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Electron paramagnetic resonance study of new centres in SiC

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Abstract

An SiC single crystal of a hexagonal polytype heat treated at 2000 °C and subsequently quenched was investigated by the electron paramagnetic resonance technique. The study has revealed the presence of several new centres in the sample. Different spectra could be separated by their individual angular dependence and response to illumination and temperature variations. In addition, an unexpected dependence of the spectra on the microwave frequency has been observed.

1. Introduction

Owing to its superior electrical, mechanical and chemical properties as well as its potential applications in device manufacturing, SiC is experiencing a renewed wave of interest [1]. This situation also stimulates research on the physics of defects in this material. In the past the electron paramagnetic resonance (EPR) technique among others has been applied to the study of SiC [2, 3]. Following these studies, several defect centres have been identified in hexagonal SiC crystals. The current improvements in SiC technology should find their immediate confirmation in EPR studies on recently grown materials.

The measurements were performed with superheterodyne spectrometers operating at frequencies of 23 and 9.2 GHz and adjusted to detect the dispersion part of the EPR signal. The magnetic field was modulated at a low frequency of 83 Hz and could be rotated in the plane which contained the *c* axis of the sample. A cylindrical TE_{011} mode silver-coated epibond cavity was used. The sample temperature was held at 4.2 K during most of the experiments but could also be elevated by a built-in heater. The experimental set-up permitted *in situ* white light illumination of the sample. Light from a halogen source was transmitted to the sample by a quartz rod.

The sample used in the experiment was supplied by Dr. V. S. Vainer. It was an SiC single crystal of a hexagonal polytype. Following crystal growth, two identical samples were cut from it. One of them received a short heat treatment at 2000 °C followed by a rapid quench to room temperature. The other sample served as reference. The sample and its position in the magnetic field are depicted in Fig. 1.

2. Experimental results and discussion

In the reference sample no EPR signal has been found. The EPR spectrum recorded for the heat-treated sample at 23 GHz is shown in Fig. 2. The total concentration of paramagnetic centres can be estimated as 10^{16} cm^{-3}. The spectrum consists of two side lines of smaller intensity (labelled here as spectrum I) and a strong central line (spectrum II). Spectrum II appears to be isotropic while spectrum I exhibits a pronounced angular dependence as shown in Fig. 3. As can be seen, a symmetric pattern is observed with a characteristic crossing point at an angle between 50° and 60°. Further, spectrum I was found to be significantly lower in intensity upon illumination as well as upon temperature increase.

Upon closer examination, spectrum II also reveals a more complicated character. Figure 4

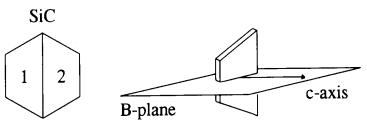

Fig. 1. Schematic representation of the crystal structure of a hexagonal polytype of SiC and the experimental orientation of the sample against the plane of the external magnetic field.

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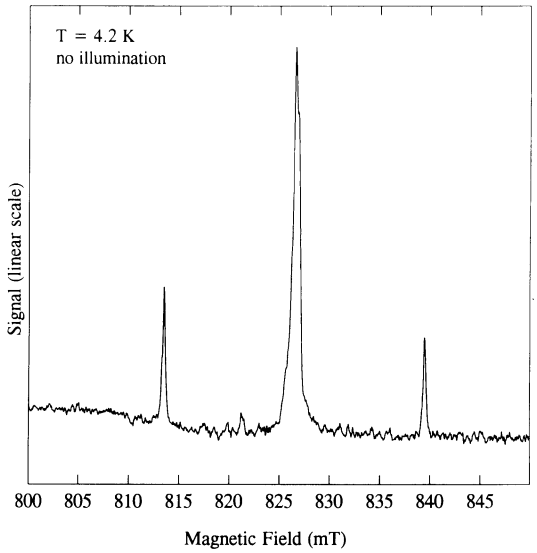

Fig. 2. EPR spectrum of heat-treated sample as measured at 23 GHz microwave frequency (without illumination) at 4.2 K.

