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Complex study of SiC epitaxial films

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Abstract. 4H-SiC epitaxial films grown on 4H-SiC in CVD reactor VP508GFR are investigated using FTIR, X-Ray diffraction, C-V measurements, stylus profiler and DIC optical microscopy.

Introduction

Silicon Carbide (SiC) is a promising material for advanced power electronics. Combination of wide-bandgap, electric strength, high thermal conductivity and high electron mobility allow to develop power semiconductor devices with high switching frequency and low energy losses [1, 2].

SiC epitaxial layer production was established at ZAO NPK «Electrovypriamitel» (Saransk). Hot wall epitaxy SiC CVD reactor VP508GFR produced by Aixtron AG is used to grow epitaxial films. It allows to grow SiC epitaxial films on 4" SiC wafers at temperature range from 1600 to 1650°C using C_3H_8, SiH_4 precursors with HCl addition in H_2 flow.

To control the parameters of grown films ZAO «NPK «Elkar» has the following equipment:

– FTIR spectrometer NICOLET 6700 produced by Nicolet Instrument Corporation enabling to perform reflectance and absorption spectra measurements in the range 300 – 7800 cm^{-1}. Spectrometer is set up to measure SiC epitaxial film thickness with interferogram and Cepstrum techniques in the range from 0,2 µm. Maximum film thickness which can be measured using this tool is determined by IR rays absorption in SiC and estimated for doping levels 10^{15} – 10^{16} cm^{-3} equal to 160 – 180 µm. Software of spectrometer allows to analyze epitaxial film thickness distribution with the accuracy 0,2 µm on SiC wafers up to 4"; results of the measurement are presented in 2D and 3D geometry.

– X-ray diffractometer Rigaku Model SmartLab with monochromator Ge (004) and automatic XY-4" Ø attachment for surface mapping used to analyze SiC: off - orientation angle of SiC substrates and also to assess the film quality on X-ray rocking curves of the diffraction peak; results of the measurement are presented in 2D and 3D geometry.

– CVmap92A produced by Four Dimentions Inc. is purposed for measuring of C-V characteristics, it is equipped with mercury probe with 0,0185 cm^2 area, which is used to measure electrically active impurity, its depth and SiC epitaxial films surface distribution; results of the measurement are presented in 2D and 3D geometry.

– Profiler P16+ KLA-Tencor is used to measure surface roughness, surface profile and coating thickness. It is equipped with set of styluses with tip radius from 0.04 to 2 µm. This tool can provide measurements and built up 3D wafer surface geometry up to 200 mm diameter with resolution 0.6 nm. The probe load is adjusted from 0,05 mg; results of the measurement are presented in 2D and 3D geometry.

– Optical microscope Nikon LV100D produced by Tokyo Boeki Ltd. with Nomarski prism is used for visual inspection of wafer surface quality. It can perform measurements in dark and bright field, in reflected and transmitted light with the use of polarized and without its use, with the use of DIC and without its use. Results of the measurement can be displayed on PC for ongoing study.

Results obtained during 4H SiC epitaxial films growth on 3" and 4" 4H-SiC wafers are presented in this paper.

Epitaxial film thickness measurement

Using FTIR spectrometer NICOLET 6700 C reflectance spectra from epitaxial layers surface with three different SiC film thickness was carried out. As a result of wave interference reflected from epitaxial film surface and from the boundary film-substrate emerged an oscillation shown in Fig.1 Oscillation period in wave number space is related to epitaxial film thickness by the following equation:

$$\Delta k = 1/(2d(n^2-\sin^2\theta)^{1/2})$$

where n – index of refraction of SiC epitaxial film, θ – incident angle, d – epitaxial film thickness.

