioisotope can directly convert the power of nuclear radiation into electric power. Betavoltaic battery is a promising as micro-scale power sources used in biomedical devices, military applications, wireless networks, and sensors in harsh environment, due to a small volume, high energy density, long lifetime, and insensitivity to environment.

Gallium nitride (GaN), as a wide-band gap (E_g = 3.4 eV) semiconductor material, is attractive for betavoltaic battery compared to Si- and SiC-based betavoltaic batteries, because not only the power conversion efficiency of betavoltaic can be increased by increasing the band gap energy, but also the radiation resistance from radioisotope is higher [1]. Several groups reported the experimental results of GaN-based betavoltaic batteries [2-4], however, the reported power conversion efficiencies are discrepant with the theoretical values. This may be due to an inadequate design of epitaxial and device structures for GaN-based betavoltaic. In our previous work [1], we studied the epitaxial structure for betavoltaic and proposed the advanced structure that can be expected the enhanced efficiency.

In this work, we fabricated GaN-based betavoltaics with different epitaxial structures and compared the characteristic of both devices. The Monte Carlo simulation for different epitaxial structures was performed to support the practical results.

2. Experiments

Different epitaxial structures for GaN-based betavoltaic were grown on GaN/sapphire template by using metal-organic chemical vapor deposition (MOCVD). Sample A is p-i-n structure, consisting of 300 nm-thick p-GaN, 200 nm-thick undoped GaN, and 400 nm-thick n-GaN layers, and Sample B is n-i-p structure, consisting of 80 nm-thick n-GaN, 200 nm-thick undoped GaN, and 300 nm-thick p-GaN layers. Sample B is studied to more improve the power conversion efficiency than Sample A [1]. The electrical properties of each layer was measured by Hall measurement, summarized in Table I.

Table I. Summary of electrical properties on each layer of epitaxial structure

Layer	Sheet resistance [ohm/sq]	Mobility [cm^2/Vs]	Concentration [/cm^3]
p-GaN	73560	11	+1.94E+17
Undoped GaN	1471	320	-6.64E+16
n-GaN	85	198	-5.30E+18

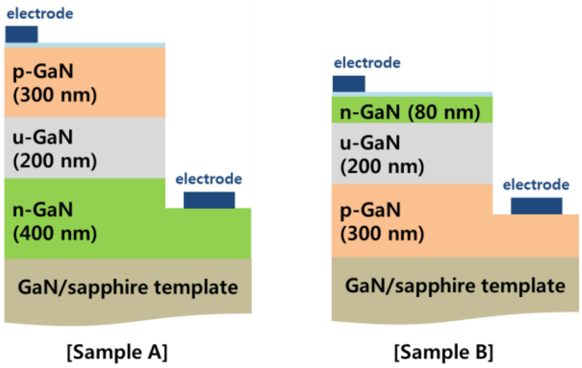

Fig. 1. Cross-sectional schematic of the fabricated betavoltaics

Both betavoltaics were fabricated as followed process: First, the window for the n- or p-electrode was defined by dry etching, and a transparent electrode consisting of Ni/Au (1 nm/1 nm) was deposited on the p-GaN or n-GaN layer, and Ti/Al-based electrodes were then deposited, which was followed by annealing for ohmic contact. Fig. 1 shows the cross-sectional schematic of the fabricated betavoltaics with different epitaxial structures.

3. Results and Discussion

Fig. 2 shows the current-voltage (*I*-*V*) characteristic of fabricated betavoltaics. Both devices has good diode characteristic. The turn-on voltage and on-current at 6 V of Sample A were about 4 V and 26 mA, respectively, which is reasonable values compared to previous reported results [2-4]. However, the turn-on voltage and on-current at 20 V of Sample B were about 11 V and 0.16 mA, respectively, which is worse than those of Sample A. This may be attributed that the out-diffusion of Mg atoms from p-GaN layer to undoped GaN layer and increasing resistance of p-GaN layer caused by etching process, which leads to severe increase of turn-on voltage and decrease of on-current. For understanding this phenomenon, secondary ion mass spectroscopy will be performed to confirm the out-diffusion of Mg atoms.

