

A Beam Line System for a Commercial Borohydride Ion Implanter

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Abstract.

We describe the features of a beam line and ion source system which is being developed for a commercial ion implanter capable of meeting the challenges of high dose, low energy implants needed to fabricate integrated circuits with critical dimensions of 60 nm and less. Intense borohydride ion beams of $B_{10}H_x^+$ or $B_{18}H_x^+$ generated from the source are used to achieve commercially acceptable wafer throughputs for the low energy, high dose applications such as poly-gate and source drain extension implants. The beam transport elements, from ion source to wafer, are designed to achieve wafer boron currents of greater than 30 pA at an implant energy of 2-4 keV, and greater than 3 pA at an energy as low as 200 eV. These high currents are obtained at low energy without the need for deceleration just prior to the wafer. Consequently, the beam impinging on the wafer is very pure with respect to energy, and is free of high energy components that can generally degrade shallow junction implants.

After magnetic analysis the beam is parallel magnetically scanned across the wafer at a frequency in the range of 100-200 Hz. In conjunction with a serial end-station, implants with high quality dose and angle uniformity can be achieved using a wafer mechanical scan rate as low as 0.5 Hz in a direction orthogonal to the beam scan direction.

As well as the high wafer throughput performance obtained by using borohydride ions, the beam-line is also capable of transporting conventional monatomic ions up to a maximum energy of 80 keV with a mass-energy capability of 12.6 amu.MeV.

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SUMMARY

The potential advantages of using molecular ions containing multiple dopant atoms have been well recognized for several years and can be summarized as follows:

1. The dose received by a wafer for a given ion beam current is increased in proportion to the atomic multiplicity of the dopant contained in the molecular ion.
2. For a given dose, the wafer receives a lower electrical charge, inversely proportional to the atomic multiplicity of the dopant ion.
3. The ions can be extracted from the ion source and transported to the wafer at a much higher energy in proportion to the ratio of molecular ion mass to dopant atomic weight. Consequently, the limitations associated with space charge forces and the intrinsic thermal ion temperature within the beam are much less.

However, there are a number of drawbacks when either decaborane $B_{10}H_{14}$ or octadecaborane $B_{18}H_{22}$ is used as a source vapor in a conventional ion implanter. Firstly, the ion source of a conventional ion implanter has

a relatively high density plasma which breaks up most of the borohydride molecules before singly charged molecular ions are produced. Secondly, referring to Figure 1, a range of different ion masses exist in the extracted beam arising from the different number x of hydrogen atoms (and also the different mixtures of the boron isotopes ^{10}B and ^{11}B) in the generated ions $B_nH_x^+$. Different mass ions describe different paths on passing through the analyzer magnet and other mass dispersive elements that might be present in the beam line. In turn, this can introduce undesirable angular and/or dose variations across the wafer surface. Finally, the relatively high mass of the molecular ions limits the single atom implant energy to just a few keV because of the limited field strength and size of the analyzer magnet (and other magnetic elements if used).

To work around these difficulties SemEquip [2] has now developed a commercial very high current borohydride ion source that uses a formed electron beam rather than a high density plasma to ionize the borohydride vapors. This is used on the beam line shown in Figure 3 which has been jointly developed by SemEquip Inc., and Nissin Ion Equipment Co., Ltd. It includes an analyzer magnet, a magnetic triplet quadrupole beam focusing element, and a magnetic scanner and collimator combi-

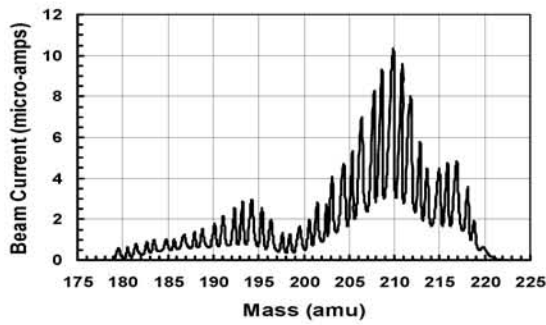


FIGURE 1. High resolution mass spectrum of ionized octadecaborane $B_{18}H_{22}$.

nation to parallel scan [1],[5] the ion beam across the wafer. The analyzer magnet has a large working aperture to accept the beam from the large aperture (12.5 mm wide \times 100 mm high) of the SemEquip ion source. It is able to analyze 80 keV octadecaborane ions, corresponding to a 4 keV particle boron implant energy (or 7 keV in the case of decaborane). Even for a source slit width as large as that used in the SemEquip ion source, a mass resolution of $m/\Delta m \geq 60$ can be realized by the analyzer magnet system, which is sufficient to properly filter conventional dopant ions. If fitted with a universal ion source, capable of providing both conventional and borohydride ions and expected [3] to be commercially available by mid 2007, the ion delivery system will meet the fab requirements of a fully utilizable tool that, in effect, minimizes device manufacturing costs for 60 nm and below.

