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Formation of Non-strained Single Crystalline SiGeB/Si Heterostructure by Ge and B Ions Implantation

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$Si_{1-X}Ge_X/Si$ heteroepitaxial growth has been intensively studied to realize new Si device such as HBT. Solid phase epitaxial (SPE) regrowth is the one of the most useful methods to form this heterostructure because of its capability of low process temperature, sharp heterointerface and heavy doping. As an example, we may use the conventional ion implantation of Ge and SPE-regrowth to form $Si_{1-X}Ge_X/Si$ heterostructure. In the $Si_{1-X}Ge_X/Si$ system, however, there is the lattice mismatch. Therefor, it is considered that the strained growth of $Si_{1-X}Ge_X$ layer is necessary to get good electrical properties$^{1)}$. We have reported$^{2)}$ that because of space limitation for the atoms which will move from random bonding to tetrahedral bonding, the critical thickness to coherent growth of $Si_{1-X}Ge_X$ film on Si by SPE method is much smaller than that by MBE$^{3)}$ and the other deposition method. Indeed, many dislocations were observed near the $Si_{1-X}Ge_X$ interface fabricated by SPE. In this paper, we propose that heavy doping of B which has a smaller atomic diameter in the $Si_{1-X}Ge_X$ system can improve the crystalline quality drastically, as the result of compensation of the lattice mismatch by B.

In experiment, Ge and B ions were implanted in Si(100) substrate which has n type carrier concentration of $4X10^{15}cm^{-3}$. The acceleration voltages for Ge and B are chosen to proper values at which the projected ranges of the ions should be almost the same. And then the sample were annealed in a furnace to recover the crystality at 700℃ for 1h.

Crystalline quality of the $Si_{1-X-Y}Ge_XB_Y$ layer estimated by RBS measurement is improved with introduction of B ions as shown in Fig. 1. In this figure, the condition of Ge implantation was that dose=$2.2X10^{16}cm^{-2}$ and energy=80keV in which the peak contents of Ge is 10% for total atoms. When the dose of B is $5.5X10^{15}cm^{-2}$;peak contents of B is 1/5 for Ge; the channeling yield estimated from Ge spectrum is about 3% that is limitation value of RBS measurement as shown in Fig. 2.

Fig. 3 shows the dependence of sheet resistance and carrier concentration measured by van der Pauw method on dose of 80keV implanted Ge^+ ion under constant dose of 15keV B^+ ion of $5.5X10^{15}cm^{-2}$. In this condition, the depth of pn junction is about 150nm from the surface. The sheet resistance has the minimum one, such as, 75Ω/□ when the dose ratio of the ions ($N_\square(Ge)/N_\square(B)$) is 4. That is fairly reasonable because it is expected that the optimum ratio of Ge to B atom concentration is predicted to be 5.6 to match the average lattice constant of $Si_{1-X-Y}Ge_XB_Y$ to that of Si, taking account of atomic diameter of the each atom.

Recently, the fact that the strained $Si_{1-X}Ge_X$ layer grown on Si is very delicate in heat treatment was reported$^{4)}$. So, it is quite important to examine the resistance to the heat treatment of the film. The depth profile of Ge and B after regrowth annealing at 700℃ for 1h and after the following annealing at 1060℃ for 30min measured by SIMS are shown in Fig. 4 and Fig. 5 respectively. From Fig. 4, we can see the two transformations of B-profile:the profile has flattop at the peak and notch at the concentration of about $3X10^{19}cm^{-3}$, whereas these phenomena are not observed before heat treatment. This indicates that there are some force between Ge and B to compensate the lattice mismatch with the notable fact that B atoms remain without diffusion even after high temperature annealing (1060℃) at the region where Ge atoms exist as shown in Fig. 5.

In conclusion, we have proposed co-implantation of Ge and B and SPE to form non-strained single crystal $Si_{1-X-Y}Ge_XB_Y/Si$ film for possible use of base layer of HBT. The film showed the features such as good crystalline quality, super low resistivity and superior heat treatment tolerance.

