Dose Retention Effects in Atomic Boron and ClusterBoron™ ($B_{18}H_{22}$) Implant Processes

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Abstract. Dose control is often assumed to be a function of tool design and calibration. Fundamental interactions, including sputtering and backscattering of ions from the surface of the wafer, modulate the equipment effects. For high dose and low energy processes, such as those necessary for poly-gate doping, these effects can be significant. The use of octadecaborane ($B_{18}H_{22}$) implantation enables production-worthy throughput but can impact these surface interactions. In this work, we have investigated the dose retention in silicon after high dose, low energy $B_{18}H_{22}$ and B implants. A wide range of effective energies and doses was studied. This analysis provides insight into the physical mechanisms and can be used to guide process control development.

Keywords: Molecular Implantation, Octadecaborane, $B_{18}H_{22}$, sputtering, poly-gate doping
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INTRODUCTION

Dual poly-gate doping for p-poly gates and source drain extension (SDE) implants are driving the need for low energy, high dose boron implants as technology nodes continue to shrink[1]. The high dose boron implants cannot be run productively at the energies required on current beam line implanters using monatomic boron or BF_2 in drift mode. In post-decel operation, very low levels (ppm) of energy contamination can impact device performance[2]. One method of overcoming this challenge is the use of molecular implant species such as decaborane ($B_{10}H_{14}$), or octadecaborane ($B_{18}H_{22}$).

Retained dose for low energy implantation is the ratio of the dopant in the silicon after implant compared to the actual implanted dose. Sputtering and backscattering from the surface cause dopant loss during implantation. This effect has been reported on in the past for low energy boron implants[3]. This work evaluates some of the surface effects and compares retained dose for B_{18} implants as a function of energy and dose as compared with monatomic boron implants. The goal is to better understand the physical interactions for these implants to assist in process development.

Other topics covered include quantification of the surface sputtering rate by high resolution SEM (HR SEM), and discussion of maximum retained dose using extrapolation from existing data. Also, measurement of surface roughness for boron and B_{18} will be compared with that reported in previous work[4,5].

Advantages of Molecular Implantation

Use of molecular implantation, such as octadecaborane, allows higher effective beam currents at lower energies as each molecule carries 18 boron atoms at ~1/20th of the implant energy for the cluster. This allows for low energy, high dose implants in drift mode operation with reduction in space charge by extracting and transporting the beam at higher energies. The use of molecular implantation can allow for productive implantation of the poly-gate and SDE applications using traditional implant architectures without using decel mode operation which can cause energy contamination[1].

Low Energy High Dose Implantation

Figure 1 provides an illustration of the primary mechanisms for dopant loss, backscattering and sputtering. For ultra shallow implants, the probability of a backscattered atom leaving the silicon surface

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increases when compared to higher energy implants. The differential scattering cross section is given by

$$\frac{d\sigma}{d\Omega} = k\frac{Z_1^2 Z_2^2}{e^4 E^2} \tag{1}$$

therefore, as the energy of the implant decreases, the probability of a backscattering event increases quadraticly. However, as the B concentration increases, the probability of a backscattering event decreases because of the Z_2^2 dependence in the cross section. The value of Z for B is less than that for Si.

Sputtering is the mechanism where near surface atoms leave the target during implantation due to recoil collisions. For a sputtered boron or silicon atom to leave the target surface, the vertical component of the recoil energy must be greater than the surface binding force. As boron concentration and sputtering at the surface increases, a steady state will be reached leading to a maximum retained boron dose.

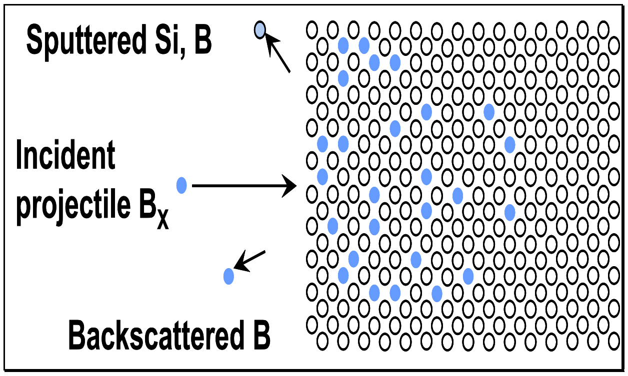

FIGURE 1. Illustration of Sputtering and Backscattering of Si and B from Silicon Surface during Ion Implant.

This effect was previously reported for monatomic boron implants, BF_2 implants, and $B_{10}H_{14}$ implants at effective boron energies <1keV[3]. A measured loss of 10% by nuclear reaction analysis, B(p,α)Be (p-alpha) at 0.5keV and 1×10^{15} ions/cm^2 boron dose was reported (20% at 200eV). As dose increases and/or energy decreases, the fraction of dopant loss increases due to the above mentioned mechanisms.

