Basic study on modification of GaN surface by atmospheric microplasma

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INTRODUCTION

GaN is usually formed by nitriding GaAs and grown on the sapphire substrate with a high dislocation density as shown in Fig. 1 [1]. For this dislocation, microchannel epitaxy (MCE) or regrowth of GaN is required to reduce dislocations. Recently, plasma treatment is used for interface treatment, regrowth of GaN and nitridation process of GaAs.

Microplasma is a atmospheric pressure nonthermal plasma and a type of dielectric barrier discharge which has small discharge gap under 100 μm which requires relatively low discharge voltage of only about 1 kV. The effect of surface treatment of GaN by atmospheric microplasma was experimentally investigated.

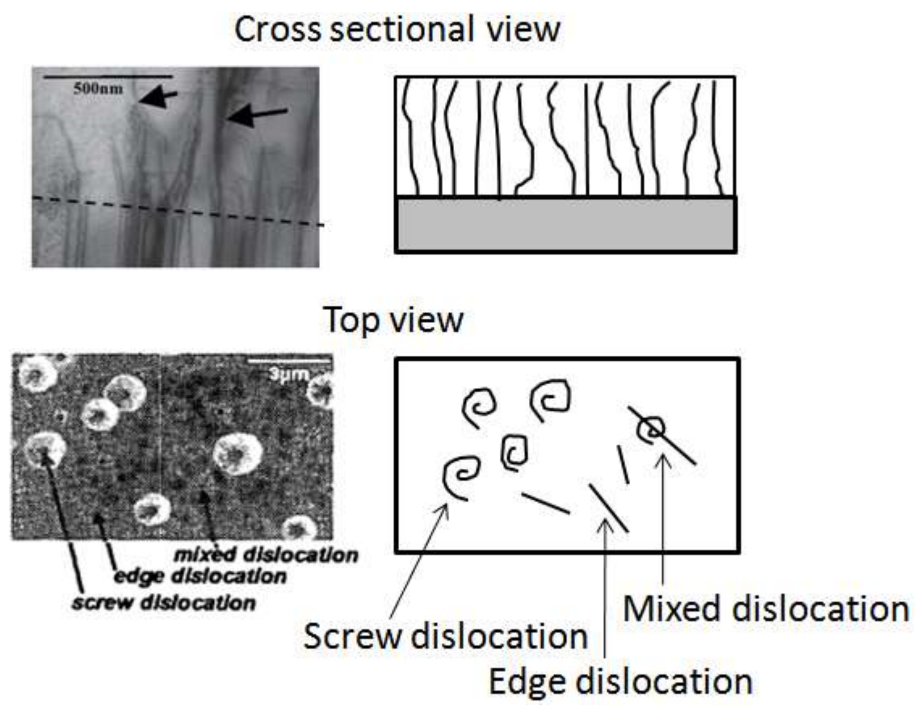


Fig. 1 Image of dislocations of the GaN substrate.

METHODS

(1) Microplasma Electrodes

Microplasma was generated with a pair of electrodes which covered with dielectric layer and faced each other at small discharge gap under 100 μm with a spacer. Due to small discharge gaps (0~100 μm) and to the assumed specific dielectric constant of ε_r = 10^4, a high intensity electric field (10^7 ~ 10^8 V/m) could be obtained with relatively low discharge voltage of only about 1 kV.

