The ESR study of conduction electrons in heavily nitrogen doped 6H SiC crystals

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In the present work the magnetic and electronic properties of the heavily doped n-type 6H SiC samples with $(N_D - N_A) \geq 10^{19}$ cm^{-3} grown by modified Lely method have been studied by continuous wave electron spin resonance (ESR) technique. The ESR experiments were carried out on Bruker ELEXSYS E580 spectrometer using the ER 4122 SHQE SuperX High-Q cavity at X-band ($\nu \approx 9.4$ GHz) at T = 150 – 5 K.

At low temperatures, two overlapping lines (narrow and broad) characterized by an electron spin $S = 1/2$ were observed in the ESR spectrum of the heavily doped n-type 6H SiC. The narrow line was observed in the temperature interval from 5 to 150 K while the broad ESR line vanished at $T > 25$ K. The narrow line with $g_{\|} = 2.0047(3)$, $g_{\perp} = 2.0034(3)$ was attributed to the conduction electron (CE) spin resonance (CESR). The obtained g-tensor value for the CE serves as evidence that there is a coupling between the CE and localized electrons (LE) spin systems, which is realized via the exchange coupling of the CE with the electrons localized on the nitrogen (N) donors residing hexagonal “h” position for $\boldsymbol{B}\|\boldsymbol{c}$ and with the electrons localized on N donors residing hexagonal “k2” position for $\boldsymbol{B}\perp\boldsymbol{c}$. The broad ESR line overlapped with the CESR signal was attributed to the exchange S-line that arises in the ESR spectrum due to the hopping motion of the electrons between the occupied and non-occupied hexagonal and quasi-cubic positions [1].

The CESR line was fitted by a Lorentzian lineshape (insulating phase) below 40 K and by a Dysonian line (metallic phase) above 40 K indicating that insulator-metal (IM) transition occurs at about 40 K. The temperature dependence of the CESR linewidth below 40 K was explained by the spin-flip scattering of the CE at the LE, corresponding to the regime of the weak exchange coupling between the LE and CE spin system referred to as an unbottlenecked Korringa relaxation mechanism [2]. At $T > 40$ K the thermal broadening of the CESR linewidth is caused by the relaxation (Orbach process) [3] of the LE via the excited levels driven by the exchange interaction of the LE with CE. The observed drop in intensity of the CESR signal at 25-30 K is attributed to the evidence for the antiferromagnetic interaction between spins occurred on the insulating side of the IM transition [4].

In addition, it was found that the IM transition characterized by a strong change in the MW conductivity (estimated from the cavity Q-factor) of the sample depends on the N concentration and shifts towards the lower temperatures for the 6H SiC samples with higher concentrations. Two mechanisms of conduction: hopping conduction and band conduction were distinguished in the range 10-25 K and 25-50 K, respectively. The obtained values of activation energies agree well with those found in [5].

The work was performed under financial support from GA ČR 13-06697P and SAFMAT CZ.2.16/3.1.00/22132 projects.

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