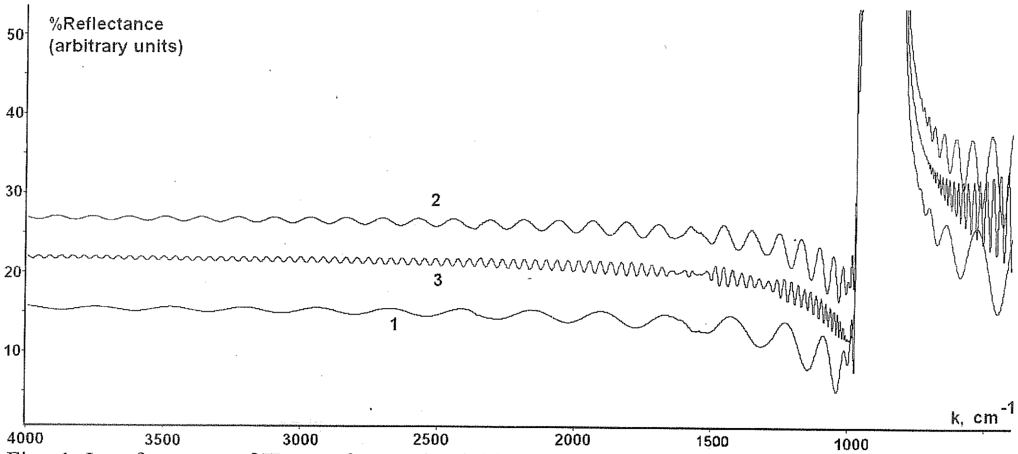


Fig. 1. Interferogram of IR rays from epitaxial layers surface with different film thickness 6 μm. (1), 12 μm. (2) and 40 μm. (3). To improve the view the curves were shifted vertically

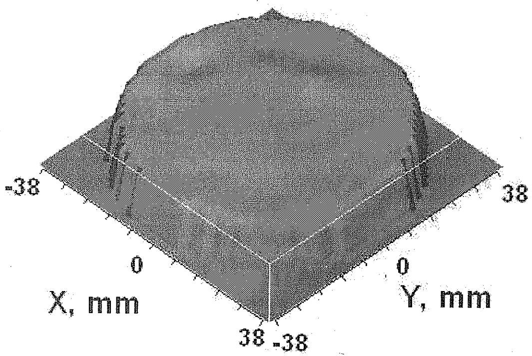


Fig. 2. 3D geometry of epitaxial film thickness distribution, average thickness 6 μm

The second technique of thickness measurement with NICOLET 6700 – Cepstrum. The technique is concluded in execution of Fourier interferogram transform from the studied sample and control sample with thicker epitaxial film. After subtraction inverse Fourier transform is carried out. The result is called sample cepstrum and contains information about epitaxial film thickness [3]. Epitaxial film thickness distribution across wafer area was measured using this technique. Typical result is shown in Fig. 2, it shows a good quality of grown film: root-mean-square deviation from average thickness (5,99±0,01) μm was 1,12%. SiC epitaxial wafers with 12 μm thickness had root-mean-square deviation 1,04%, SiC epitaxial wafers with 40 μm thickness – 1,62%.

Doping concentration measurement

The system for measuring of C-V characteristics CVmap92A enables to measure electrically active impurity concentration, its depth and SiC epitaxial films surface distribution. Results obtained for epitaxial film 12 μm are shown in Fig.3. This technique is nondestructive: in order to measure doping concentration on selected depth one should apply applicable bias voltage on mercury-SiC contact.

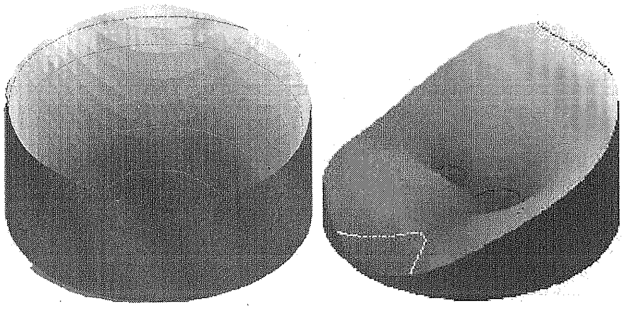


Fig. 3. Donor concentration distribution (nitrogen) across 12 μm epitaxial film area surface (a) and on the depth 4 μm (b). 3" 4H-SiC wafer.

Epitaxial film surface average donors concentration equals to $5{,}77\cdot10^{15}$ cm^{-3}, maximum donor concentration - $6{,}63\cdot10^{15}$ cm^{-3}, minimal – $5{,}13\cdot10^{15}$ cm^{-3}. Concentration change 9,7%. Doping concentration slightly decreases with the depth and on the depth 4 μm comprises: average value - $5{,}12\cdot10^{15}$ cm^{-3}, maximum - $5{,}41\cdot10^{15}$ cm^{-3}, minimum - $4{,}79\cdot10^{15}$ cm^{-3}. Concentration change 3,7%.

