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An Experiment on the Alleviation of Wafer-bending for CVD grown heavily Al-doped 4H-SiC Epi-wafer by co-doping of N

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Abstract

To alleviate the wafer-bending (convex) of heavily Al-doped 4H-SiC epi-wafer, nitrogen was doped during CVD growth. A remarkable reduction of wafer bow has been achieved, and it suggests that the introduction of N-impurities alleviates the large wafer bow due to the declined lattice constants differences between epilayer and substrate.

1. Introduction

Silicon carbide (SiC) has attracted great attention in the field of high power devices, and the novel devices gradually came into view. The chemical vapor deposition (CVD) was widely employed to construct multilayer structures in these devices. However, there still exists problem in CVD homoepitaxy of SiC, *e.g.*, the serious wafer-bending due to the growth of thick epilayer. For high-voltage devices like the insulated gate bipolar transistor (IGBT), a thick Al-doped p^+ layer with an Al-doping level (N_{Al} ~1×10^{19} cm^{-3}) is required [1]. Around this N_{Al} range, a direct relation between Al-doping and wafer bow has been reported by Kallinger *et al.* [1,2]. The substitutional Al having a larger covalent radius of 1.25 Å than Si (1.17 Å) was believed to be responsible for the increases of lattice misfit, resulting in a convex wafer bow [2-6].

In Si-C system, N with a tetrahedral radius of 0.719 Å usually substitutes for C (0.774Å) and perhaps reduces lattice constants on account of a shortened Si-C bond by 0.055 Å [4,5,7]. Though Stockmeier *et al.* said an increase of *c*-lattice constant by N-doping [4], the calculation presented by Matumoto *et al.* reveals *a*- and *c*-lattice constants decreasing along N-doping [8], where they change apparently with nitrogen concentration (N_N) above 5×10^{18} and 3×10^{19} cm^{-3}, respectively. Contrarily, the *a*- and *c*-lattice constants of Al-doped SiC increase when $N_{Al}>1\times10^{19}$ cm^{-3}, where the change in *c*-lattice constant is greater than that in *a*-lattice constant. By co-doping of Al to highly N-doped 4H-SiC epilayer, we have demonstrated the improvement of crystal structure without changing the conductive type [9].

In view of above mentioned facts, the authors expected that the introduction of small N-atoms to Al-doped SiC, in another word, co-doping of Al and N can bring about a lattice contraction against the expansion induced by Al incorporation, and hence reduces the lattice mismatch strain, which may alleviate the wafer-bending.

In this work, an epilayer with N_{Al} ~5×10^{19} cm^{-3} was adopted as the objective p^+ epilayer, which shows an apparent wafer-bending. During the growth of p^+ epilayer, N_2 gas was flowed into the reactor as well as TMA to produce a series of epilayers with various N_N, and their lattice constant changes and wafer-bending were investigated.

2. Experimental and Results

Experimental

A horizontal hot-wall CVD system equipped with standard precursors and gases, silane (SiH_4), propane (C_3H_8), trimethylaluminium (TMA), was employed. The as-received 3-inches n^+ 4H-SiC wafers, 4° off-oriented towards [11-20], with a thickness of ~355±1 μm and a wafer bow within a range of ±1 μm were used as substrates. For all experiments, the growth was carried out at the reactor pressure of 10 kPa and the substrate temperature of 1620 °C. The carrier gas was H_2 that supplied at 80 slm. The flow rates of source gases, SiH_4 and C_3H_8 were respectively set at 30 and 10 sccm, corresponding to a growth rate of ~7.5 μm/h. The growth duration was 1 hour and the substrate was rotated at 60 rpm. TMA was supplied in 26 μmol/min as p-type dopant, while N_2 gas was flowed into the reactor at 0, 0.5, 1 and 2 slm. Secondary ion mass spectrometry (SIMS) was used to obtain the incorporated impurities concentrations. Hall-effect measurement was carried out to check the conductive type of the epilayers. High-resolution x-ray diffraction (HR-XRD, Panalytical X'Pert MRD) equipped with an asymmetric 4-crystal Ge (220) monochromator in triple-axis mode was utilized to examine the crystal quality and the wafer bow that is expressed as the curvature radius deduced from the rocking curves' peak positions of 4H-SiC (0004) plane at two different positions on the surface of the epi-wafer. In addition, the lattice constant change was deduced from the measurement of reciprocal space mapping (RSM).

Results

Figure 1 shows the curvature radius (*R*) derived from the measurements at two positions ±20 mm around the center on 3" epi-wafer as a function of the supplied N_2 flow.

