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Suppressing Al Memory-Effect on CVD growth of 4H-SiC Epilayers by adding Hydrogen Chloride Gas

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Abstract

By using site-competition growth with the assistance of HCl gas, Al memory-effect on CVD growth of 4H-SiC was suppressed to an extremely low level. Al concentration differences more than five orders of magnitude were obtained, *e.g.*, steep change from 10^{20} to 10^{14} cm^{-3}.

1. Introduction

The 4H polytype of silicon carbide (SiC) material is very competitive to Si in application fields of high power/ frequency devices. The chemical vapor deposition (CVD) was widely used to fabricate SiC device structures. However, an intrinsic problem exists that, in p-type 4H-SiC growth, the memory-effect is strong: the former growth run interferes the succeeding growth run by releasing dopants acting as an additional doping source. The severe case is the unpredictable change of conductivity type [1].

Since it has been reported that devices formed by a continual multilayer growth demonstrates superior performance than that by an interrupted growth [2], we has studied the methods using site competition growth to realize a continual growth of p^+/n epilayers in the same reactor [3]. The reduction factor (the ratio of Al concentration N_{Al}, in p^+ layer and that in the following undoped layer) of about 1/17,000 has been achieved, *e.g.*, N_{Al} from 9×10^{19} to 6×10^{15} cm^{-3} or from 1.7×10^{20} to 1.0×10^{16} cm^{-3}. While, La Via *et al.* reported the growth using trichlorosilane can suppress Al-impurity level to 10^{14} cm^{-3} after a p^+ layer growth of N_{Al}~1×10^{18} cm^{-3}[4], but it causes an up-limit of Al doping level around 10^{18} cm^{-3}. Nordell *et al.* tried to suppress unintentional Al doping by using HCl flushing combined with varying C/Si ratios [5]. Abrupt Al distributions (N_{Al} at surface layers 10^{19} to 2×10^{15} cm^{-3}; inner layers 1.5×10^{20} to 7×10^{15} cm^{-3}) have been obtained. However, Al-impurity level around mid of 10^{15} cm^{-3} are thought insufficient for fabricating insulated gate bipolar transistor (IGBT) multilayer structures [6], where it grows an n-type field stopper layer (1×10^{17} cm^{-3}) right after a p^+ layer. The precise control of n-type doping in field stopper layer seems requiring a further reduction of Al-impurity level below 10^{15} cm^{-3}.

To form the succeeding layer with extremely low Al-impurity level (~10^{14} cm^{-3}) right after the growth of heavily Al-doped layer (~10^{20} cm^{-3}), this work was carried out basing on the previous findings [2, 5]. In addition, HCl gas was introduced into the CVD growth process as well as using site competition growth, and the related HCl inletting effect was investigated and discussed.

2. Experimental and Results

Experimental

A horizontal hot-wall CVD system equipped with standard precursors and gases, SiH_4, C_3H_8, trimethylaluminium (TMA) and dilute HCl (10% in H_2), was employed. On as-received n-type 8° off-oriented 4H-SiC wafers, the growth was carried out at the pressure of 10 kPa and the temperature of 1620 °C. H_2 was used as the carrier gas and constantly supplied at 80 slm for all growth. TMA and SiH_4 flow rates were set at 40 and 30 sccm, respectively, while C_3H_8 flow rate was varied in the range of 4~10 sccm in C:Si mole ratios of 0.4~1. Secondary ion mass spectrometry (SIMS) was used to obtain Al-impurity concentrations.

Results

Figure 1 shows N_{Al} profiles of the interfacial area around samples consisting of an Al-doped and an undoped epilayers grown at C/Si=1 (a) without and (b),(c) with HCl flushing at various dilute HCl flow rates. Between the growth of heavily Al-doped layer and that of undoped layer, 1 minute interruption of source gas flows (only H_2 flow) was inserted. In the case without HCl flushing, the reduction factor defined by dividing N_{Al} of undoped layer by that of doped one is found about 1/50 as shown in Fig.1(a). Introducing a 5 min HCl flushing reduces N_{Al} in the undoped layer as seen in Fig. 1(b) and (c). The figure indicates that HCl flushing procedure effectively remove Al species probably absorbed on reactor wall. However, a slow decreasing of N_{Al} with growth is seen in Fig. 1(c). Figure 2 shows the HCl flow rate dependence of the reduction factor, which reveals a saturation of Al suppression effect with the increase of HCl flow rate. From these results, in the growth stage of undoped layer, the main source of Al impurities is considered to be decomposition or H_2 etching of Al-SiC alloy deposited on reactor parts during the growth of heavily doped layer, and therefore, it is hard to diminish due to concurrent H_2 etching after HCl flushing. To reduce

