Improving Beam Current and Performance in Boron Ion Implantation via Boron Trifluoride (BF_3) and Diboron Tetrafluoride (B_2F_4) Mixture

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INTRODUCTION

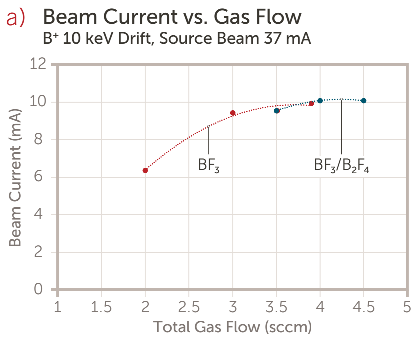
In semiconductor wafer manufacturing, boron ion implantation poses a productivity challenge for conventional beamline ion implanters due to the high dose and low energy demands of advanced technologies. While BF_3 has traditionally been used as the dopant, alternative materials like B_2F_4 and BF_3/H_2 mixtures have been explored.[1,2,3] Studies indicate that B_2F_4 can enhance beam current compared to BF_3, but it decomposes above 600°C, requiring hardware modifications to prevent this. The BF_3/H_2 mixture reduces fluorine effects and extends source lifetime but does not improve beam current. This study investigates the performance of a BF_3 and B_2F_4 mixture on boron beam current and source lifetime.

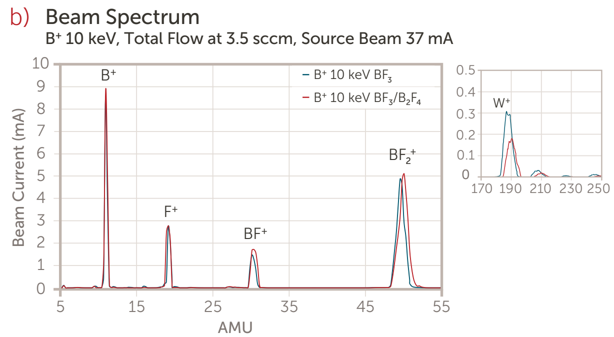
TOOL AND EXPERIMENT SETUP

This experiment used an iPulsar Plus ion implanter, a high-current 300 mm single-wafer tool by Advanced Ion Beam Technology Inc. (AIBT), equipped with a tungsten indirectly heated cathode (IHC) ion source. To assess a mixture of diboron tetrafluoride (B_2F_4) and boron trifluoride (BF_3), SDS® BF_3 and VAC® B_2F_4 gases were introduced separately via distinct gas sticks, allowing precise control over flow rates and mixture ratios. Testing focused on B^+ and BF_2^+ ions at energies of 10 keV and below, particularly for low-energy performance. Experiments included B^+ ions at 10 keV, 5 keV drift, and 2 keV decel modes, and BF_2^+ ions at 10 keV and 5 keV drift modes.

