Optimisation of epitaxial layer growth with HCl addition by optical and electrical characterization.

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Abstract

High growth rate of 4H-SiC epitaxial layers can be reached with the introduction of HCl in the deposition chamber. The effect of the Cl/Si ratio on this epitaxial growth process has been studied by optical and electrical measurements. Optical microscopy shows an improvement of the surface morphology and luminescence measurements reveal a decrease of epitaxial layer defects with increasing the Cl/Si ratio in the range 0.05–2.0. The leakage current measured on the diodes realized on these wafers is reduced of an order of magnitude and DLTS measurements show a decrease of the $EH_{6,7}$ level concentration in the same range of Cl/Si ratio. The value Cl/Si=2.0 allows to grow epitaxial layers with the lowest defect concentration.

Introduction

Silicon carbide (SiC) is well established as suitable material for high power devices. In particular, Schottky diodes are quite attractive for power conversion applications requiring high breakdown voltage (> 600 V) and low sheet resistance [1,2]. Nevertheless even if promising devices have been realized, the characteristics of large area diodes (> 1 mm^2) show high reverse current density and low yield. This excess of current and the low yield of the large devices can be due to defects present in the epitaxial layer and can be reduced by an accurate study on the CVD process. Another limitation of this process is the low growth rate (6-7 μm/h) that is correlated to the homogeneous nucleation of silicon droplets in the gas phase when a high Si/H_2 ratio (dilution ratio) is reached [3]. It has been reported [4,5] that this limitation can be overcame with the introduction of HCl in the deposition chamber.

In this paper, the influence of the Cl/Si ratio on the epitaxial layer grown process with HCl addition has been investigated by optical and electrical measurements. In particular the effect on the electrical characteristics of Schottky diodes and on the deep levels introduced in the energy gap has been studied in detail.

Experimental details

The epitaxial films were grown in a hot-wall reactor build by the LPE Epitaxial Technology company. The substrates were 4H-SiC (0001), Si face, n-type (≅ 10^{18} cm^{-3}) off-axis (≅ 8° off towards the [1120] direction). The epitaxial layers were grown at 1600 °C with a fixed Si/H_2 and C/Si ratios (Si/H_2=0.1% and C/Si=1.5) and different Cl/Si ratios. These wafers were characterised by optical microscopy and by room temperature photoluminescence.

Then on these epilayers several Schottky diodes with different contact areas have been realized with a simple process using Ni_2Si as Schottky barrier and an implanted edge termination. These diodes were characterized by I-V maps on the entire wafer to obtain statistical information and spatial distribution of defects. On selected diodes Deep Level Transient Spectroscopy (DLTS), in the temperature range 100-700 K, were performed to detect the levels introduced in the energy gap.

Results and Discussion

In the growth process with HCl addition the hydrochloric acid flux influences the *SiC* epilayer properties. The surface roughness and the amount of defects are correlated to the Cl/Si ratio. In Fig.1 three different optical micrographs of the epitaxial layer surfaces obtained with different Cl/Si ratios are reported. At the lower value (Cl/Si=0.05) the surface (Fig.1a) is very rough on the entire wafer. Increasing the hydrochloric acid flux of a factor ten (Cl/Si=0.5) the surface appears with rough and specular flat regions (Fig.1b). Increasing the Cl/Si ratio to 2.0 the surface (Fig.1c) is flat on the entire wafer.

The Cl/Si ratio has also a great relevance on the defects present in the epitaxial layers. In Fig.2 three different photoluminescence spectra measured at room temperature are reported. The spectra show the presence of a peak at 3200 meV related to band-band transitions and a large band between 2100 and 2800 meV. This band has been related to the formation of stacking faults in the epitaxial layers, as shown by cross section TEM (not reported here)[6].

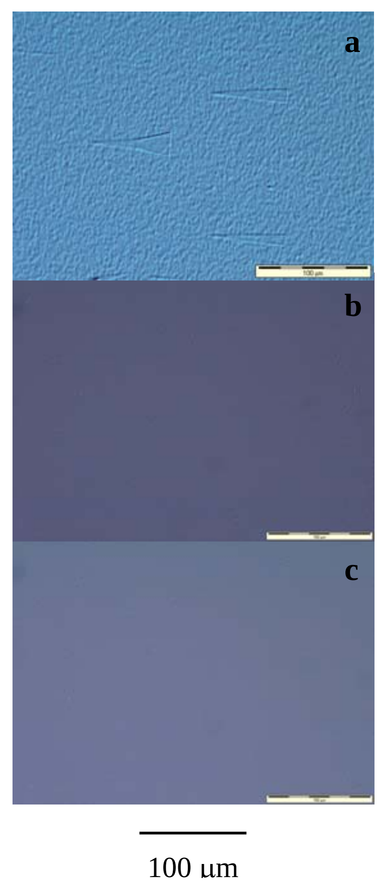

Fig. 1 – Optical micrographs of epilayers grown with different Cl/Si ratios: (a) Cl/Si=0.05, (b) Cl/Si=0.5, (c) Cl/Si=2.

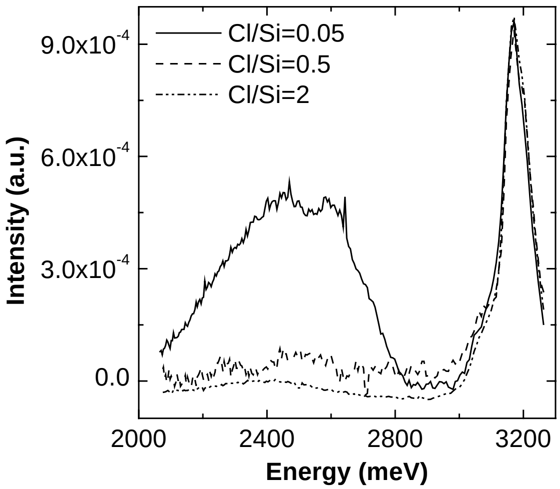

Fig.2 – R.T. photoluminescence of epitaxial layers grown with different Cl/Si ratios.