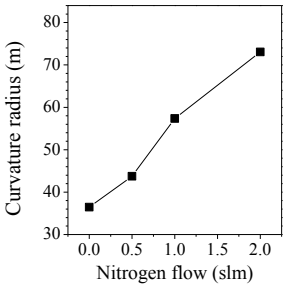

Fig. 1 XRD measured curvature radius from (x=±20 mm, y=0) on epilayers as a function of the supplied N_2 flow rate.

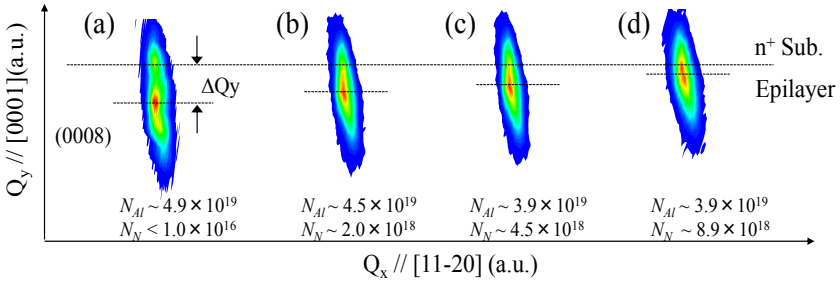

Fig. 2 The measured reciprocal space mapping in symmetric 0008 reflection for the epilayers grown with N_2 flow rates (a)0, (b)0.5, (c)1 and (d)2 slm, and the SIMS impurities concentration. Dot-lines mark the peaks for substrate and epilayer.

R increases with N_2 flow and is almost doubled at N_2=2 slm comparing with that with N_2=0 slm. The figure indicates the wafer bow of Al-N co-doped epilayers are reduced in comparison to that without co-doping of N. Additionally, it should be noted that all Al-doped/Al-N co-doped epilayers have high crystalline quality with the full width at half maximum (FWHM) of rocking curve on (0004) plane below 12 arcsec and are confirmed to be p-conductive type.

Figure 2 presents the RSMs from symmetric 0008 reflection on a series of epilayers grown at various N_2 with a fixed TMA. The SIMS impurities concentration of Al and N, N_{Al} and N_N are also shown in the figure. N_N increases in a direct proportional to N_2 flow, though it produces N_{Al} with a small decrease. The peak split in RSM, ΔQy, which means the difference of *c*-lattice parameters between epilayer and substrate ($\Delta c=c_{epi}-c_{sub}$), was found decreasing along N_2 flow rate and diminishing close to detection-limit at N_2=2 slm. RSMs from asymmetric 10-18 reflection (not shown) revealed the epilayers were fully strained [10]. The reductions of Δc and *R* with co-doping of N suggest that N incorporation causes a lattice contraction and leads to a reduction of mismatch strain.

The N_{Al} dependent *c*-lattice change ($\Delta c/c_{sub}$) was summarized in Fig. 3, where the hollow squares are our previous results on heavily Al-doped 4H-SiC epilayers on 8° off substrate [10]. The solid square and triangle are derived from RSMs in Fig. 2(a) and Fig. 2(d), respectively. It tells that, the $\Delta c/c_{sub}$ value for Al-doped 4H-SiC with N_{Al} ~4.9×10^{19} cm^{-3} lies exactly on the extrapolated line of heavily Al-doped ones, while that for Al-N co-doped epilayer with N_N ~8.9×10^{18} cm^{-3} remarkably declines. It indicates the lattice misfit being lowered by co-doping of N.

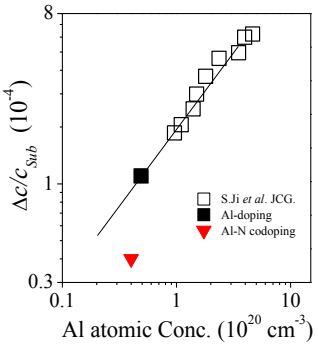

Fig. 3 The *c*-lattice constant change derived from RSM as a function of the incorporated Al concentration.

3. Conclusions

The Al-N co-doping process was employed to alleviate the wafer-bending by intentionally adding N_2 to Al-doped 4H-SiC growth. It is considered that, the introduction of N-atoms retracts the expansion of lattice in 4H-SiC induced by Al-atoms incorporation and leads to a lattice contraction, which results in moderating the misfits in the lattice constants and thus reduce the wafer bow. Details of the results and discussion will be reported on the conference.

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