Annealing Behavior of Donors Formed by High Fluence Irradiation of High Energy Particles in p-type Silicon

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B-doped p-type Si has been converted into n-type by high fluence irradiation (higher than $1x10^{17}$ cm^{-2} fluence irradiation for 1 MeV electrons or higher than $1x10^{14}$ cm^{-2} fluence irradiation for 10 MeV protons). We have investigated the annealing behavior of donors or hole traps induced by irradiation from Hall-effect measurements, and have determined the density (N_B) of boron that behaves as an acceptor from Fourier-transform infrared measurements at 8 K.

Si wafers were irradiated by 10 MeV protons with between $3x10^{12}$ and $1x10^{14}$ cm^{-2} or 1 MeV electrons with $1x10^{17}$ cm^{-2}. N_B decreased with the fluence, and hole traps were formed by irradiation. These suggest that the hole concentration p(T) should decrease with the fluence. However, the decrease of N_B and the formation of hole traps cannot lead to the conversion of p-type to n-type, and donors must be induced by irradiation.

p(T) decreased by less than $6x10^{13}$ cm^{-2} fluence of 10 MeV protons have not been recovered by 150 ^oC annealing at all. However, p(T) reduced by $1x10^{14}$ cm^{-2} fluence has been increased by this annealing, and n(T) in the type-converted Si irradiated by $1x10^{17}$ cm^{-2} fluence of 1 MeV electrons has been decreased by the annealing. Moreover, this type-converted Si has been converted into p-type by 250 ^oC annealing again.

From the temperature dependence of the electron concentration n(T) in the type-converted Si, donors are found to be located at approximately 0.3 eV below the conduction band minimum. A complex (B_i-O_i) of an interstitial boron and an interstitial oxygen is reported to be annealed out at higher than 200 ^oC, while a complex of a vacancy and an interstitial oxygen as well as double vacancies are not annealed out at lower than 300 ^oC. Therefore, these experimental results indicate that the donors should arise from B_i-O_i.