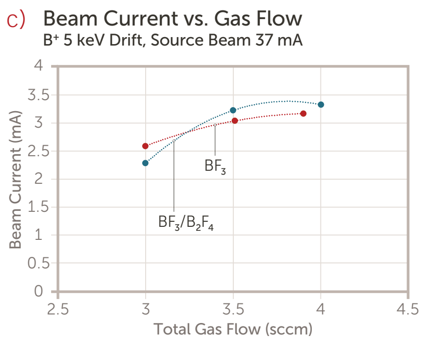
EXPERIMENT AND TEST RESULTS

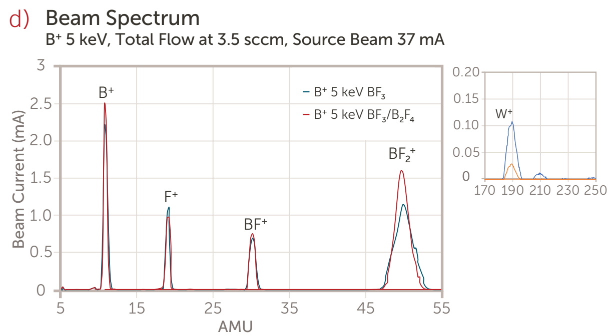
B+ 10 keV





B+ 5 keV





B+ 2 keV

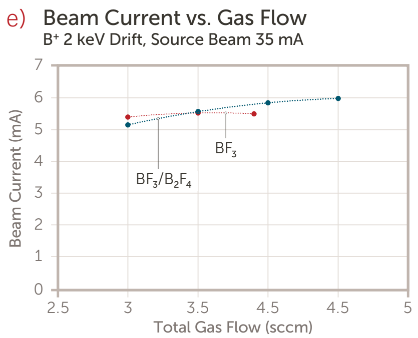


Figure 1. B^+ beam current performance and beam spectrum comparison for BF_3 vs. BF_3/B_2F_4 mixture at 10 keV drift; 5 keV drift and 2 keV decel mode.

a) B^+ beam current vs. total gas flow at 10 keV drift
b) Beam spectrum for BF_3 vs. BF_3/B_2F_4 for 10 keV at total flow 3.5 sccm
c) B^+ beam current vs. total gas flow at 5 keV drift
d) Beam spectrum for BF_3 vs. BF_3/B_2F_4 for 5 keV at total flow 3.5 sccm
e) B^+ beam current vs. total gas flow at 2 keV decel

As illustrated in Figure 1, the BF_3/B_2F_4 mixture consistently produced higher beam currents compared to pure BF_3, especially at lower energies. As shown in the 10 keV drift mode (Figure 1a), the improvement of B^+ beam current is approximate 1 to 2 percents. At a reduced energy of 5 keV, the B^+ beam current improved by approximately 5% under the same drift mode condition, as shown in Figure 1c. When the energy was further reduced to 2 keV, a decel mode was employed to maintain adequate B^+ beam current. Under these conditions (Figure 1e), the BF_3/B_2F_4 mixture achieved a beam current of 6 mA at a total flow of 4.5 sccm, while pure BF_3 reached a peak of 5.53 mA at 3.5 sccm, representing an 8% improvement with the BF_3/B_2F_4 mixture.

The beam spectra comparisons for 10 keV and 5 keV are depicted in Figure 1b and 1d, respectively. A notable observation is the significantly lower W^+ peak for the BF_3/B_2F_4 mixture compared to pure BF_3. At 10 keV, the W^+ beam current for pure BF_3 was approximately 0.308 mA, whereas it decreased to 0.181 mA for the mixture. At 5 keV, the W^+ beam current dropped from 0.108 mA to 0.029 mA with the BF_3/B_2F_4 mixture. These results suggest a potential for longer source life with the BF_3/B_2F_4 mixture due to reduced halogen cycling inside the arc chamber.[4]

