CHARACTERIZATION OF EPITAXIAL 4H-SiC AS MATERIAL FOR SPECTROMETRIC RADIATION DETECTORS

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1. Introduction

SiC is a wide bandgap (up to 3.26 eV) semiconductor, which became object of an intensive study during last decade, thanks to its unique physical properties including high saturation velocities of the charge carriers, high breakdown field, high thermal conductivity [1] and the device's ability to operate at elevated temperature. One of the potential application of SiC lies in the field of radiation detection in harsh environments of hot plasmas in nuclear fusion reactors. Such detectors should operate at elevated temperatures with superior spectrometric characteristics for soft X-ray detection, particularly in the photon energy region 1 ÷ 5 keV. The required energy resolution of the spectrometric channel should be better than 500 eV in FWHM (full width at half maximum) and the noise threshold should not exceed 1 keV. The spectrometric performances of epitaxial SiC detectors were demonstrated by Bertuccio et al. [2, 3]. The present work is devoted to preparation, electrical and structural characterization, and detection performances of Schottky barriers prepared on high purity n-type 4H-SiC layer grown by liquid phase epitaxy (LPE) by the L.P.E. spa, Catania, Italy.

2. Experiment and discussion

Detector structures were prepared from a 100 μm thick LPE grown nitrogen-doped SiC on a fragment of 3" 4H-SiC wafer, by the insertion of a 0.5 μm thick n^+-SiC buffer layer with concentration 1×10^{18} cm^{-3}. The epitaxial 4H-SiC polytype with the hexagonal layer structure

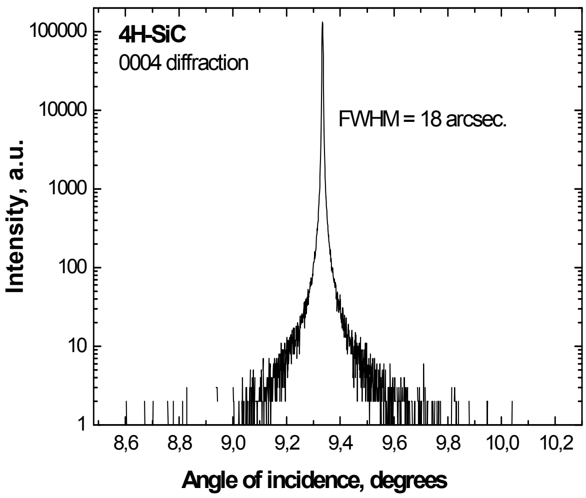

Fig. 1: *High resolution X-ray diffraction of the 4H SiC epitaxial layer. The optimum crystal order is confirmed by the FWHM of the peak.*

was analyzed by high resolution X-ray diffraction. The lattice parameters for this structure are c = 10 Å and a = 3.0730 Å. The sample surface was 8° off the 0001 basal plane. The 0004 diffraction from the basal plane corresponding to a Bragg angle of 17.83° was performed by a high resolution X-ray diffractometer using a Bartel Ge220 monochromator, with an instrumental resolution of approximately 12 arcseconds. The 0004 rocking curve of the measurement (ω, ω–2θ scan) is shown in Fig. 1. The peak has an FWHM of 18 arcseconds, just slightly more than the 12 arcseconds instrumental resolution, corresponding to a very good crystal quality. It is worth to note that the very narrow and sharp 0004 peak, with no broadening or diffuse scattering indicates that the crystal quality of epilayer and SiC substrate are equivalent. The reciprocal lattice map around the 0004 node of the diffraction also evidenced the very good quality of the layer [4].

Detectors were prepared by evaporation of a double layer of Au-Ni/4H-SiC with thickness 80-40 nm on both sides of the wafer fragment with a high vacuum electron gun apparatus. The Schottky barrier contacts were formed on the epitaxial layer through a contact metal mask. Evaporated circular contacts had diameters of about 0.3, 0.6 and 0.9 mm.