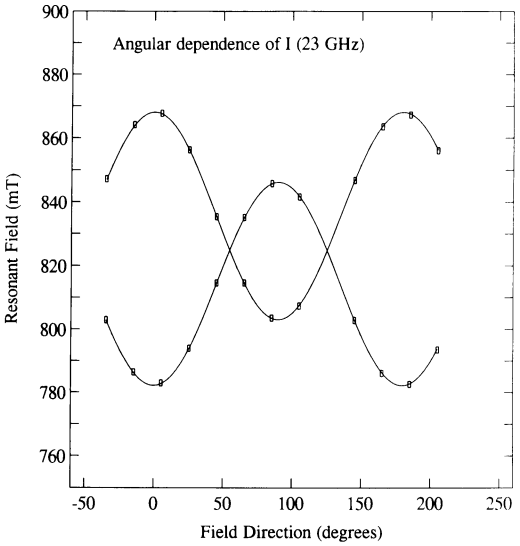

Fig. 3. Angular dependence of spectrum I as measured at 23 GHz microwave frequency and 4.2 K. The magnetic field has been rotated in the plane as indicated on Fig. 1.

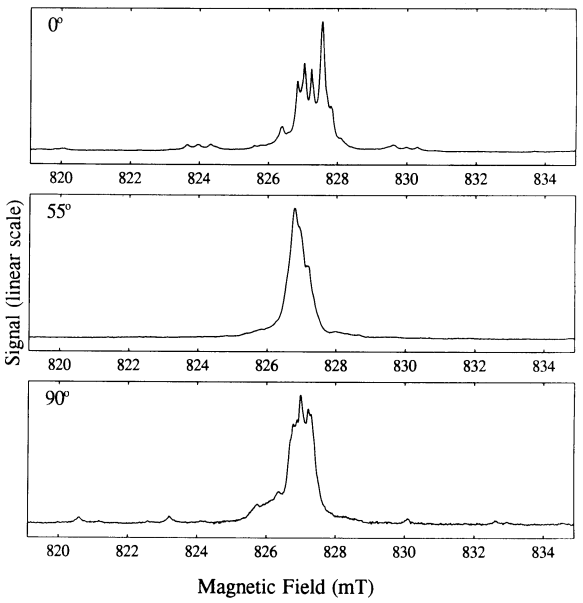

Fig. 4. Spectrum II as recorded at 23 GHz microwave frequency in three different directions of the magnetic field.

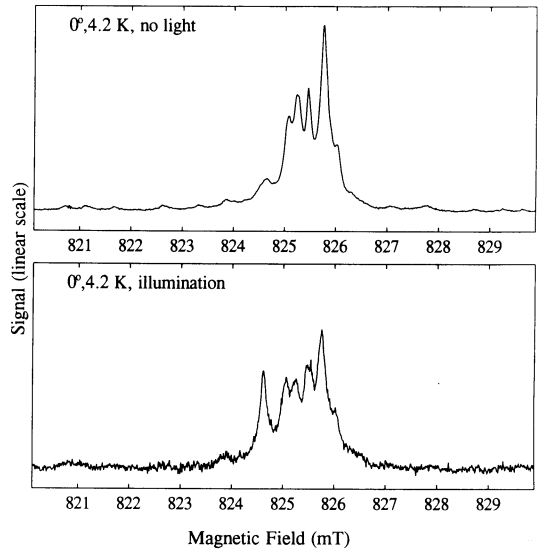

Fig. 5. Influence of white light illumination on spectrum II as measured at 23 GHz microwave frequency and 4.2 K.

presents spectrum II as measured without illumination and at liquid helium temperature for three characteristic angle values of 0°, approximately 55° and 90°. A clear multicomponent, angle-dependent character may be observed, while the linewidth of the separate resonance lines is very small, of the order of 0.1 mT. To investigate further the components of spectrum II, the influence of white light illumination has been monitored. The results are depicted in Fig. 5. As can be seen, most of the individual lines decrease their intensity upon illumination, while one line increases. This indicates that at least two different EPR components are included in spectrum II. The band gap illumination of the sample, apart from changing the occupation of the impurity levels, may also increase the sample temperature. In order to eliminate the influence of this side effect, the temperature dependence of spectrum

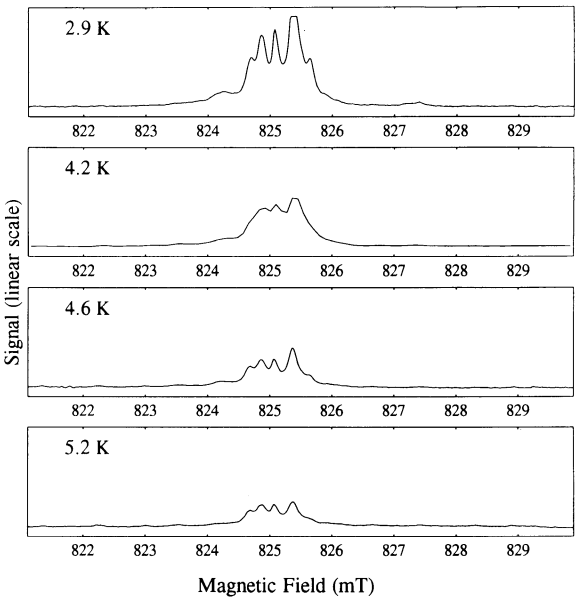

Fig. 6. Temperature dependence of spectrum II as measured at 23 GHz microwave frequency.