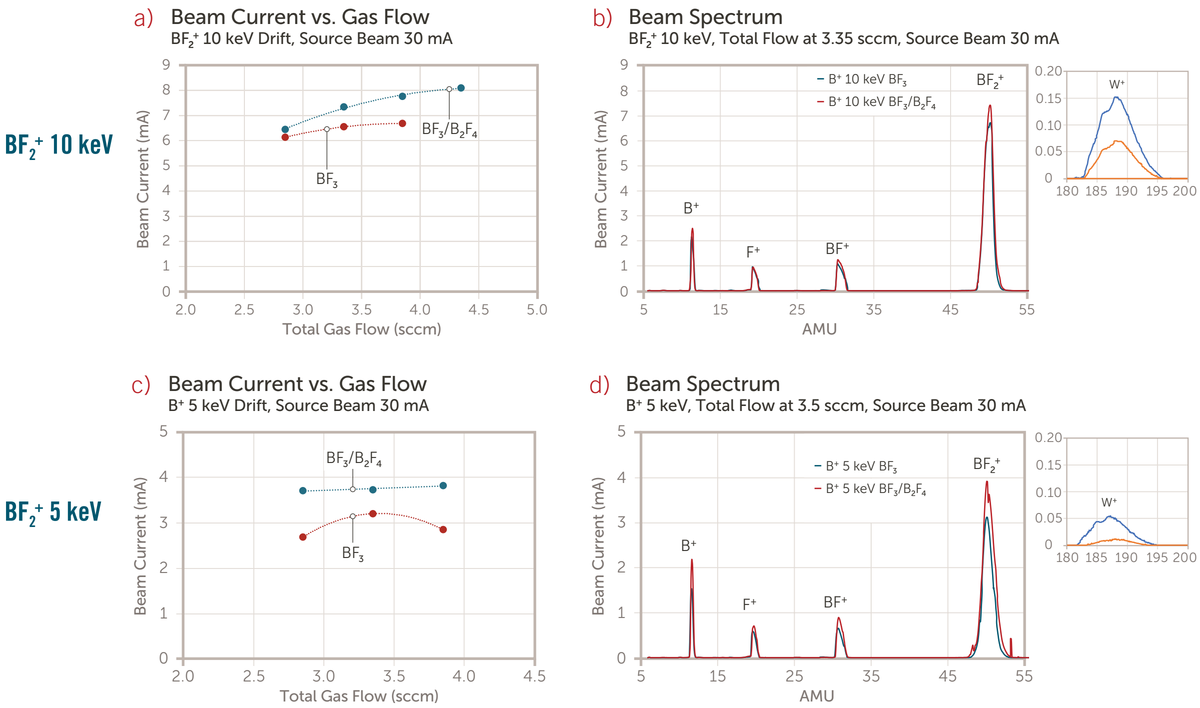


Figure 2. BF_2^+ beam current performance and beam spectrum comparison for BF_3 vs. BF_3/B_2F_4 mixture at 10 keV drift and 5 keV drift mode.
a) BF_2^+ beam current vs. total gas flow at 10 keV drift *b) Beam spectrum for BF_3 vs. BF_3/B_2F_4 for 10 keV at total flow 3.35 sccm*
c) BF_2^+ beam current vs. total gas flow at 5 keV drift *d) Beam spectrum for BF_3 vs. BF_3/B_2F_4 for 5 keV at total flow 3.35 sccm*

The BF_3/B_2F_4 mixture significantly improved performance over pure BF³. At 10 keV, the BF_2^+ beam current with pure BF_3 was 6.68 mA, whereas the mixture increased it to 8.09 mA at 4.35 sccm, a 21% improvement. At 5 keV, pure BF_3 yielded a peak current of 3.2 mA at 3.35 sccm, while the BF_3/B_2F_4 mixture achieved a peak of 3.82 mA, an over 19% increase.

Beam spectra comparisons (Figure 2b and 2d) show that W^+ peaks for BF_2^+ beams are lower than those for B^+ beams at the same energy. The BF_3/B_2F_4 mixture also reduced W^+ beam currents significantly: from 0.15 mA to 0.07 mA at 10 keV, and from 0.055 mA to 0.012 mA (22% of the pure BF_3 current) at 5 keV. This reduction suggests decreased tungsten migration and deposition, indicating potential for extended source life.

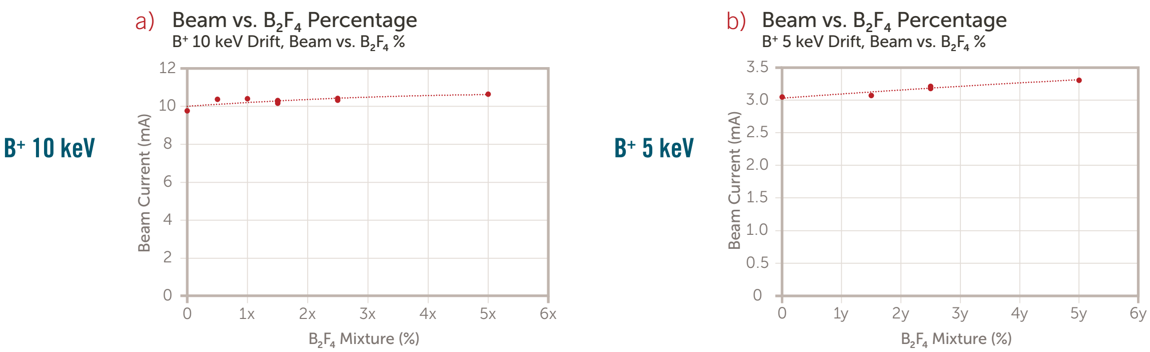


Figure 3. B^+ beam current vs. B_2F_4 mixture percentage.
a) B^+ beam current at 10 keV drift mode. BF_3 and B_2F_4 total flow at 3.5 sccm
b) B^+ beam current at 5 keV drift mode. BF_3 and B_2F_4 total flow at 3.5 sccm

