A TEMPLATE MODELING FOR AN ASSEMBLY CONTROL - JIG DESIGN

By

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ABSTRACT

The purpose of this thesis is to identify a solution for one of the several mechanical concerns that Varian Semiconductor Equipment is facing to achieve its goal. Managers and engineers are trying to lead Varian Semiconductor Equipment to a flow line shipment program, the intent being to eliminate the clean room area and ship all of the components of the ion implanter directly from the flow line to the customer, without the currently necessary step of a final assembly. In particular this work examines the correct alignment of the source chamber inside the terminal module prior to the final assembly of ion implantation equipment. In the flow line shipment context, the correct alignment of subassembly components becomes a critical aspect and needs to be checked before a shipment, since assembly errors or out of specification components from suppliers may lead to long delays and reworks. This last aspect cannot be ignored, since if adjustments and modifications can easily be accomplished in the flow line without conspicuous waste of time, the same cannot be said in the field, thousands miles away from the factory.

Specifically, the contribution of the project is to achieve the right orientation of the source chamber in relation to the position of the feet of the terminal module, by designing a mechanical fixture. The tool has been conceived to be used directly in the terminal module flow line, in order to allow technicians to quickly perform a correct alignment and easily point out any possible misalignment due to bad components or assembly errors. The main components of the fixture are the jig that checks the position of the insulators and a vertical target where two lasers shoot to align the source chamber.

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CONTENTS

CHAPTER 1

INTRODUCTION

This chapter will give a brief overview of ion implantation technology history, an overview of Varian Semiconductor Equipment and, at the end, the work organization of the thesis, which is finalized to the correct alignment of a sub-assembly component of the ion implanters through the realization of a mechanical fixture. In particular the thesis will present a procedure to align the Source Chamber inside the Terminal module, one of the three main components of an ion implanter.

1.1 Ion Implanting

Ion implanters are essential to modern integrated-circuit (IC) manufacturing. Doping or otherwise modifying silicon and other semiconductor wafers relies on ion implantation technology, which involves generating an ion beam and steering it into the substrate so that the ions come to rest beneath the surface. Ions may be allowed to travel through a beam line at the energy at which they were extracted from a source material, or they can be accelerated or decelerated by dc or radio-frequency (RF) electric fields [1].

Semiconductor processors today use ion implantation for almost all doping in silicon ICs. The most commonly implanted species are arsenic, phosphorus, boron, boron difluoride, indium, antimony, germanium, silicon, nitrogen, hydrogen, and helium.

Implanting goes back to the 19th century, and has been continually refined ever since. Physicist Robert Van de Graaff of the Massachusetts Institute of Technology and Princeton University helped pioneer accelerator construction, and the high-voltage technology that emerged from this effort was instrumental in building High Voltage Engineering Corp. (HVEC) in the late

1940s and 1950s. HVEC served as an incubator for the technology essential to building the first commercial ion implanters and the individuals who pioneered the field [1].

William Shockley first recognized the potential of ion implantation for doping semiconductor materials, and his 1954 patent application demonstrates a remarkable understanding of the relevant process issues long before implantation entered mass production. However, the patent expired in 1974, just as the commercial ion implantation market began taking off. So although Shockley demonstrated visionary insight, his patent earned few royalties.