The current-voltage (*I-V)* characteristics of the Au-Ni/SiC diodes, measured at different temperatures in the 325 ÷ 445 K range, are shown in Fig. 2. For lower temperatures the reverse branches of the barriers were under the detection limit (1×10^{-12} A) of our experimental apparatus (Keithley 236 source measure unit). Fig. 3 reports the $1/C^2$ vs. V plots obtained from capacitance-voltage (*C-V*) measurements at different temperatures of the 4H-SiC based detector (contact diameter 0.9 mm) together with the corresponding calculated concentration profiles. As shown in figure, the free carrier concentrations are almost constant within the explored depth (3 ÷ 6.5 μm) with a value of about 1.4×10^{14} cm^{-3}, confirming the high purity of the layer. To investigate the depth profile in a wider range, Schottky barriers with a larger diameter are required in order to obtain more reliable capacitance values at high reverse voltages. Even though the character-ristics are not linear on the whole explored voltage range, from the fitting of the experimental points at low biases a barrier height Φ_b of about 1.54 eV can be estimated. It should be noted that the barrier height, calculated by determining the saturation currents obtained from the extrapolation of the forward *I-V* characteristics at different T (Fig. 2), is about 1.2 eV. This discrepancy could be attributed to the relatively high

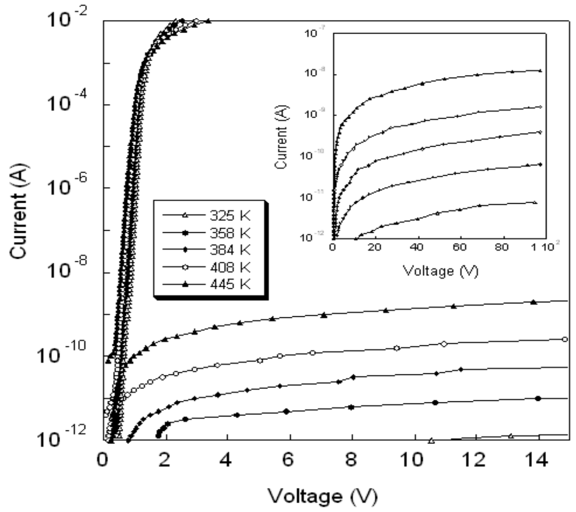

Fig. 2: *I-V characteristics of a typical Au-Ni/4H-SiC Schottky barrier measured at different temperatures. The ideality factors of the diodes, calculated in the current interval of $10^{-9}\div10^{-5}$ A, are in the range of 1.2÷1.4. The reverse characteristics up to 100 V are shown in the inset.*

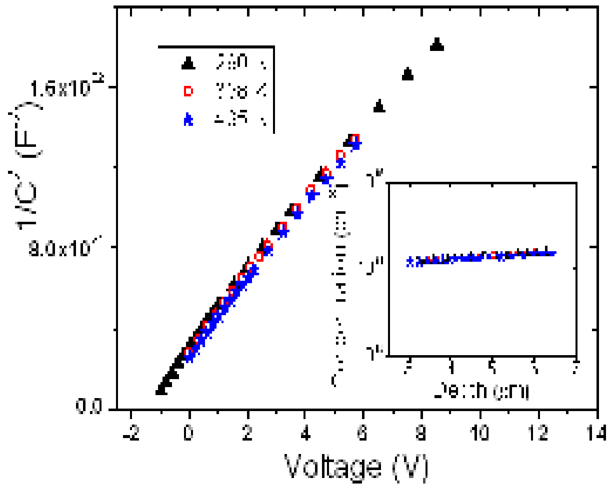

Fig. 3: *$1/C^2$ vs. V plots of a Au-Ni/4H-SiC Schottky barrier (0.9 mm in diameter) obtained from C-V measurements carried out at three different temperatures. The corresponding free carrier concentration profiles are reported in the inset.*

ideality factor (1.2÷1.4).

Deep-levels in the forbidden gap of SiC were investigated by deep-level transient spectroscopy (DLTS) technique using a Semi-trap lock-in type spectrometer. As shown in Fig. 4, two main DLTS peaks, corresponding to two main deep donor levels, labeled as A and B, were detected. The respective activation energies E_T, capture cross sections σ_T and concentrations N_T are listed in Fig. 4.