Figure 2 shows the magnetically scanned boron particle currents, derived from octadecaborane, measured at the exit port of the collimator vacuum housing labelled in Figure 3. The beam current was essentially unchanged over the entire scan sweep frequency range from dc to 170 Hz. The measured particle beam currents are very much higher than hitherto reported from conventional fixed beam, high current ion implanters. Furthermore, these beam currents have been achieved in drift mode - i.e. without the need to use deceleration just prior to the wafer - therefore avoiding undesirable implantation of higher energy particles neutralized prior to or during deceleration.

ANALYZER MAGNET

The analyzer magnet has a bending angle of $\phi = 120$ degrees and a center bending radius of $R = 500$ mm. The nominally uniform gap of 118 mm and pole width of 166 mm is sufficient to accept the beam emerging from the SemEquip source [2] and allow graphite lin-

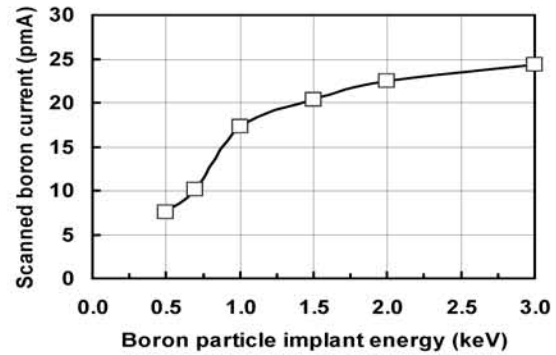


FIGURE 2. Magnetically scanned $B_{18}H_x^+$ beam currents.

ers to cover the pole faces, generally needed to avoid beam sputtering of heavy metallic ions from the iron pole surfaces. The entrance and exit pole edges are normal to the beam axes and there are no significant first order field gradients in the working gap of the magnet. Consequently, in the dispersive plane (i.e. the horizontal plane for the beam line arrangement shown in Figure 3), the conjugate image points for the source object and mass resolving aperture are simply determined by Barber's rule [4]. Specifically, the object source point is set at 400 mm prior to the effective entrance field boundary and the mass resolving aperture is at $b = 195$ mm from the effective exit field boundary of the magnet. The object distance of 400 mm is the minimum space needed to accommodate high speed vacuum pumping, an in-line vacuum isolation valve, and a wide energy range extraction optics system.

On passing through the magnet the paths of ions having the same energy but differing mass become spatially separated. For a mass deviation $\Delta m/m$ the spatial separation Δx at the mass resolving aperture is given by [4]

$$\Delta x = D \frac{\Delta m}{2m} \quad (1)$$

where the quantity D , called the dispersion, is given by

$$D = R(1 - \cos \phi) + b \sin \phi. \quad (2)$$

The dispersion D and mass resolving power $m/\Delta m$ increase with bend radius R and bend angle ϕ , in the regime $\phi \leq 180^\circ$. Referring to Figure 4, which applies to the present case of $b = 195$ mm, it may be seen for example that increasing the bend angle from just 70° to 120° increases D and hence $m/\Delta m$ by a factor of 1.7. For the 120° magnet here, Equation (2) yields a dispersion value of $D = 919$ mm.