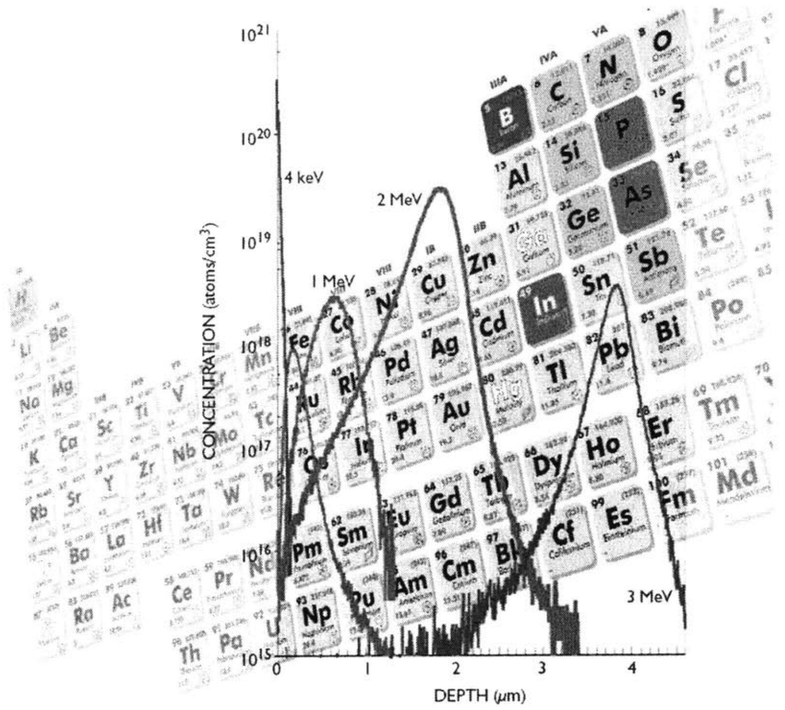


FIG. 1.1 – Concentration vs Depth: *Some of the most commonly implanted species highlighted on the periodic table, along with typical concentration-versus-depth traces for various implant energies.*

Ion-implantation equipment and applications gradually came together in the 1960s. Experience gained in building research accelerators improved hardware reliability and generated new techniques for purifying and transporting ion beams. Theorists refined the hypothesis of ion stopping, which enabled the precise placement of ions based on the energy and angle of implantation and experimenters determined that high-temperature post-implant annealing could repair implantation-induced crystal damage. Initially, these anneals were done at a temperature of 500 to 700° C, but after several years, semiconductor processors found that the optimum annealing temperature ranged from 900 to 1,100° C. After the resolution of process integration issues, ion implantation rapidly displaced thermal diffusion of deposited dopants as the dominant method of semiconductor doping because it was more precise, reliable, and repeatable.

IC manufacturers, especially IBM and Western Electric, designed and built many of the early ion implanters, almost exclusively for in-house use. But in the early 1970s, the market for commercial ion implanters began opening as start-up companies tapped the technology spun off from HVEC and the technology developed by IC manufacturers, who became their customers.

Today, some memory circuits now sell for less than 20 nanodollars/transistor and implanters and other fabrication hardware must meet aggressive productivity targets to achieve this minuscule cost. A large wafer fabricator may process up to 50,000 wafers/month, with each wafer requiring 20 to 30 implants. This output requires the use of about 20 implanters, each with the capacity to implant more than 200 wafers/h. In practice, maximum implanter throughput typically ranges from 250 to 270 wafers/h, including placing the wafers into and removing them from sealed cassettes used by automated material-handling systems. This throughput is achieved for wafer sizes of 150, 200, and 300 mm.

Depending on the configuration of the beam line and the end station (the wafer-processing chamber), an implanter occupies an area of 16 to 28 m^2. Thus, fabrication space poses almost as significant a barrier as capital cost against compensating for poor throughput by installing additional implanters.

A modern ion implanter costs about $2–5 million, depending on the model and the wafer size it processes. Makers have shipped more than 6,000 ion implanters worldwide since 1980. Two companies located 25 km apart on Boston's North Shore, Varian and Axcelis, manufacture roughly 70% of all ion implanters (Table 1). This siting is not entirely coincidental, because many of the same people founded and/or helped build the two companies, Varian in 1971 and Axcelis in 1978. It is unlikely that a significant amount of ion-implanter design will migrate to new areas because of the machines' complexity. The expertise required to design a new beam line is not easily duplicated, which makes ion implanters the Swiss analog watches of the semiconductor industry. They are an elegant, complex product designed and made mostly by a small number of skilled craftspeople in a small corner of the world.

1.2 VSEA, Inc. Overview

Varian Semiconductor Equipment Associates, Inc. (VSEA) designs, manufactures, and services semiconductor processing equipment used in the fabrication of integrated circuits. It is dedicated to meeting the exacting demands of IC production and satisfying the ion implantation needs of IC manufacturers worldwide. With more than 3,300 high current, medium current and high energy implanters installed throughout the world, Varian Semiconductor systems implant more than 5 million wafers each and every day, more than all of its competitors combined.

Varian Semiconductor provides customers with support, training, after-market products and services that ensure higher utilization and productivity, reduced operating costs, and extended capital productivity of their investment. The company is ISO 9001:2000 certified and it has celebrated ten years on the prestigious VLSI Research Inc 10 Best list, having won first place for ten of the last eleven years [2].