Physical Description: B_{18}

Borohydride molecules have been used for decades as source feed material. B_2H_6 has been commonly used. In the last 10 years $B_{10}H_{14}$ has been investigated[6,7,8] for use as a path to low energy high dose p-type implants. In the last couple of years $B_{18}H_{22}$ has become a prime candidate for low energy high dose implants. This large molecule has a molecular weight of 216 AMU. This is of course an average weight because there are two isotopes of boron, mass 10, 20% and mass 11, 80%. There is a binomial distribution of the 18 boron atoms in the molecule. The lightest possible weight would be 202 AMU, which would occur if all 18 B atoms were mass 10. The heaviest possible weight would be 220 AMU; this would occur if all 18 B atoms were mass 11.

Figure 2 is a ball and stick model of $B_{18}H_{22}$. It is of interest that there are six divalent hydrogen atoms in this molecule. These are known to boron chemists as *Bridging Hydrogen Bonds.*

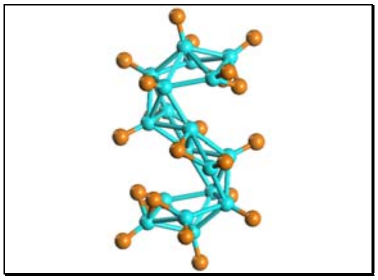

FIGURE 2. Octadecaborane ($B_{18}H_{22}$) model. Note the six bridging hydrogen bonds. They are 3-centre, 2-electron B-H-B bonds containing rare divalent bridging hydrogen atoms.

DOSE RETENTION AND SURFACE EFFECTS FOR B_{18} AND ^{11}B IMPLANT

Surface Sputtering

Figure 3 illustrates the sputtering on Si surface for a high dose B_{18} implant. Sputter yield was measured in silicon for 1.25keV, 9×10^{16} B/cm^2 B_{18} implants, and the sputter depth was measured by high resolution SEM (HRSEM). The sample was patterned resist covered with a vertical stripe removed. After implant, all the photoresist was stripped off the wafer, and a sample was sent for SEM to measure the thickness of the sputtered layer in Si and SiO_2

Based on the SEM data and implanted boron dose, a calculated sputtering yield (Y_B) per boron atom of 1 was calculated (Y_{B18}~18). This value is slightly higher than the estimated value[9] for equivalent boron of ~0.3 to 0.4. This could be due to sputtering from an amorphous surface as dose increases or molecular effects from B_{18}. For typical SDE implant doses, high e14 and low e15 range, this would equate to a couple of angstroms surface loss, which is still in the native oxide. For p-poly gate implants, there is potential to sputter on order of 20-30 Å for low e16 doses. This effect leads to lower retained dose as discussed below and must be considered when designing a process, regardless of implementation (monatomic, or molecular doping).

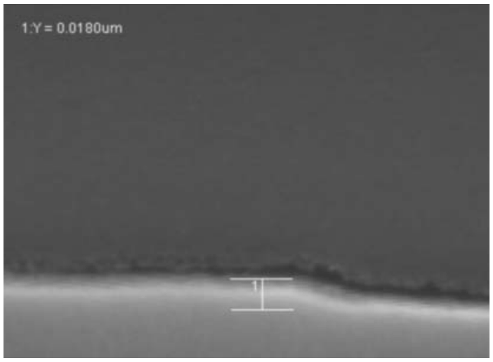

FIGURE 3. HRSEM picture - Si surface of partial PR coated wafer after high dose B_{18} implant to illustrate sputtering by implant at PR interface.

Surface Roughness

Li et al reported at IIT2002 that high dose (1×10^{17} at 5keV and 12keV) implants using decaborane molecules[4] had an effect of smoothing the silicon surface compared to an argon implanted sample. Figure 4 compares doses typical for SDE and P-poly applications. $B_{18}H_{22}$ at 5×10^{15} and 1×10^{16} ions/cm^2 and ^{11}B at $1 \times 10^{15}$and 5×10^{15} ions/cm^2 were implanted into polished silicon wafers. The surface roughness was determined by atomic force microscopy (AFM) measurement on an un-implanted sample, and on samples implanted at the above doses.

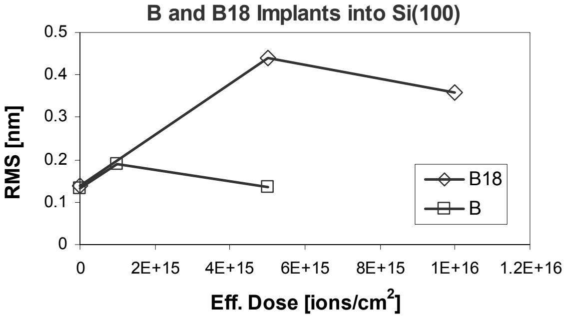

FIGURE 4. Surface Roughness Measurement (RMS) by AFM for ^{11}B and B_{18} implants at various doses

The data indicate a 3x higher RMS roughness for the B_{18} implants at 5×10^{15} ions/cm^2 dose. Both boron and B_{18} implants show greater roughness at the lower dose (1×10^{15} and 5×10^{15} respectively) followed by turnover and then smoothing as dose increases. This supports the findings of smoothing with molecular implant at 1×10^{17} ions/cm^2 dose reported in earlier work[4].