As for the mass resolving power, we observe that the ion beam is typically formed with a waist near the source aperture region and with a horizontal width X_o equal to

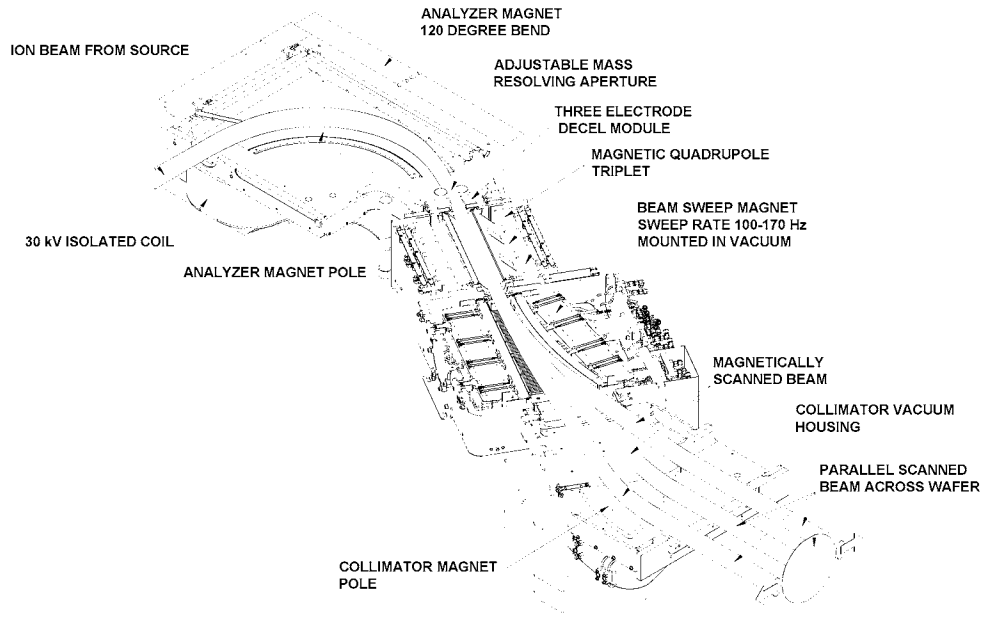


FIGURE 3. Beam line components.

about 60% of the source aperture width - i.e. $X_o \simeq 8$ mm. Therefore, in order to transmit all the ions in the beam of a given mass m through the horizontal mass resolving aperture, the width X_i of the latter is set at a minimum value of $X_i = |M| X_o$ where M is the conjugate image magnification of the beam waist X_o . The realizable mass resolution is therefore

$$\frac{m}{\Delta m} = \frac{D}{2X_i} = \frac{R(1 - \cos \phi) + b \sin \phi}{2 |M| X_o}. \quad (3)$$

For the present magnet $M = -0.838$ and therefore $m/\Delta m \simeq 68$ which is entirely adequate for the case of conventional ions and corresponds to a mass resolving aperture width of $X_i \simeq 6.7$ mm.

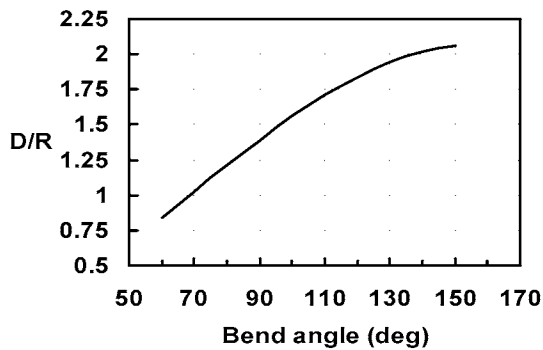


FIGURE 4. Variation of dispersion with bend angle.

In principle it is possible to increase the dispersion and mass resolving power by increasing R . Also, for a given

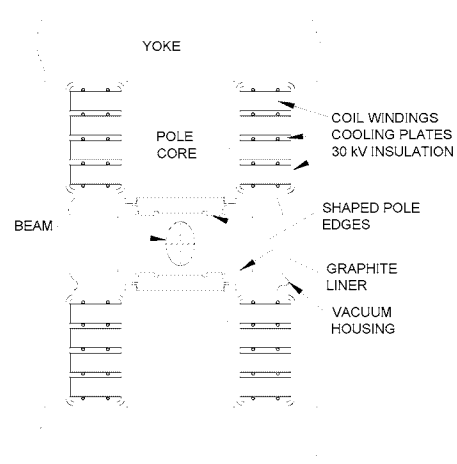


FIGURE 5. Analyzer magnet pole and coil detail.

bending power, increasing R reduces the magnetic field strength needed in the gap, the coil power, and finally the overall weight of the magnet. However, from another standpoint, it is generally preferred to keep $R\phi$ at a minimum because this reduces the path length through the magnet. The value $R = 500$ mm selected in the present magnet requires a gap field of 1.2 tesla in order to bend 80 keV octadecaborane ions. Up to this value of field, the fringing field shapes do not vary significantly with field strength. Consequently the poles can be kept reasonably narrow and shaped as shown in Figure 5 to provide appropriate second, third, and fourth order field compo-

nents that minimize image aberrations at the mass resolving aperture over the entire magnetic field range.

