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Boron Heavy Doping and Simultaneous Doping with Boron and Oxygen for Si Molecular Beam Epitaxy

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Recently interests of heavy doping of B with usual Knudsen cell have been growing for Si molecular beam epitaxy (MBE). We have been using sintered BN plates combined with B_2O_3 and B doping level up to 7×10^{19} cm^{-3} was realized at crucible temperature of 1350 ^oC.[1)] Ostrom and Allen used pure B_2O_3 and highest boron level was 3×10^{19} cm^{-3} at crucible temperature of 1100 ^oC and they reported the evaporating molecule was $B_2O_3(g)$.[2)] But higher doping level did not attained because of the temperature limit of crucible. Then we used HBO_2 source, H_2O-absorbed B_2O_3 powder, as evaporating material. Maximum carrier concentration has reached 6×10^{20} cm^{-3} at crucible temperature of 900 ^oC. Still more, to obtain heavily doped and wide band-gap material that is important for the wide band-gap emitter of Si bipolar transistors, we tried simultaneous doping with B and O. The Ultra-Violet (UV) irradiation during growth was found to enhance O doping.

Experiments were performed in Si MBE system (ANELVA 430) which has the spurazil viewing port at cell port for UV irradiation from a 500W Hg-Xe lamp.

Figure 1 shows carrier concentration dependence on crucible temperature, where the growth rate was 10 Å/s and the growth temperature was 700 ^oC. Si films were doped from two different boron sources, sintered plates of BN combined with B_2O_3, which was already reported[1)], and H_2O-absorbed B_2O_3 powder. B might evaporate in the form of HBO_2 in the latter case. Figure 2 shows the comparison of vapor pressure between B_2O_3 and HBO_2. The activation energy (E_a) for doping from sintered BN plates with B_2O_3 was 5.4 eV which is close to E_a of B_2O_3 and in the case of the B_2O_3 powder, E_a was 1.6 eV which is close to that of HBO_2. The vapor pressure of HBO_2 is 10^5 times larger than that of B_2O_3 at 900 ^oC. Then the higher doping could be realized at the lower crucible temperature.

Figure 3 shows ultra-violet reflection spectra of B doped films from H_2O-absorbed B_2O_3 powder source with and without UV irradiation during growth. The growth rate was 0.5 Å/s and the growth temperature was 850 °C. The carrier concentration was 1×10^{20} cm^{-3}. In the case of doped film, the peaks of transition of $\Gamma'_{25}-\Gamma_{15}$ and X_4-X_1 shift toward longer wave length in comparison with bulk Si. This shift becomes larger with UV irradiation. According with AES depth profle measurement, O peak was observed in the film grown with UV irradiation but was not observed without UV irradiation. This means that O atoms evaporate with B, get into epitaxial layer and change Si band structure. UV irradiation may accelerate this reaction, but it was not determined how electrical band-gap of Si changed. Further analysis is now in progress. There was no UV irradiation effect on the carrier concentration change.

In conclusion, high doping level of B up to 6×10^{20} cm^{-3} was realized in Si MBE utilizing HBO_2 ,source (H_2O-absorbed B_2O_3 powder). Oxygen doping was effectively attained by UV irradiation.

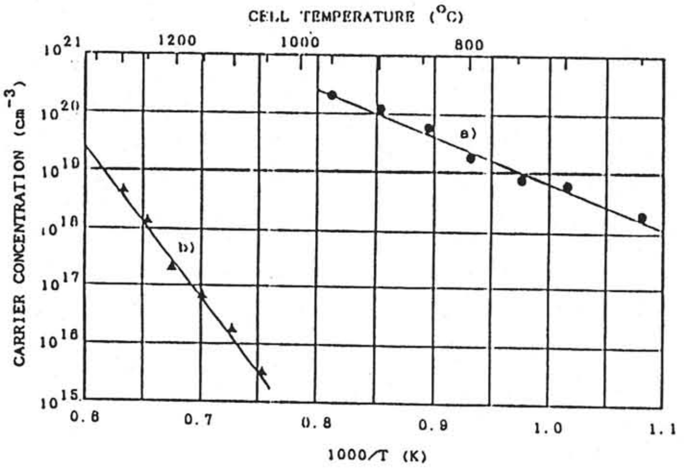

Fig.1 The carrier concentration dependence on crucible temperature doped from a) pure B_2O_3 powder and b) sintered plates of BN combined with B_2O_3

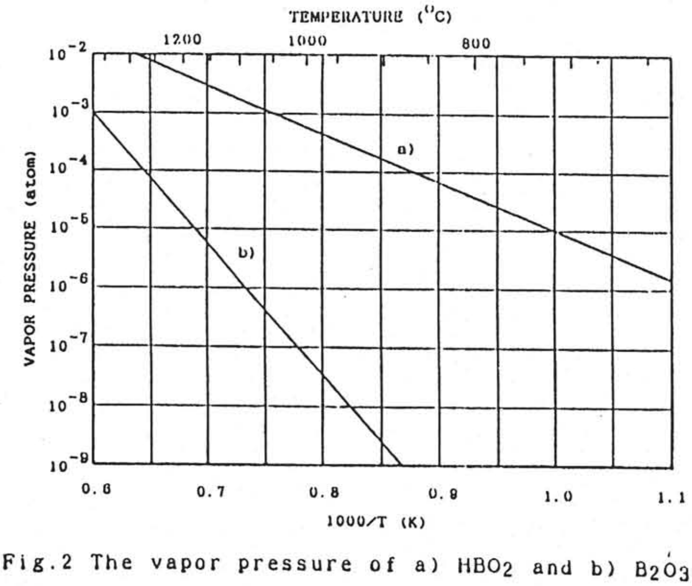

Fig.2 The vapor pressure of a) HBO_2 and b) B_2O_3

References

1)N.Aizaki and T.Tatsumi,Extended Abstracts of the 17th Conference on Solid State Devices and Materials,Tokyo 1985,pp.301-304.

2)R.M.Ostrom and F.G.Allen, Appl.Phys.Lett.48(3)(1986)221.

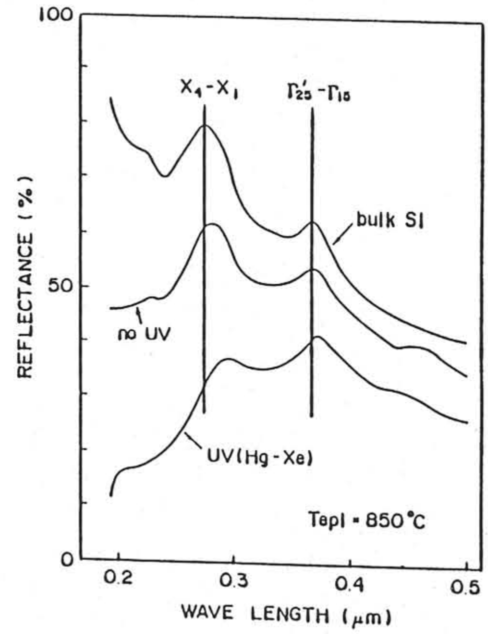

Fig.3 The ultra-violet reflection spectra of B doping films with or without UV irradiation