Varian Semiconductor is focused on customers and their drive for improving cost of ownership. The company is the leader in technology development, productivity optimization, and production support, the three areas that matter most to IC manufacturers. Recently, it has introduced the next generation VIISta™ product line. This technology leverages the single wafer processing pioneered on the E200 and E500 line of medium current implanters, to a wider spectrum of energies and implant applications. These single wafer VIISta products are differentiated by their unique processing capabilities, higher throughput, and improved process yields [2].

Varian Semiconductor Equipment Associates started over 30 years ago, when Varian Associates, Inc. entered the ion implantation market in 1975 through the acquisition of Extrion Corporation in Gloucester, Massachusetts and its medium current ion implanter products. This signaled the beginning of a program of research, product development and technological innovation that has resulted in a diversified product line family of ion implanters.

In April 1999, Varian Semiconductor Equipment Associates, Inc. (NASDAQ: VSEA) spun-off of Varian Associates, one of the founding companies of California's Silicon Valley. Today, it continues to design, manufacture, market and service semiconductor processing capital equipment all over the world used in the fabrication of integrated circuits.

1.3 Product Overview

Varian Semiconductor offers a full suite of single wafer ion implanters covering a wide range of doping and materials modification used in semiconductor applications. All applications use the VIISta Platform . The VIISta platform has enabled the transition from batch to single wafer systems, by providing precise angle control, low defectivity and particle control and high productivity. All VIISta single-wafer, single-platform products utilize a common single-wafer backbone with optimized beam lines for specific ion implantation applications.

The VIISta single wafer platform commonality results in manufacturing flexibility, reduced support requirements and high productivity. Semiconductor manufacturers can match their choice of VIISta beamlines to application requirements to optimize work in progress and tool utilization for both 200 mm and 300 mm wafers. In addition, the Varian Control System (VCS™), common across the VIISta platform, provides process control coupled with e-diagnostic capabilities for tool-to-tool and fab-to-fab operating efficiencies.

The VIISta™ single wafer systems are based on a common platform and are used in Medium Current, High Current, and High Energy applications [3]:

- *High current*
    - VIISTA HCP
    - VIISTA HC

  - VIISTA 80HP
- *Medium current*
  - VIISTA 810HP
  - VIISTA 810XE
  - VIISTA 900HP
- *High Energy*
  - VIISTA 3000HP

<u>*High Current*</u>

Varian Semiconductor was the first to introduce single wafer, high current systems. The VIISta high current series is the high current market share leader. VIISta HCP includes features for both high yield and high productivity. For example, a dual magnet ribbon beam architecture results in improved beamline transmission, higher on-wafer beam utilization, and higher beam current output. Implant source chambers and beamline elements create particles due to depositions and beam strike. The dual magnet ribbon beam architecture of VIISta HCP isolates the wafer from sources of particles. The second magnet filters out particles generated from beamline elements. In addition, the measures and adjusts beam steering. The closed-loop Varian Positioning System (VPS™) delivers accurate, repeatable and interlocked incident angle control for the true zero degree and precise tilted angle implants.

<u>*Medium Current*</u>

The VIISta 810 is Varian's series of medium current implanters. The VIISta 810XP provides high overall throughput, precise doping and contamination control. The single wafer, parallel path wafer handling architecture delivers more than 500 wafers per hour mechanical throughput. To achieve a clean medium current beamline, the VIISta 810XP beamline sets final ion acceleration before the analyzer magnet, eliminating the potential for energy contamination associated with downstream charge exchange, and isolating the wafer from optics beamstrike.

The VIISta 810XE's dose control system ensures precise implanting for high volume production. The closed loop Varian Positioning System (VPS™) delivers accurate and repeatable angle control over the full range of desired implant angles.

In many high performance devices, the energy levels have dropped into sub MeV ranges for most, or in some cases, all of the well implants used in the device. This provides an opportunity to reduce or eliminate the use of less productive batch MeV implanters. For greater bay productivity, existing MeV systems can be dedicated to MeV applications and reduce costs of capacity expansions.

The VIISta 900XP has all of the capability of the VIISta 810XP but with an extended energy range. The VIISta 900XP achieves productive p- and n- retrograde well implants that can be two times more productive than MeV implanters. It features a high throughput of over 500 wafers per hour mechanical throughput. It features a dose control system and the closed loop Varian Positioning System (VPS™) for precise dopant placement needed in advanced devices; a dual magnet beamline delivers up to 10X better contamination performance than batch systems.