Surface roughness

Profiler P-16+ measured epitaxial film surface roughness. Results in 3D geometry are shown in Fig.4. Roughness Ra was 2,2 nm, that corresponds to typical results for production grade SiC epitaxial films [3].

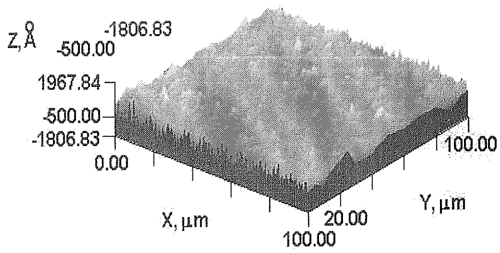
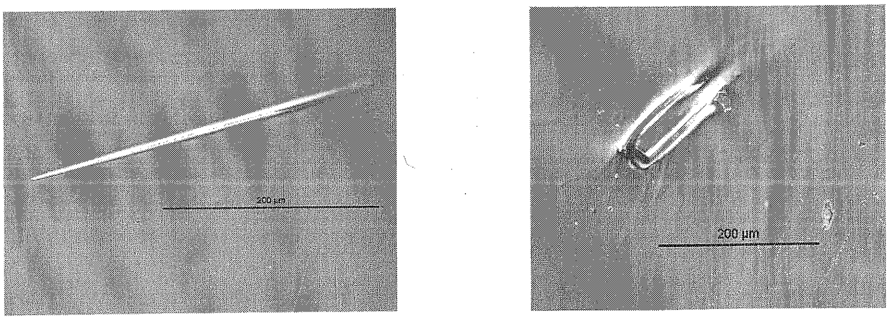


Fig. 4. 3D topography of 12 μm epitaxial film surface

Epitaxial film surface defects

Optical microscope Nikon LV100D examined epitaxial film surface. Selective etching wasn't carried out in this study.

Defect samples observed on 40 μm epitaxial film surface are shown in Fig.5. Carrot defect is shown in Fig.5a, Fig.5b – micropipes (named according to [4]). Images were obtained with the use of Nomarski contrast for the best image view although such defects can be observed both in dark



a b

Fig. 5. Carrot (a) and comet (b) defects on 40 μm epi film surface, obtained with the use of Nomarski microscopy

and bright fields without its use. On 3" SiC wafer 18 carrot and 8 comet defects were found. Comet defects are located 2 mm from edge exclusion. Carrot defects are equally distributed across epitaxial film total area.

Crystal perfection measurement

To evaluate crystal perfection rocking curves were measured using X-ray diffractometer Rigaku with CuKα radiation. In Fig.6 diffraction peak 4H-SiC (0008) for two epitaxial films is shown. Rocking curves are obtained in ω-scanning. Peak shown in Fig.6b corresponds to film shown in Fig.5, and it is quite wide indicating the existence of large elastic strains.

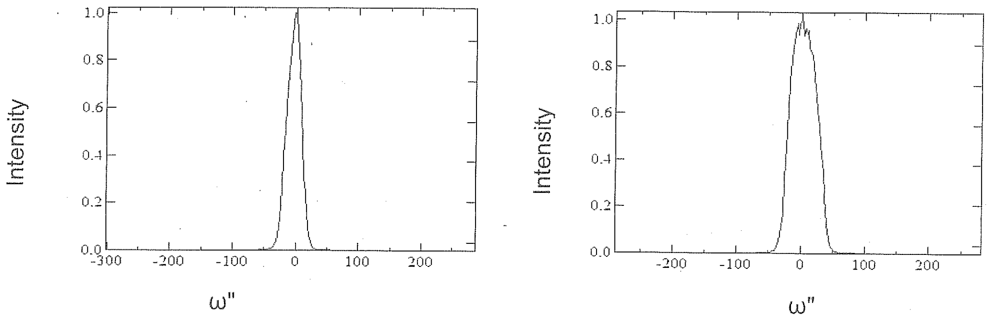


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Fig. 6. Rocking curves at the (0008) plane 4H-SiC for two epitaxial films. (a) FWHM=29", (b) FWHM=51"

1. This material is based upon work supported by Profinvest Ltd. in purpose of target program realization in Mordovia.
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