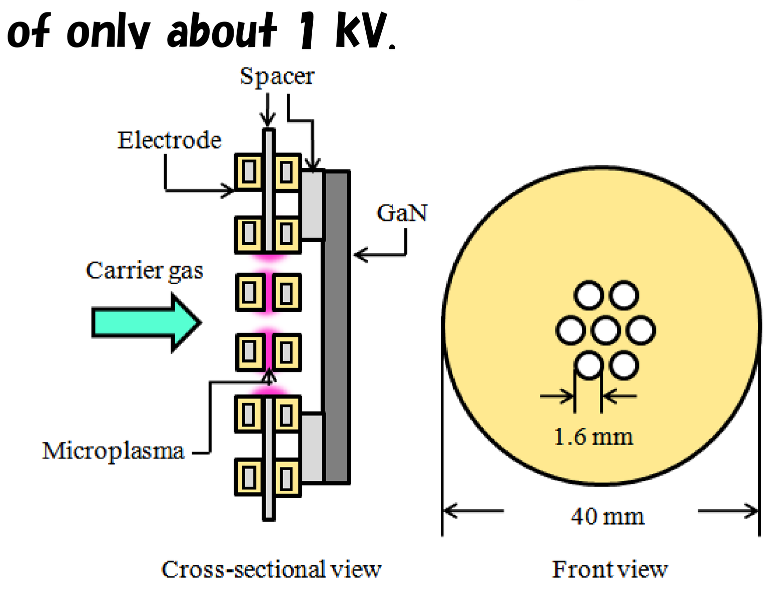


Fig. 2 Microplasma electrodes.

Structure of microplasma electrodes

Hole size: 1.6 mm
Total area of holes: 14 mm²
Discharge gap: 100 μm
Distance between GaN surface and electrode: 1 mm

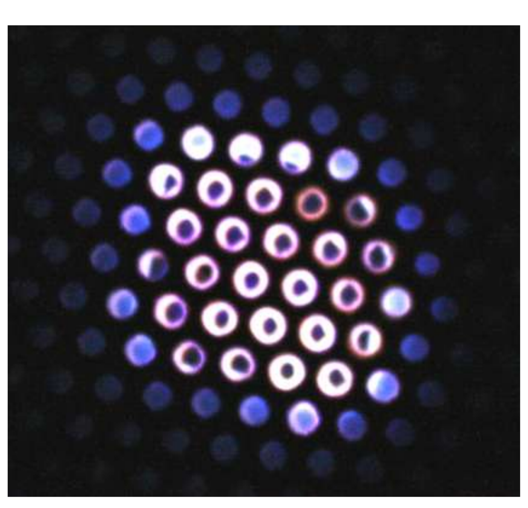


Fig. 3 Image of microplasma.

Fig. 3 shows the discharge voltage and discharge current waveform during generating microplasma. Pulse width was about 1 μs and frequency was 1 kHz.

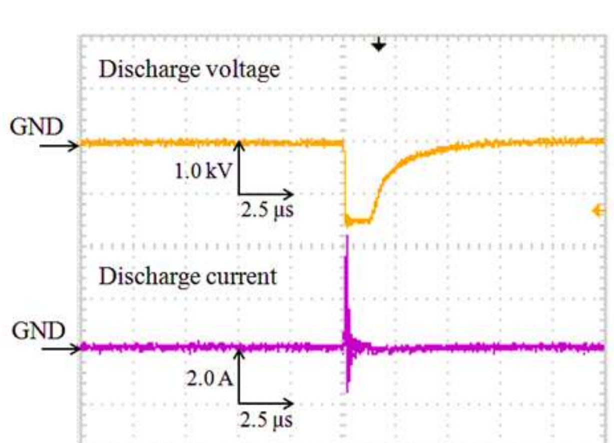


Fig. 4 Discharge voltage and current waveform.

(2) Experimental setup

Fig. 5 shows the experimental setup for surface treatment of GaN substrate. In this study, a negative pulse power supply was used to generate microplasma. Streamers were generated between electrodes could generate various radicals and ions. These active species could affect a target surface [2].

An X-ray Photoelectron Spectroscopy (XPS) analysis and image of GaN surface by Field Emission Scanning Electron Microscope (FE-SEM) was performed before and after microplasma treatment.