Al-impurity level by hindering Al atoms incorporation further, site competition growth (Si-rich) as well as adding HCl in the growth was performed. In this experiment, the growth was done at C/Si=0.4~0.8. Figures 3(a) and (b) show N_{Al} profiles of samples grown with HCl flushing at C/Si=0.4, where dilute HCl flow rates are 200 sccm and 2 slm, respectively. Noting that, to minimize the influence of remaining HCl in reactor, after HCl flushing, a 5 min waiting (only H_2) has been performed. Comparing with the results in Fig. 1, the figures reveal the decrease in N_{Al} about one order to 10^{16} cm^{-3}. Figures 3(c) and (d) show the N_{Al} profiles of samples grown by introducing HCl during growth, instead of HCl flushing procedure, where the dilute HCl flow rates are 200 sccm and 2 slm, respectively. After the growth of Al-doped layer, a 1 min interval of ceasing all source gases flow (only H_2 in) was inserted. The figures show the reduction of N_{Al} in undoped epilayer down to the order of 10^{14} cm^{-3}, which suggests that HCl inletting during the growth efficiently hinder Al incorporation at low C/Si ratio, which brings about an additional one order reduction of Al-impurity level. The relations between the reduction factor and the C/Si ratios for various HCl inletting conditions are summarized in Fig.4. The reduction factor ~1/105,000 was attained by adding 2 slm dilute HCl during the growth of undoped layer at C/Si=0.4.

3. Conclusions

The suppression of Al memory-effect in growing 4H-SiC by hot-wall CVD was investigated. The site competition growth combined with adding HCl gas successfully suppresses Al memory-effect, and a five order reduction in N_{Al} has been achieved, *e.g.*, from N_{Al}~10^{20} cm^{-3} in a heavily Al-doped layer to 10^{14} cm^{-3} in an undoped one. The achieved results are thought valuable to devices involving heavily Al-doped layers. Detailed characterizations and the growth will be reported on the conference.

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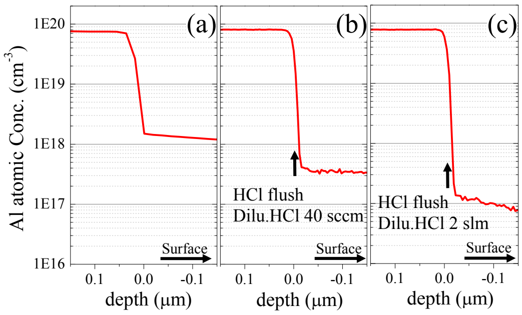

Fig. 1 Al concentration profiles of samples consisting of a heavily Al-doped and an undoped epilayers grown at 1620 °C and C/Si=1, (a) without and (b),(c) with a HCl flushing procedure.

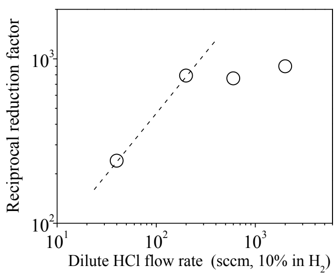

Fig. 2 The flow rate of dilute HCl for flushing dependence of the deduced reciprocal reduction factor of N_{Al}.

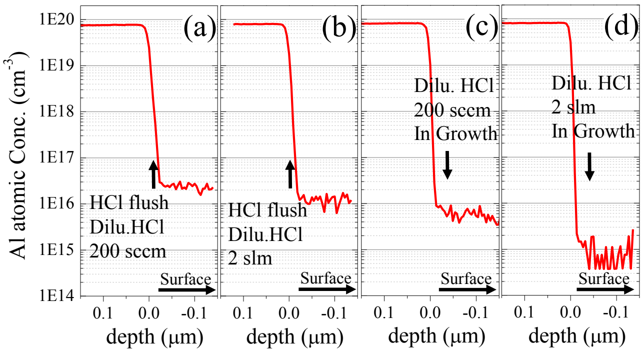

Fig. 3 Al concentration profiles of samples consisting of a heavily Al-doped and an undoped epilayers grown at 1620 °C and C/Si=0.4, (a), (b) with a HCl flushing procedure and (c), (d) adding HCl in the growth.

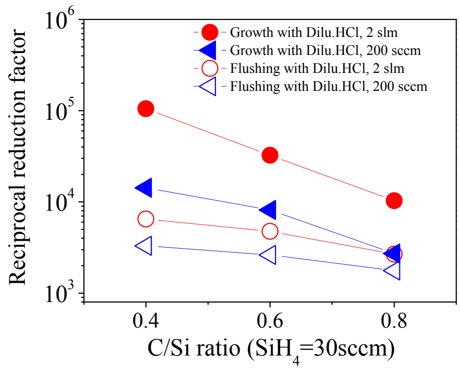

Fig. 4 The C/Si ratio dependences of the deduced reciprocal reduction factor of N_{Al} for various HCl inletting conditions.