VIISta 810XP	Energy: 2keV - 810keV Dose: 1E11 - 1E16cm^{-2} 500 wph Mechanical Throughput
VIISta 810XE	Energy: 2keV - 810keV Dose: 1E11 - 1E16cm^{-2} 400 wph Mechanical Throughput
VIISta 900XP	Energy: 2keV - 900keV Dose: 1E11 - 1E16cm^{-2} 500 wph Mechanical Throughput

High Energy

The VIISta 3000XP is Varian Semiconductor's third generation, single wafer high energy tool with dual magnet architecture. The VIISta 3000XP features angle precision with true zero capability needed in advanced device manufacturing. The VIISta 3000XP is a third generation evolutionary tool, and the latest addition to Varian Semiconductor's low dose platform. This single wafer high energy ion implanter is more in common with the VIISta 900XP, the Company's flagship medium current ion implanter.

More than five years of both VIISta 3000 and VIISta 810 series experience is now incorporated in the VIISta 3000XP with improved production worthiness, process capability, and productivity. The VIISta 3000XP features the same single wafer end station, integrated loadlock (ILL), dosimetry, closed-loop faraday and control system (VCS) as the medium current VIISta 900XP.

VIISta 3000XP	Energy: 10keV - 3MeV Dose: 5E10 - 1E16cm^{-2}

1.4 Thesis Outline

After this introductory chapter, **Chapter 2** will present a brief description of the VIISTA 810XE Medium Current ion implanter, which is the machine we work with, while **Chapter 3** will describe the basic ion implanter theory. These two chapters are closely drawn from Varian literature [2, 3, and 5]. **Chapter 4** will illustrate the Flow Line Shipment project and more precisely the reader will find the need for this change and the benefits that it will add to the company. **Chapter 5** will provide the problem statement, that is, the correct alignment of the source chamber inside the Terminal module, and the timeline of the work followed at Varian. Finally **Chapter 6** is focused on my personal work at Varian. You will find there a description of the process adopted to design the fixture and, in the appendix of the thesis, all the engineering drawings. The source chamber alignment is the effort of my colleague Simone Guerra and you will find the related chapter at the end of his thesis; a brief description of his effort is presented here in **Chapter 7**. Finally, **Chapter 8** presents conclusions from this projects and suggestions for future works.

1.5 Job Division

In this thesis, I dealt with the matter with my colleague Simone Guerra and we worked as a team with technicians, engineers, designers and managers on different aspects to achieve our goal. Chapter 1 through 5, and Chapter 8, of this thesis result from our joint effort, and are jointly written. In particular the jig design is my personal effort, thus the reader can find a description of the process adopted to design the fixture and, in the appendix of the thesis, all the engineering drawings. The source chamber alignment is a personal effort of my colleague and you will find the related chapter at the end of his thesis *"A Template Modeling for an Assembly Control – Source Chamber Alignment"* [14].

CHAPTER 2

THE VIISTA 810XE MEDIUM CURRENT ION IMPLANTER

The following sections describe the main components of VIISTA 810XE Ion Implanter, which is the machine we work with. After the implanter overview, the Terminal Module, the Beamline Module and the End Station Module are introduced. The entire chapter has been drawn from corporate literature [2, 3, and 5].

2.1 Implanter Overview

In this thesis we will refer to the VIISTA 810 series Ion Implanters which are high throughput, medium current ion implanters, designed around the emerging needs of 300mm wafer fabrication. In this chapter we will review the VIISTA 810XE ion implanter and describe the main parts of the entire machine.

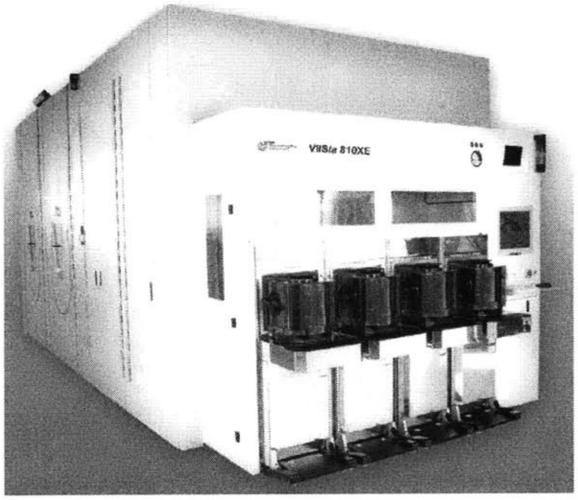


FIG. 2.1 - 810XE Ion implanter.

