Activating Ion Implants in 4H-SiC by Annealing with an AlN or BN Cap

K.A. Jones, P.B. Shah, M.H. Ervin, M.A. Derenge
Army Research Lab
2800 Powder Mill Rd., Adelphi, MD 20783
R.D. Vispute
University of Maryland
Physics Dept., College Park, MD 20742
J.A. Freitas
Naval Research Lab
Code 6877, 4555 Overlook Ave., Washington, DC 20375
G.J. Gerardi
William Paterson University
Chemistry & Physics Dept., Wayne, NJ 07470

Planar SiC devices are fabricated using ion implantation because the rates of diffusion of dopants into SiC are too low even at temperatures as high as 1800°C to be technologically useful. However, the implanted material must be annealed to activate the dopants at temperatures where the Si preferentially evaporates and severely roughens the surface as is shown in Fig. 1. We show that an AlN film has the necessary properties to act as an annealing cap for temperatures up to 1600°C; it retains coverage of the SiC surface during the anneal, does not react with the SiC surface during the anneal, and can be removed selectively without harming the SiC surface after annealing. The properties of the AlN film and the AlN/SiC interface as-deposited and after annealing at various temperatures is briefly discussed. For the higher annealing temperatures required for implanted p-type dopants, we show that a BN/AlN composite cap can be used when the BN cap is ion milled off and the remaining AlN is etched off preferentially. The properties of the as-deposited BN film and films annealed at various temperatures are briefly discussed.

The utility of using the cap is demonstrated for the electrical activation of N, Al, and Al/C co-implants. The n-type N implants become measurably activated by 30 min anneals at 1400°C, and are almost completely activated by anneals at 1500°C with only marginal improvement seen by going to 1600°C. That the N is only partially activated by the 1400°C anneal and is essentially completely activated by the 1600°C anneal is further confirmed by the sheet resistance, $R_{sh,}$ vs measurement temperature data; R_{sh} decreases with the temperature for samples annealed at 1400°C, whereas it increases for samples annealed at 1500 and 1600°C. It is also shown that the marginal reductions in R_{sh} can be obtained by annealing for longer times up to 60 min for samples annealed at 1600°C. Samples implanted with Al or Al/C and annealed at 1400°C were so resistive that measurements could not be made on them. As shown in Fig. 2, R_{sh} is much lower after a 1650°C anneal than it is after a 1500°C anneal for both Al and Al/C implanted samples with the difference being larger for the co-implanted wafer. Whereas there is little difference in R_{sh} for the Al and Al/C implanted samples annealed at 1650°C, there is a factor of five difference for samples annealed at 1500°C demonstrating the utility of the co-implant for the lower annealing temperatures. Also, there is little difference between R_{sh} for Al/C samples annealed at 1600 and 1650°C suggesting that the activation is essentially complete after the 1600°C anneal.

The CL, EPR, and RBS spectra of Al and Al/C implanted and annealed samples are also presented. A typical CL spectrum is shown in Fig. 3. The L_1, L_2 doublet near 2.9 eV associated with the D_I defect increases relative to the peak thought to be an exciton bound to an Al acceptor near 3.0 eV. This can be explained by the Al acceptor 0.25 eV above the valence band being compensated by the D_I donor-like state 0.35 eV above the valence band. There are more D_I defects, thought to be divacancies, at the higher annealing temperatures because the vacancies that form them are more mobile. This effect apparently more than offsets the greater amount of activation of the Al at the higher annealing temperatures. That the implanted Al does not just become activated as an acceptor is confirmed by EPR measurements where no Al signal was detected - only isotropic signals associated with defects were. We also noted that the intensity of the L_2 peak increased relative to the L_1 peak as the annealing temperature increases suggesting that one of the two inequivalent sites in the 4H-SiC lattice was preferred. The effect was larger in the co-implanted sample. After initially decreasing with increasing annealing temperature χ_{min} from the RBS spectra increases suggesting the D_I defects interrupt the periodicity of the crystal lattice.

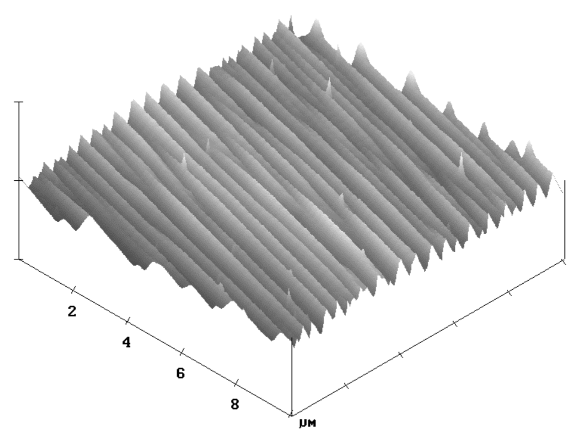

Fig. 1 AFM of a SiC surface annealed at 1600°C.

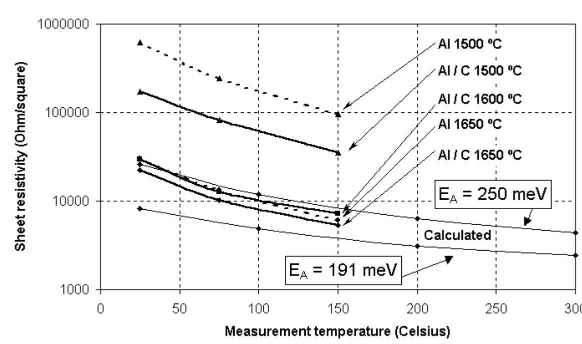

Fig. 2 Sheet resistance for Al and Al/C implanted samples annealed at various temperatures.

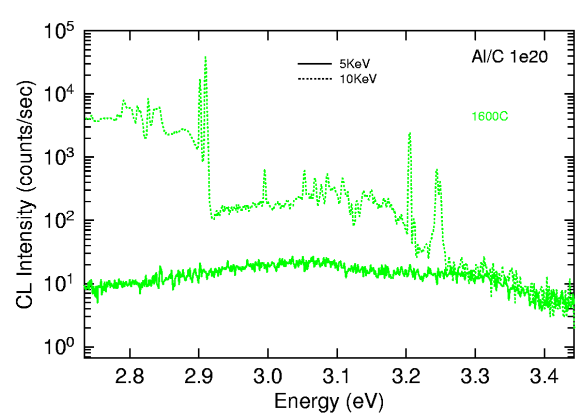

Fig. 3 A typical CL spectra.