The Monte Carlo simulation (GEANT4) was performed for Sample A and B to evaluate the distribution of beta particles and generation rate of electron-hole pairs (EHPs) by beta particle. The generation rate of EHPs in depletion region of Sample B is almost 2 times higher than that of Sample A, as shown in Fig. 3. As a result, total 124 EHPs are generated by one beta particle in Sample A, which is ~55% larger than that in Sample B. These results indicate that Sample B is suitable for high efficiency betavoltaic. Both devices will be exposed under electron beam irradiation to confirm a practical characteristic of fabricated betavoltaics.

4. Conclusions

The characteristic of GaN-based betavoltaics fabricated on different epitaxial structures were compared. The proposed betavoltaic with n-i-p structure has worse turn-on voltage and on-current characteristics than those of device with p-i-n structure. From simulation results, however, the proposed betavoltaic has better generation rate of EHPs by a beta particle than that of device with p-i-n structure. The power conversion efficiency of both devices will be evaluated by electron beam irradiation.

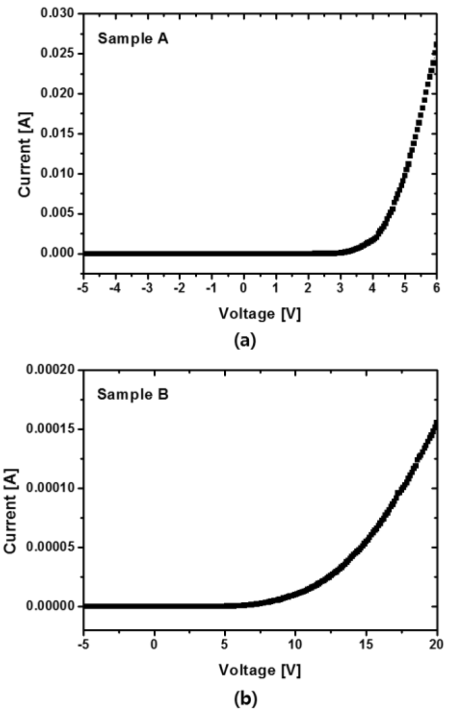

Fig. 2. I-V characteristic of the fabricated betavoltaics on (a) p-i-n structure (Sample A) and (b) n-i-p structure (Sample B)

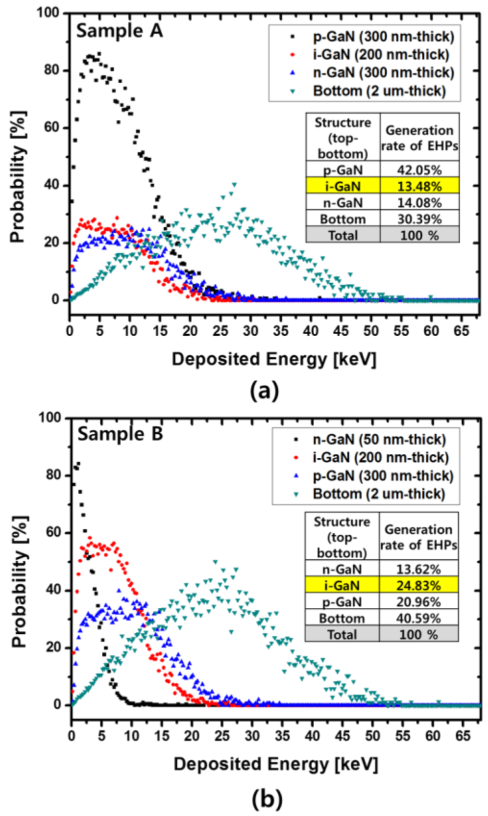

Fig. 3. Generation rate of EHPs by a beta particle for (a) Sample A and (b) Sample B simulated by GEANT4

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