The spectrometric performances of the SiC detectors with the largest contact diameter (0.9 mm) were investigated by the measurement of the pulse height spectra of the ^{241}Am. An AMPTEK CoolFet preamplifier, with the lowest available noise of 670 eV FWHM (Si, zero input capacitance), was used in the measurements. The observed spectrum is shown in Fig. 5.

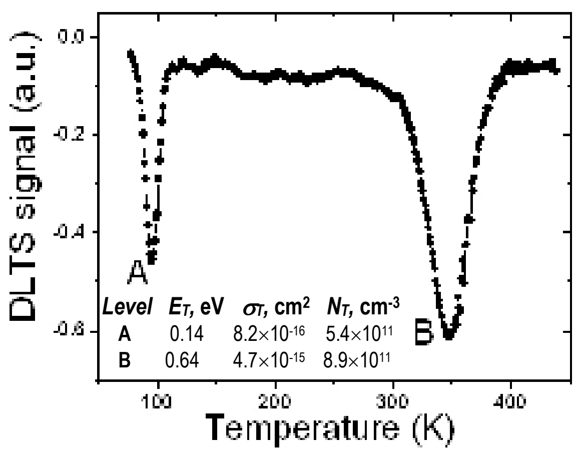

Fig. 4: *DLTS spectrum of the Au-Ni/4H SiC Schottky barrier: pulse frequency 264 Hz, pulse width 135 µs, reverse voltage -3 V, pulse voltage 0 V.*

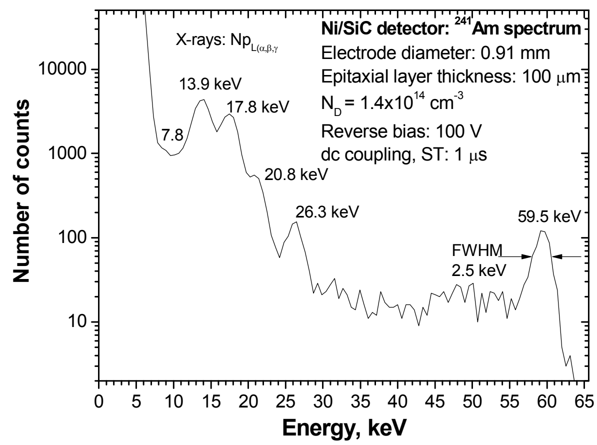

Fig. 5: *Pulse-height spectrum of the ^{241}Am radionuclide revealed by the fabricated 4H-SiC detector plotted in semi-log scale.*

The estimated energy resolution of the 59.5 keV photopeak is about 2.5 keV FWHM. Also the Np X-ray lines (13.9, 17.8, 20.8 keV) are detected and the threshold noise reaches about 6.5 keV limited by the noise performance of the used preamplifier (pulser measurement gives 2.3 keV in FWHM). It should be noted that a careful attention must be devoted in the application of SiC detectors in low noise spectrometry: due to its 3.26 eV wide band gap, the energy for production of the electron-hole pair is high, 7.8 eV (both valid for the polytype 4H-SiC [1]), more than twice comparing to Si. Hence also the detected signal amplitude will be correspondingly low and used preamplifier must perform with much lower noise to reach the same signal-to-noise ratio as in the case of Si or GaAs detectors. Additional studies on the resistance of SiC detectors to the damage induced by neutrons and gamma rays are in progress.

3. Conclusion

High purity epitaxial layers of n-type 4H-SiC were grown by nitrogen doped LPE on SiC substrates. Schottky barrier detectors with three different areas were fabricated using Au-Ni metallization and characterized by using *X*-ray diffraction, *I-V, C-V,* DLTS and by the measurement of the ^{241}Am pulse height spectra. The obtained results confirmed a high purity and an excellent crystallographic quality of the grown epitaxial layer. Low free carrier concentration and deep level density lower than 1×10^{12} cm^{-3} were observed in the epilayer. The fabricated detectors exhibited extremely low leakage currents (< 1 pA/cm^2) at 100 V (RT) and an excellent spectrometry limited by the noise of the employed spectrometric preamplifier.

Acknowledgement

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