In the case of borohydride ions, the mass resolving aperture width X_i needs to be set at a wide enough value to accept several of the borohydride peaks in order to achieve a high beam current. For example, in the case of octadecaborane, mass peaks from about 205 amu to 218 amu, i.e. $\Delta m/m = 0.061$, account for most of the useful beam and are all selected by setting the resolving aperture width at about $X_i = (D/2)(\Delta m/m) = (919/2)(0.061) = 28$ mm. In the case of decaborane the usable mass peaks lie between 108 amu and 115 amu which requires a similar resolving aperture width of 29 mm.

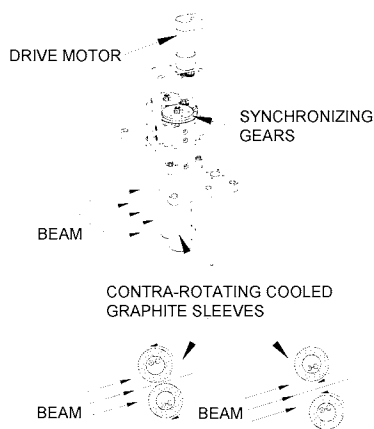


FIGURE 6. Adjustable (6-30 mm) mass resolving aperture.

DECELERATION MODULE

A three electrode deceleration module is located immediately after the mass resolving aperture as shown in Figure 3. Its purpose is to boost low energy beam currents with up to 30 kV deceleration. An adjustable focus voltage applied to the center electrode compensates for the strong divergence generated in the horizontal plane by the internal space charge forces of the beam. Although the applied deceleration voltage biases the entire magnet body from ground potential, a 30 kV insulating cocoon built around the coil windings and cooling plates, as shown in Figure 5, enables the coil power supplies and cooling water to remain at nominal ground potential, avoiding the need for costly high power transformer isolation and high volume deionized water cooling.

It is important to emphasize that high energy particles remaining in the beam after deceleration do not reach the wafer because they are filtered out of the beam by the 30 degree deflection produced by the scanner and collimator combination.

QUADRUPOLE TRIPLET

The magnetic quadrupole triplet shown in Figure 3 is configured as a DFD (i.e. defocus-focus-defocus) array for ion motion in a horizontal plane and, correspondingly, FDF for motion in a vertical plane. The beam size and angular divergence at the wafer are controlled by differentially adjusting the strength of the individual quadrupole elements in the triplet. In the case of borohydride ions the triplet also compensates for the collective mass dispersion introduced by the analyzer magnet, beam scanner, and collimator. In fact, by appropriately setting the quadrupole element strengths, the angular deviation arising from the multiple mass components can be reduced to less than 0.15 deg over the entire scan range.

CONCLUSIONS

This joint development by SemEquip Inc., and Nissin Ion Equipment Co., Ltd. clearly shows the practicality of and the tremendous improvement in drift-mode beam current that can be realized by using borohydride molecules. The results pave the way for a new generation of ion implanter tools and have put to rest previous and somewhat widely held concerns that such beams could turn out to be difficult to transport, and even more difficult to scan, in the vacuum system and general beam line architecture commonly used in ion implanters. Even with the long beam path through the scanning and collimator magnets, gas attenuation measurements show that the beam loss from gas scattering, neutralization, and ion break-up, is only a few percent.

REFERENCES

1. H. F. Glavish, *System and method for producing oscillating magnetic fields in working gaps useful for irradiating a surface with atomic and molecular ions*, US Patent 5,311,028, May 1994
2. SemEquip Inc., Billerica, MA 01862, USA, *Model 350 Ion Source*, 2005.
3. SemEquip Inc., Billerica, MA 01862, USA, *Private communication*, 2006.
4. H. A. Enge, *Deflecting Magnets*, Focusing of Charged Particles, Vol II, Ed A. Septier, Academic Press, New York, p203-264, 1967,
5. H. F. Glavish et al, *System and method for unipolar magnetic scanning of heavy ion beams*, US Patent 5,393,203, August 1995.