THE INTERACTION AMONG DEFECTS DURING HIGH TEMPERATURE ANNEALING OF HIGH PURITY SIC

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It is known that thermal instability can significantly affect the operation of high temperature/high power components. Here, we show that a defect in high purity SiC that anneals between 1000 and 1500 ^{o}C may alter the Fermi level by transferring charge to two other defects.

High purity SiC substrates were heat-treated in 99.999% pure Ar or O_2 for 0.5 hr at temperatures up to 1600 °C. The minimization of O_2 during the Ar treatment was verified by oxide thickness measurements showing that Ar produced an oxide film at least an order of magnitude thinner than that generated by oxygen. The samples were studied using X-band electron paramagnetic resonance (EPR) between 4 and 300 K. Detection of an EPR signal typically implies the presence of a defect with an unpaired electron; thus, only certain charge states of a defect may be observed. Since EPR data are typically recorded in derivative mode, the total number of centers is obtained from the double integral of a spectrum and comparison to a standard.

Figure 1 depicts EPR spectra measured prior to annealing (A) and after treatment in Ar at 1000 ^{o}C (B) and 1600 ^{o}C (C). The spectra were normalized to the same peak-to-peak amplitude to emphasize the linewidth change. Figure 2 shows the total number of EPR-active defects measured after each Ar (■) and O_2 (○) anneal relative to the number in the unannealed sample. Spectral analysis shows that the major contribution to the reduction seen in Figure 2 is a 10 G wide line, which is seen in Fig. 1a superimposed on a sharper, more thermally stable signal. The broad line-width and low temperature for the onset of the concentration decrease suggest that the 10 G wide spectrum represents randomly oriented dangling bonds found very near the surface. The surface density of this defect before annealing was approximately $2x10^{13}$ cm^{-2}. The similarity of the O_2 and Ar data (Fig. 2) indicates that the decrease in the dangling bond concentration is due to annealing rather than oxidation.

After the 1000 ^{o}C anneal when the broad line is almost eliminated (Figs. 1B and 2), rotation of the sample with respect to the applied magnetic field (B) resolves the remaining spectrum into at least two signals at B=3476 G and 3472.3 G (Fig. 3A) with concentration ~10^{14} cm^{-3}. However, the 1500 ^{o}C treatment reduces the amplitude of the line at 3476 G by more than a factor of ten, while the 3472.3 signal is increased by a factor of two and accompanied by a series of additional lines (Fig. 3B).

Two of the three centers present in the sample after the 10 G wide signal is reduced have been previously identified. The 0.7 G wide signal at B=3472.3 G in Figure 3 is thought to be a carbon vacancy [1-3]. 4 K EPR measurements indicate that the multi-line pattern which is barely resolved in the post-1500 ^{o}C anneal spectrum (Fig 3B) is due to the shallow boron acceptor. Photo-induced charge exchange between these two centers has been reported earlier [3]. Here we show that charge transfer may also be induced by high temperature annealing. The data suggest that reducing the concentration of the center at B=3476 G alters the charge state of both the carbon vacancy and boron acceptor. Presumably, the elimination of the defect represented by the 3476 G line releases an electron or hole that is subsequently transferred to the carbon vacancy and/or boron acceptor creating additional paramagnetic states of these centers. Such a rearrangement of charge may shift the Fermi level and ultimately change the response of a SiC device. Note that the spectrum shown in Figure 1C indicates that defects remain in the samples up to heat-treatment temperatures of at least 1600 ^{o}C.

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2) N. T. Son, P.N. Hai, and E. Janzen, Phys. Rev. B **63**, 201201 (2001).
3) M. E. Zvanut and V. V. Konovalov , Appl. Phys. Lett., Jan. 2002, to be published,

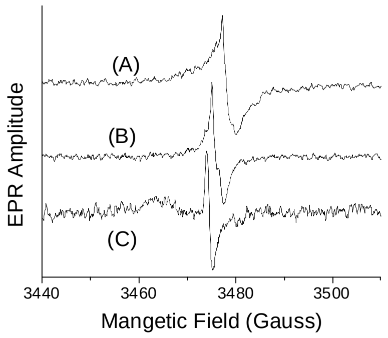

Figure 1. 77K EPR spectra of SiC before anneal (A); after anneal in Ar at 1000 ^{o}C (B) and 1600 ^{o}C (C). Data have been normalized to the same amplitude for clarity.

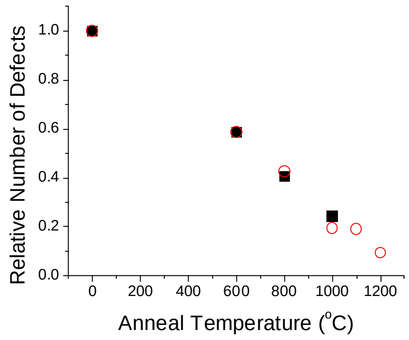

Figure 2. Relative number of total defects measured at room temperature after a 0.5 hr Ar (■) or O_2 (○) anneal. The major cause for the reduction at T<1000 ^{o}C is the linewidth decrease, and it is most likely due to a surface defect.

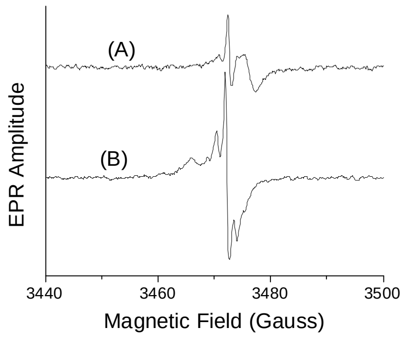

Figure 3. 77 K EPR spectra of SiC annealed in Ar at 1000 ^{o}C (A) and 1500 ^{o}C (B). The sample was rotated 90^{o} about the $(11\bar{2}0)$ axis compared to the orientation used to obtain Figure 1 data.