Dose and Energy Dependence for Retained Dose

Dose dependence is illustrated at 1keV effective boron energy in Figure 5. At 1keV and above, monatomic boron shows a 1 to 1 ratio at doses studied.

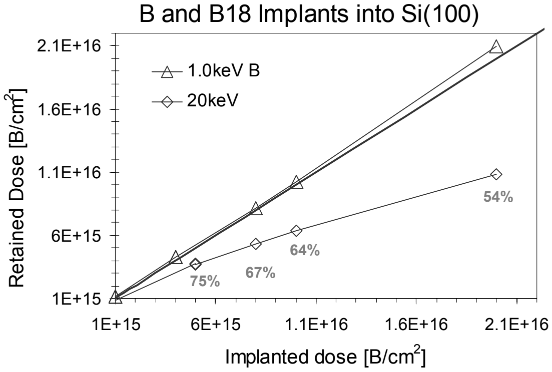

FIGURE 5. Dose Retention of 1 keV B by B_{18} implant in silicon as measured by SIMS and verified by p-alpha

A decrease in retention was quantified with SIMS and p-alpha as implant dose increases at a given energy. As shown the effect can exceed 50% as the maximum retained dose is approached. The energy dependence is illustrated in Figure 6.

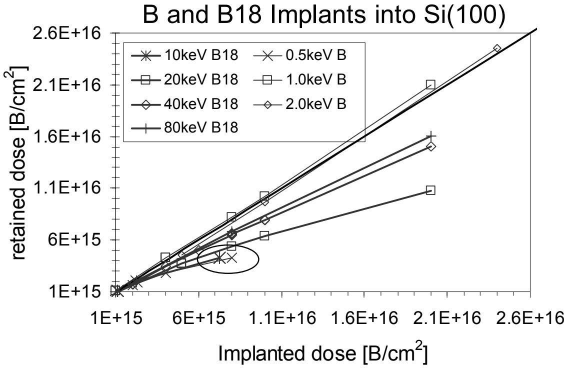

FIGURE 6. Dose Retention by B_{18} energy of B implant in silicon as measured by SIMS and verified by p-alpha

Higher energy implants result in better retention as dose increases, and a higher maximum retained dose. Again, the effect approaches 50% as the maximum retained dose is approached.

Maximum Retained Dose

Based on the above data, there will be a maximum dose of boron in a sample for a given energy. Figure 8 extends the dose to 1x10^{17} for 30keV and 60keV B_{18} implants. The plot shows the retained boron dose at 30keV as leveled off somewhere before 7x10^{16} B/cm^2. This is the point where the dopant loss from surface sputtering is equivalent to the dose entering the surface. The 60keV B_{18} implant doses are still increasing at 1.2x10^{17} B/cm^2, although retained dose is decreasing as implant dose rises.

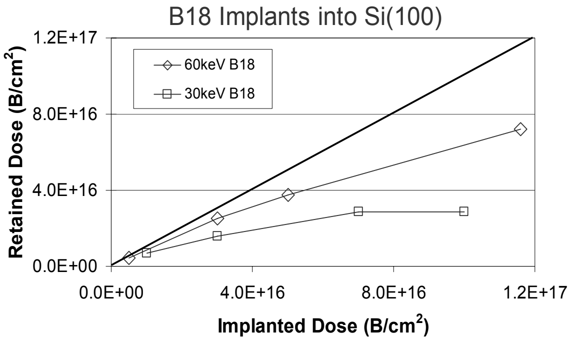

FIGURE 7. Maximum Retained Dose illustrated for 30 keV B_{18}, and Compared with 60keV B_{18}

The above data were collected by SIMS with validation by p-alpha measurement at select points. Both techniques measure the same effect for maximum retained dose in the samples. In addition, the effect was the same at 30keV for implant into 1000Å poly silicon.

SUMMARY

Dose loss for low energy high dose implants results from sputtering and backscattering. The various doping methods (monatomic implant, cluster implant, and plasma doping) will all see this depending on the implantation conditions. The amount of retained dose depends on the doping technique, the effective energy, and the effective dose. This work discusses the effects for octadecaborane implants compared with monatomic boron implants for doses and energies typical for dual poly-gate implants. Topics discussed were surface sputtering loss, surface roughness in relation to dose, retained dose comparisons for B_{18} and boron, and extrapolation to maximum retained dose using existing data for B_{18}.

ClusterBoron™ implants have been shown to match current processes for poly-gate doping[10] and source drain extension[11] applications, and are a viable alternative for significantly improving productivity for energy-pure boron implants using well-known, existing implant architectures. The goal of this work was to document the surface effects and describe some of the physical interactions that will allow a more thorough understanding for guiding process development. It is also pointed out that there is some variability based on how the process is being integrated and some experimentation is required for optimizing the process to fit each case.

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