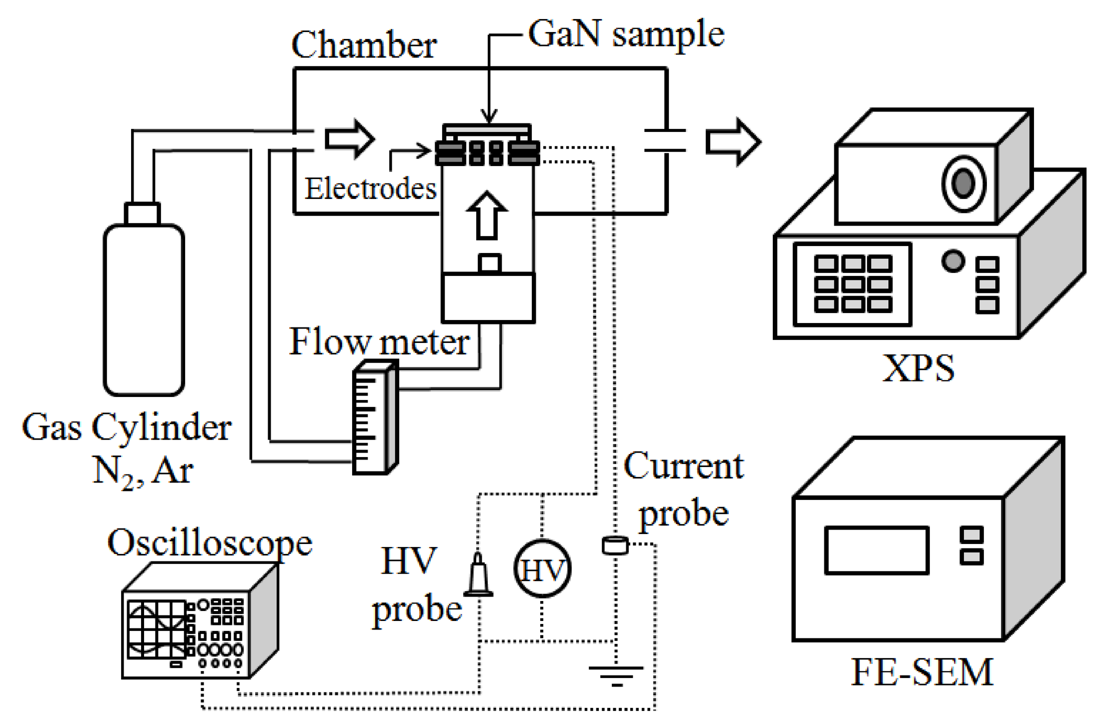


Fig. 5 Experimental setup for surface treatment of GaN substrate.

Table 1 Experimental conditions.

Atmosphere gas / Carrier gas	Ar	N_2
Carrier gas Flow rate [m/s]	5	
Discharge voltage [kV]	-1.3	-1.6
Discharge gap [μm]	100	0
From GaN surface to electrode [mm]	1	
Treatment time [s]	5 ～ 30	

RESULT

(1) SEM image of GaN surface

Images of GaN surface was taken by FE-SEM to check a damage of GaN surface by microplasma treatment and confirm a effect of reducing dislocations of a GaN surface on a substrate (Fig. 6). All of following GaN sample surface were treated for 10 s with Ar microplasma and N_2 microplasma.