It must be pointed out that, increasing the *Cl/Si* ratio from *0.05* to *0.5*, the large peak between 2100 and 2800 meV decreases to zero. Increasing more this ratio, no further differences in the photoluminescence spectrum can be observed.

The optical microscopy and the luminescence results indicate that a value of Cl/Si>0.5 must be used to obtain flat surface and to decrease the concentration of staking faults in the epilayer.

In order to test the electrical proprieties of the grown material, Schottky diodes were realized on these wafers, which were tested by I-V measurements.

In Fig.3 the statistical distributions of the leakage current at –200 V over more than 400 diodes with an active area of 1 mm^2 realized on wafers grown with different Cl/Si ratios have been reported.

From these data it can be observed that increasing the Cl/Si ratio from 0.05 to 0.5 the leakage current increases little from 2.05×10^{-6} A to an average value of 3.08×10^{-6} A. Then increasing the Cl/Si ratio from 0.5 to 2.0 the leakage current decreases to 1.6×10^{-7} A.

These leakage current results can be related to the levels introduced in the energy gap by the defects of the epitaxial layers. In order to identify these levels, DLTS measurements were performed on several diodes in the same sample and in Fig.4 are reported the average spectra for the samples grown with the tree different Cl/Si ratios.

The spectrum obtained for a Cl/Si ratio of 0.05 shows the presence of a level at about 620 K, which has a distance of 1.6 eV from the conduction band. This level has been already detected by J.Zhang et al.[7] and was associated to a carbon vacancy [8] or to a C-Si divacancy [9].

The increase of the Cl/Si ratio from 0.05 to 0.5 induces an increase of about a factor two in the concentration of the $EH_{6/7}$ level and the appearance of two small peaks at 300 K (Z_1/Z_2) and at 420 K ($RD_{1,2}$).

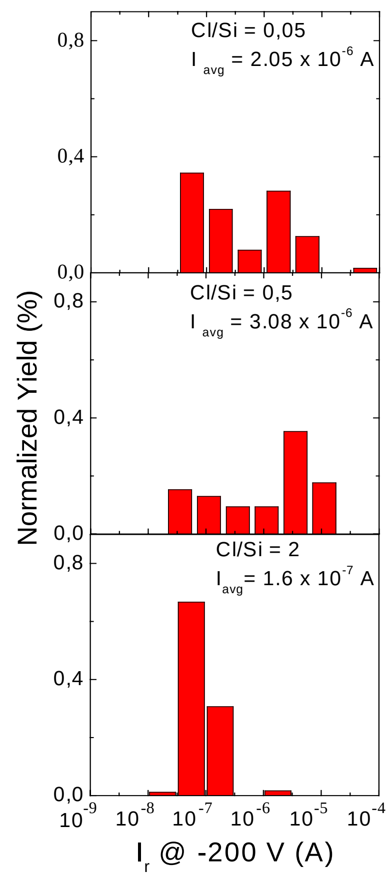

Fig. 3- Leakage current distribution at a reverse bias of -200 V for different Cl/Si ratios

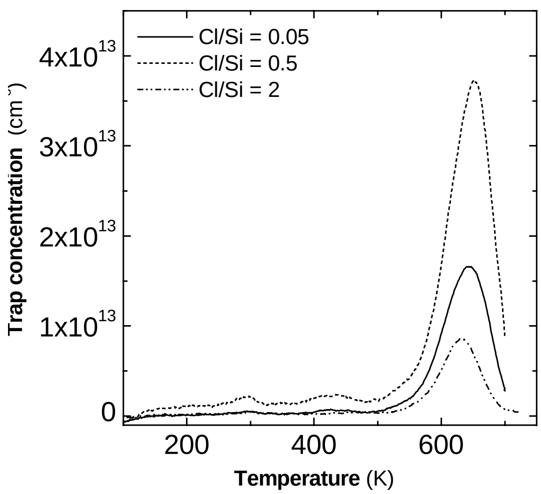

Fig. 4 - DLTS spectra of epitaxial layers grown with different Cl/Si ratios

However the concentration of these two traps is very low, below $10^{12}cm^{-3}$.

The further increase of the Cl/Si ratio to 2.0 shows a reduction of the $EH_{6/7}$ level, whose concentration becomes 7×10^{12} cm^{-3} and the absence of the Z_1/Z_2 and $RD_{1,2}$ levels.

The correlation between I-V and DLTS measurements shows that the reduction of the leakage current is related to the reduction of the generation current due to the level $EH_{6/7}$. Then the electrical measurements bring to 2.0 the value of the Cl/Si ratio that allows to grow epitaxial layers with very low concentration of defects.

Conclusions

The new epitaxial process with the introduction of HCl has been optimized by optical microscopy, luminescence spectroscopy and Schottky diodes electrical characterization. It has been observed that increasing the Cl/Si ratio from 0.05 to 2.0 the surface morphology is greatly improved and the concentration of epitaxial layer defects (stacking faults and point defect) is greatly reduced. DLTS measurements show that the $EH_{6/7}$ is mainly responsible of the leakage current measured in the Schottky diodes.

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