Low-loss Power Semiconductors

Background and Objective

Further electrification and the use of low-carbon power sources are essential from the viewpoint of conserving the global environment and the highly efficient use of energy. The wider use of low-loss and downsized next generation power converters has become an important common technological task faced by electrification technologies associated with plug-in hybrid cars, electric vehicles, IH equipment and heat pump equipment. This task is also faced by power control technologies for the maximum utilisation of nuclear and renewable energies. For this reason, great expectations are placed on the practical use of SiC power semiconductors which can achieve a lower power loss, higher voltage and downsizing compared to Si semiconductors which are used for conventional power conversion equipment.

This project theme is introduced to develop a production technology of low defect single SiC crystals and improve the performance of high voltage SiC devices with a view to developing practical systems using low-loss and downsized power converters.

Main results

1. Development of a novel formation technique for SiC/oxide interfaces

In the development of high-voltage SiC switching devices using an oxide film as a gate for on/off operation, reduction of defects near the SiC/oxide interface is crucial for loss-reduction and reliability improvement towards practical use of the devices. Through a comparison of interface properties of the SiC/oxide interfaces formed under the different conditions shown in Table 1, it is revealed that the interface defects are reduced by performing the heat treatment in nitrogen (N_2 treatment) before the oxide deposition (Fig. 1). Localization of nitrogen atoms near the SiC/oxide interface is confirmed in the samples using the N_2 treatment, indicating passivation of defects near the interface by nitrogen atoms introduced by the N_2 treatment. Base on the results, we propose the N_2 treatment before oxide deposition as a novel technique to realize a considerable reduction of interface defects [Q10009].

2. Visualization of defects in SiC crystal films

A high density of defects (extended defects: dislocations and stacking faults), which can affect the electrical performance of devices, exists in currently available SiC crystal films. Development of a visualization technique for the defects is important to achieve a reduction of the defect density. Here, photoluminescence (PL) characteristics of Frank-type defects on the basal plane, which had been found in 4H-SiC crystal films for the first time by our group before 2009, were investigated to obtain a quick detection technique for the defects. The characteristic PL spectra for each type (intrinsic-type, multilayer-type and extrinsic-type) of Frank-type defects were revealed as shown in Table 2. As a result, it is possible to detect and discriminate the Frank-type defects in 4H-SiC crystal films by examination of their PL spectra.

Other reports

1. Patent application: 2010-217756 “Fabrication method of SiC semiconductor devices and electron devices”
2. H.Tsuchida et al., Physics Status Solidi B 246, 1553 (2009).
3. I. Kamata et al., Applied Physics Letters 97, 172107 (2010).

Table 1 Process sequences
(HTO: high-temperature oxide deposition, RTA: rapid thermal annealing)

process / sequence	witout N_2 treatment				**with N_2 treatment**	
	HTO	HTO+RTA	H_2+HTO	H_2+HTO +RTA	N_2+HTO	N_2+HTO +RTA
①	wet cleaning	wet cleaning	wet cleaning	wet cleaning	wet cleaning	wet cleaning
②	oxide depo.	oxide depo.	H_2 treatment	H_2 treatment	H_2 treatment	H_2 treatment
③		anneal	oxide depo.	oxide depo.	**N_2 treatment**	**N_2 treatment**
④				anneal	oxide depo.	oxide depo.
⑤						anneal

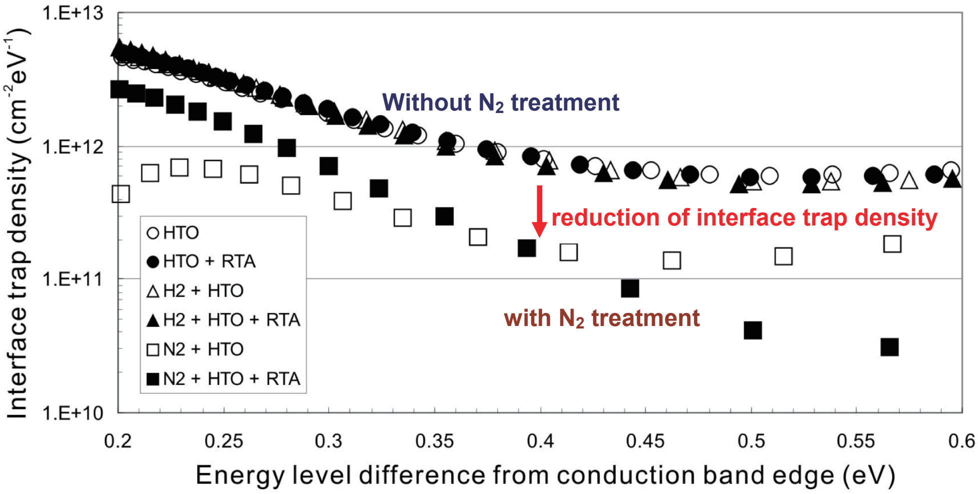
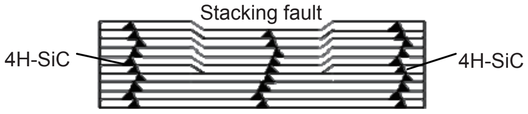
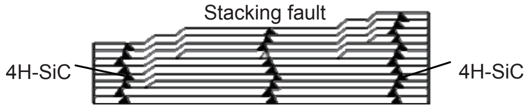
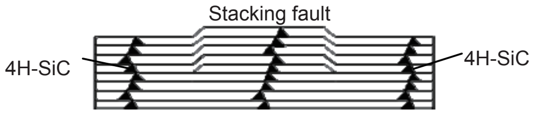


Fig. 1 Effects of N_2 treatment for 4H-SiC/oxide interface

Reduction of interface trap densities (determined by capacitance-voltage analysis) is confirmed in the samples with the N_2 treatment. This implies a reduction of the defect density near the SiC/oxide interface.

Table 2 Relation between three types of Frank-type defects in 4H-SiC crystal films and PL spectra

Defect type	Stacking structure (◢ indicates stacking sequences of 4H-SiC and stacking faults)	PL peak wavelength at room temperature (nm)
Intrinsic type		488
Multilayer type		457
Extrinsic type		424

The peak wavelength of PL corresponding to each type of stacking fault is evaluated. The peak wavelength reflects each stacking fault structure. From the correspondence, it is possible to detect and discriminate the Frank-type defects by PL measurement for 4H-SiC crystal films.