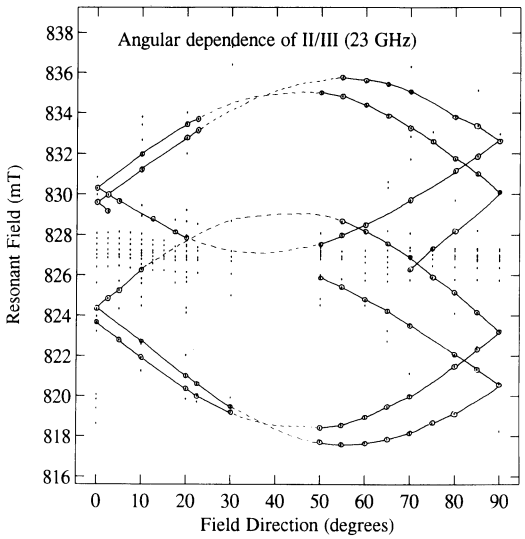

Fig. 7. Angular dependence of spectrum II as measured at 23 GHz microwave frequency (without illumination) and 4.2 K. The magnetic field has been rotated in the plane as indicated on Fig. 1.

II was checked. The results are shown in Fig. 6; they indicate that upon temperature increase, all the components similarly lower their intensity. Finally, the angular variation of spectrum II has been measured and is depicted in Fig. 7. It shows generally two major features: the outer, lower intensity resonances which most probably originate from the hyperfine interactions and exhibit

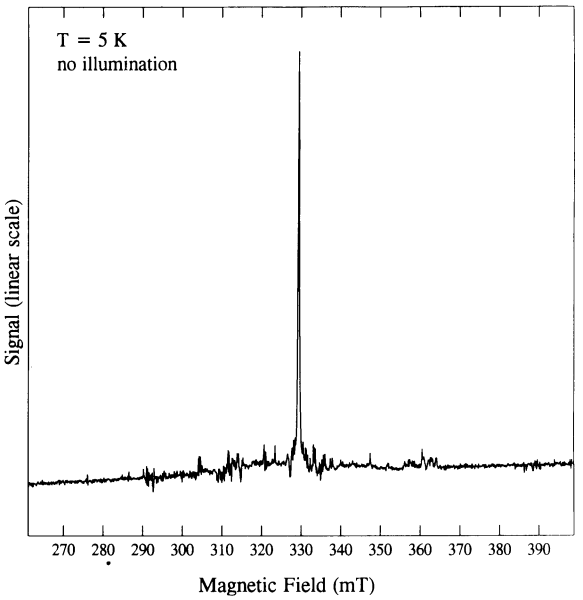

Fig. 8. EPR spectrum of heat-treated sample as measured at 9.2 GHz microwave frequency and liquid helium temperature.

pronounced anisotropy, and the inner, stronger lines whose anisotropy is contained in a narrow field range of approximately 2 mT. On the basis of both the angular and illumination dependences, one can conclude that indeed not two but three distinct EPR spectra are present in the sample studied. In order to facilitate identification of the observed centres, which is not possible at this stage of the research, additional measurements were performed at a lower microwave frequency, namely 9.2 GHz. By comparing the EPR spectra obtained for one centre in two different frequency bands, it is usually possible to separate the hyperfine interactions from those influenced by the external magnetic field. The results obtained at 9.2 GHz are presented in Fig. 8 for the non-illuminated sample and are quite unexpected. As can be seen, the spectrum differs very much from that obtained at 23 GHz (Fig. 2): it contains only the central line, which appears to be very sharp, strong and homogeneous, while spectrum I has totally vanished.

The experimental results presented above do not permit identification of the observed defect centres at this stage. It can nevertheless be concluded that, most probably, three different defects are present in the sample. They exhibit quite different degrees of anisotropy, indicative of either different local symmetries or degrees of

delocalization. Further investigations, currently under way, will aim at a full understanding of the observed defect centres. Hopefully they can also provide an explanation for the peculiar microwave frequency dependence, which is the most puzzling result of the studies presented here.

References

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