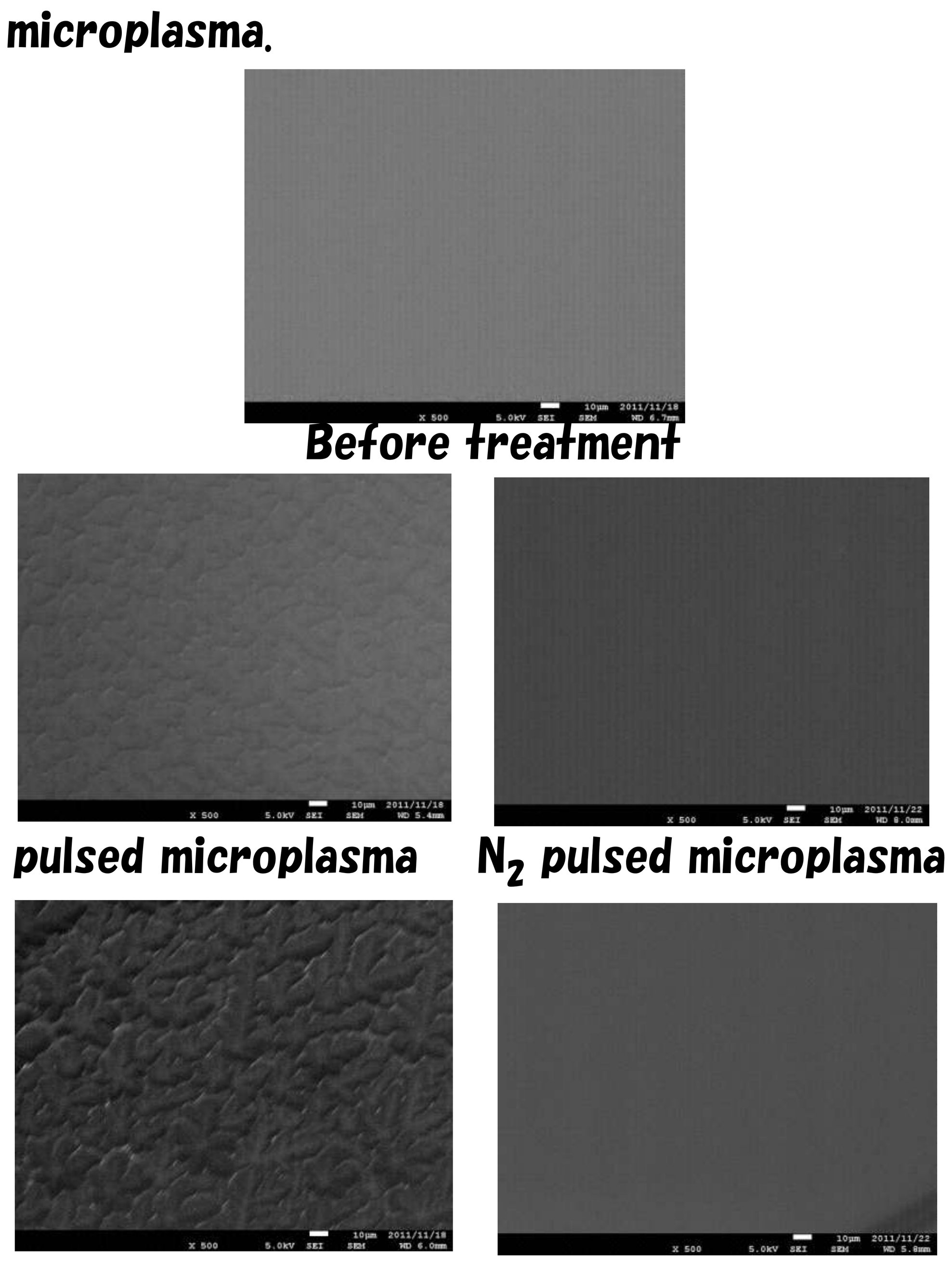
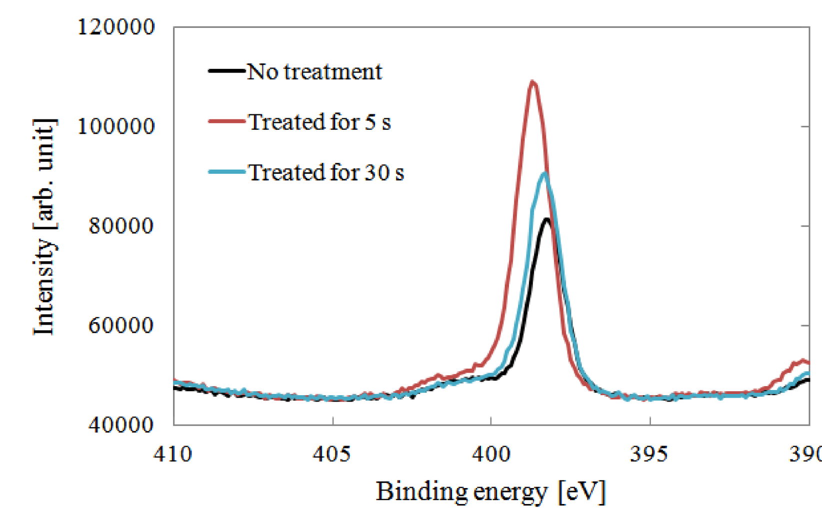