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References

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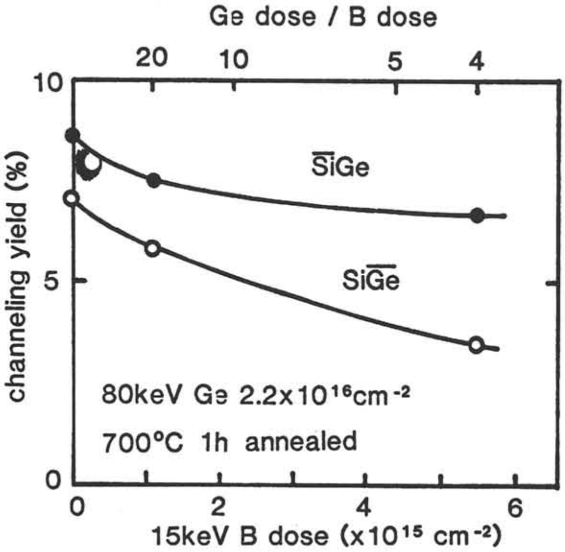

Fig. 1 Dependence of crystalline quality estimated by RBS on 15keV B dose.

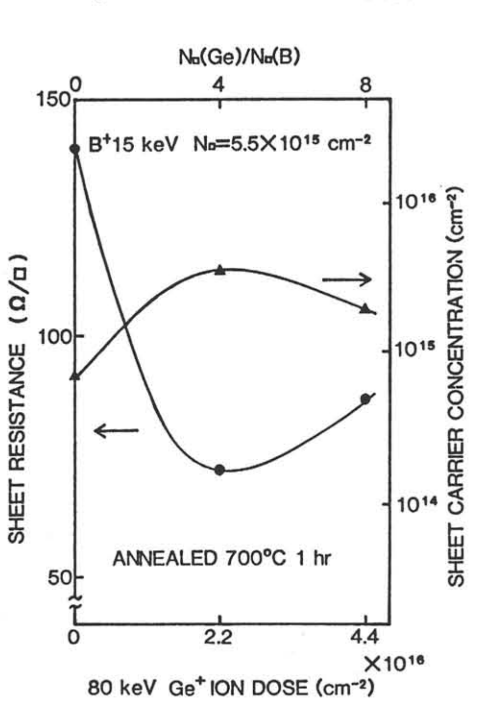

Fig. 3 Sheet resistivity and carrier concentration of 15keV B implanted Si as a function of 80keV Ge dose.

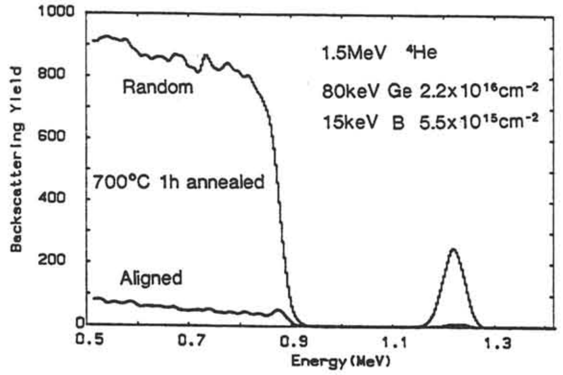

Fig. 2 An exsample of RBS spectrum of the SiGeB/Si under lattice matched condition.

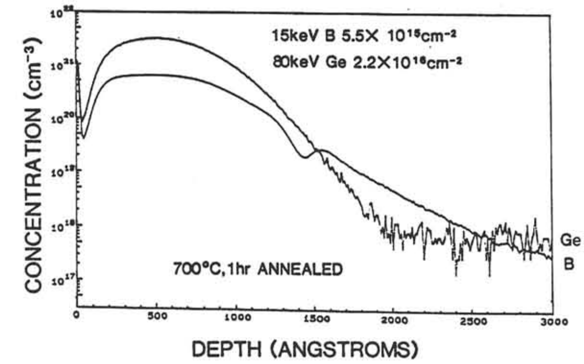

Fig. 4 SIMS profile of Ge & B atoms in 80keV Ge & 15keV B implanted and 700°C, 1h annealed Si.

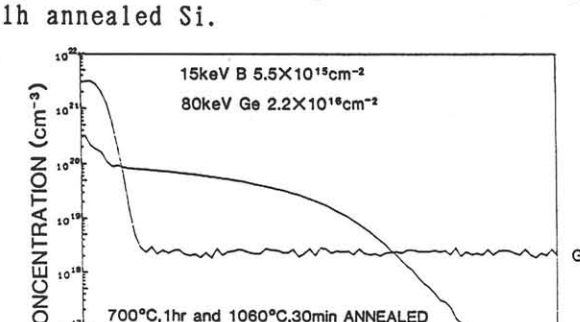

Fig. 5 SIMS profile of the sample shown in Fig. 4 after 1060°C, 30min annealing.