The last experiment aimed to evaluate B^+ beam current by varying the B_2F_4 percentage in the BF_3/B_2F_4 mixture at 10 keV and 5 keV. Starting with pure BF_3, B_2F_4 was gradually added while keeping the total flow rate at 3.5 sccm. The results, shown in Figure 3, use "1x" or "1y" labels on the x-axis to indicate the B_2F_4 mixture percentage. The B^+ beam current increased almost linearly with the B_2F_4 percentage. At 10 keV (Figure 3a), the improvement was modest but linear. At 5 keV (Figure 3b), the current increased from about 3 mA with pure BF_3 to 3.3 mA with a 5y B_2F_4 mixture, also showing a nearly linear trend.

a)

b)

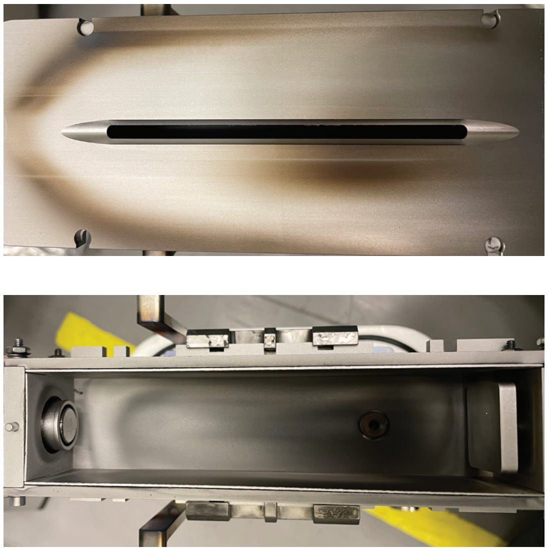


Figure 4. Arc chamber and arc slit conditions after approximately four days of running the BF_3/B_2F_4 mixture experiment.
a) Arc slit condition   b) Arc chamber condition

After about four days of running the BF_3/B_2F_4 mixture, the source was inspected. Figure 4 shows the arc slit (Figure 4a) and arc chamber (Figure 4b). The arc slit was clean with minimal discoloration and no deposits. The arc chamber had slight darkening on the anti-cathode side but no significant residue. No abnormalities were noted from the fluoride gases over this period. Both the anti-cathode and cathode were in excellent condition.

CONCLUSION AND DISCUSSION

The performance of the boron trifluoride and diboron tetrafluoride (BF_3/B_2F_4) mixture showed several advantages over pure BF_3 gas. Both B^+ and BF_2^+ beam currents improved with the mixture. For B^+ species, the gain in beam current is particularly notable at lower energy levels. In our experiment, the B^+ beam current increased by approximately 8% at the 2 keV decel mode. This is a significant benefit, as low-energy B^+ implantation is a major challenge and bottleneck in wafer manufacturing. For the BF_2^+ species, the beam current improvement was greater and consistently around 20% for both 10 keV and 5 keV conditions. Comparisons of the beam spectra for BF_3 versus BF_3/B_2F_4 mixtures reveal that the W^+ peaks are significantly lower with the mixture gases. Depending on the recipe conditions, the W^+ beam current reduction ranges from approximately 40% to up to 80%. This reduction suggests a substantial decrease in halogen cycling effects inside the arc chamber when using the BF_3/B_2F_4 mixture gases, indicating an expected improvement in source life.

References

[1] Ying Tang, et al., Improvements in B^+ and BF_2^+ Beam Currents Through the Use of Diboron Tetrafluoride (B_2F_4) Gas, IIT2010 Proceedings, p. 167–170

[2] Ying Tang, et al., Beam Current Improvement and Source Life Performance of Diboron Tetrafluoride (B_2F_4) for Boron Implantation on Applied Materials VIISta High Current Implanters, IIT2012 Proceedings, p. 386–389

[3] Ying Tang, et al., Investigation of Boron Gas Mixtures for Beamline Implant, IIT2016 Proceedings, p. 184–187

[4] O. Byl, et al., Tungsten Transport in an Ion Source, IIT2008 Proceedings, p. 356–359

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