Fig. 6 Images of GaN surface.

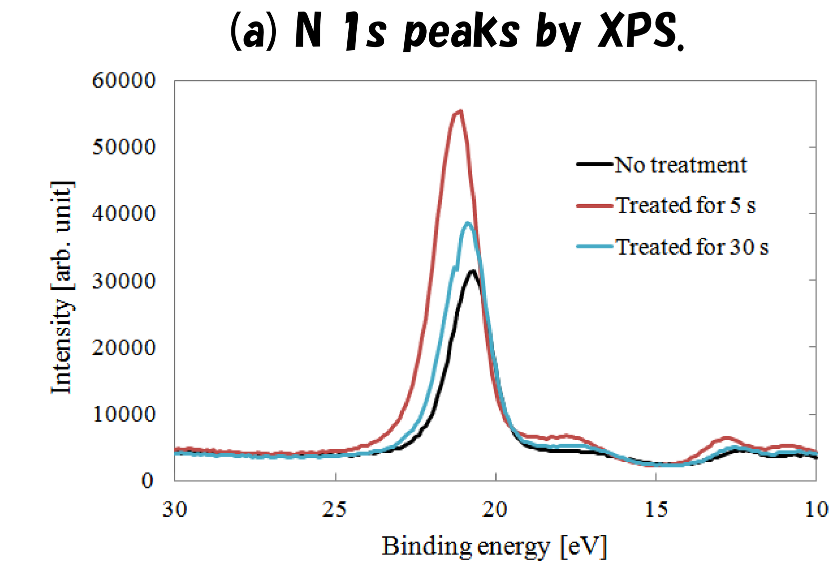
(2) XPS analysis

Chemical bonds on the GaN substrate surface were analyzed by XPS. Excited Ar species and metastable N_2 species were generated from microplasma, mainly contributed to surface modification of GaN substrate. These active species have relatively long life time, thus these active species could affect the GaN surface.

Increase of the N-Ga bonds could occur due to the Ar microplasma which has a high potential. This high potential affected the GaN surface or a problem of changing surface potential on a GaN surface (Fig. 7). In contrast, decreases of the peaks was observed in N_2 microplasma treatment. A decrease of nitrogen on the GaN surface means that GaN surface became a nitrogen deficiency state (Fig. 8). In this state there are some possibilities of applying the nitriding process or regrowth of GaN.

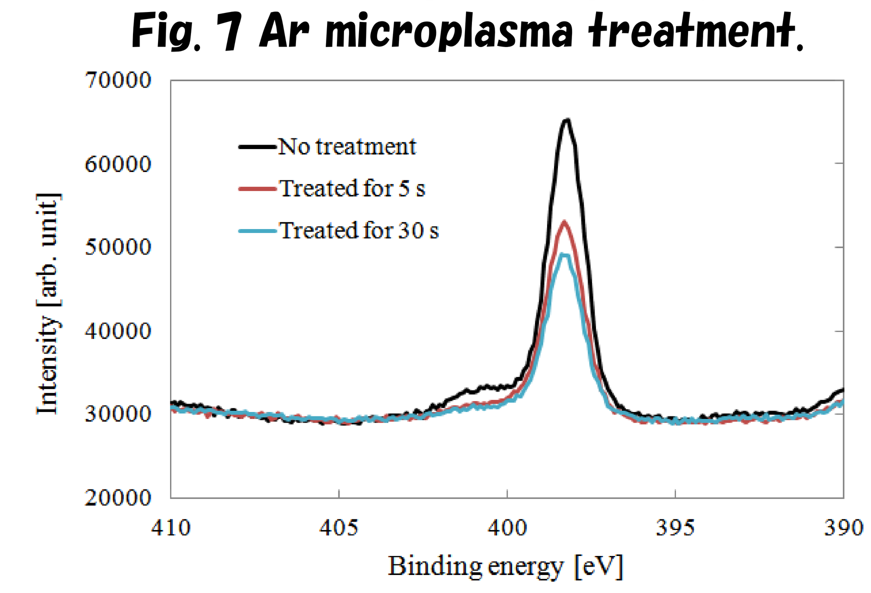


(a) N 1s peaks by XPS.

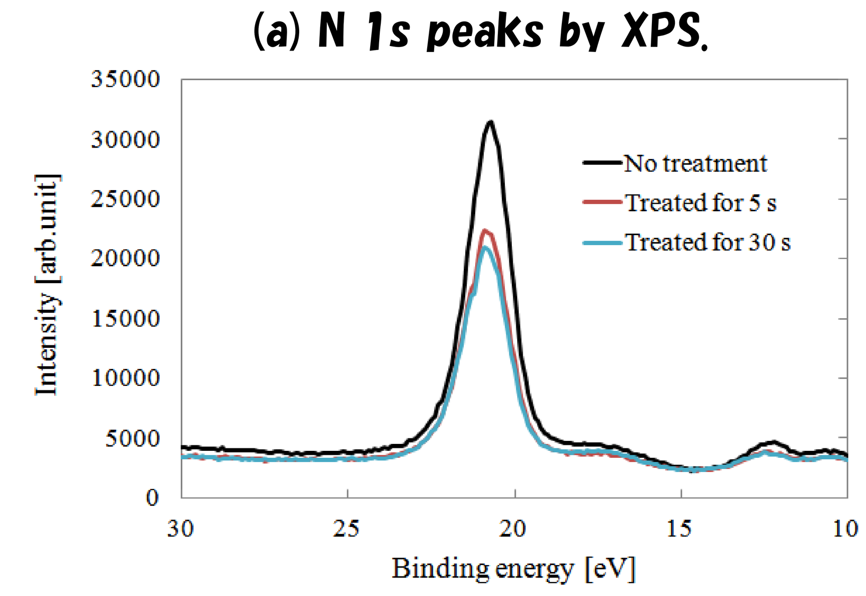


(b) Ga 3d peaks by XPS.

Fig. 7 Ar microplasma treatment.



(a) N 1s peaks by XPS.



(b) Ga 3d peaks by XPS.

Fig. 8 N_2 microplasma treatment.

CONCLUSIONS

In this study, the following conclusions were obtained.

1. The possibility of the GaN surface modification by atmospheric microplasma had confirmed.
2. It could be considered that physical damage for GaN surface can control by choosing appropriate process gas, power supply and treatment time.
3. Different changings of N 1s and Ga 3d peaks was observed in Ar microplasma treatment and N_2 microplasma treatment.

REFERENCE

[1] X. H. Wu, L. M. Brown, D. Kapolnek, S. Keller, B. Keller, S. P. DenBaars and J. S. Speck, *J. Appl. Phys.* **80**, 3228 (1996).

[2] K. Shimizu, A. Umeda, S. Muramatsu, M. Blajan, *J. Appl. Phys.* **50**, 08KA03-1 (2011).