The design of this machine (figure 2.1) is driven by two key requirements: the first is for higher productivity, the second is for reduced defect density. With this architecture, components of the beam that are not required are removed as early as possible in the beamline, at low energy and far from the wafer. Also, energy contamination through charge exchange prior or during acceleration is eliminated by momentum analysis at final energy [4].

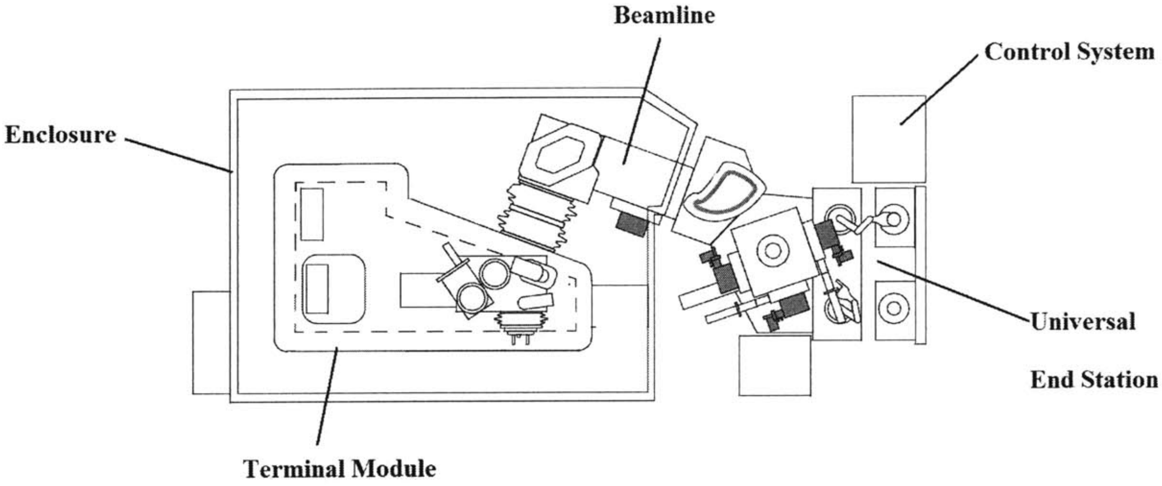


FIG.2.2 - VIISTA 810XE: *Ion implanter layout.*

The VIISta 810XE medium current ion implanter is a highly automated production tool. The implanter delivers to a silicon wafer an ion beam consisting of a single dopant ion species. The ion beam is produced under exact criteria specified by process recipes that are created utilizing the VCS control system. The recipes are designed to control dopant species selection, applied dose, ion beam energy, implant angles, and the number of processing steps.

In the diagram of figure 2.3 we present the three main functional sections of the Ion Implanter: the source or terminal, the beam and the end station modules.

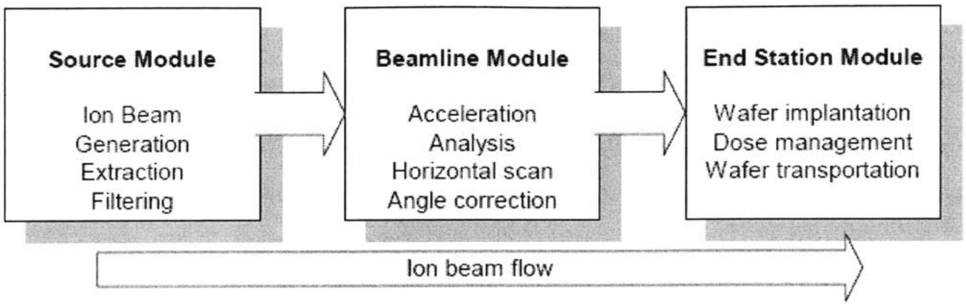


FIG 2.3 – VIISTA 810: *functional section.*

The basic operation of the system is as follows [5] : The beam, output from the source chamber module, is accelerated or decelerated to final energy before entering the 90 degree analysis magnet (figure 2.4). After the analyzed beam has passed through the mass slit, horizontal electrostatic scanning at 1KHz produces uniform beam. The angle correction magnet ensures a parallel beam, 200mm or 300mm wide, entering the end station and the wafer, which is electrostatically clamped, is implanted as the platen is moved vertically through the beam.

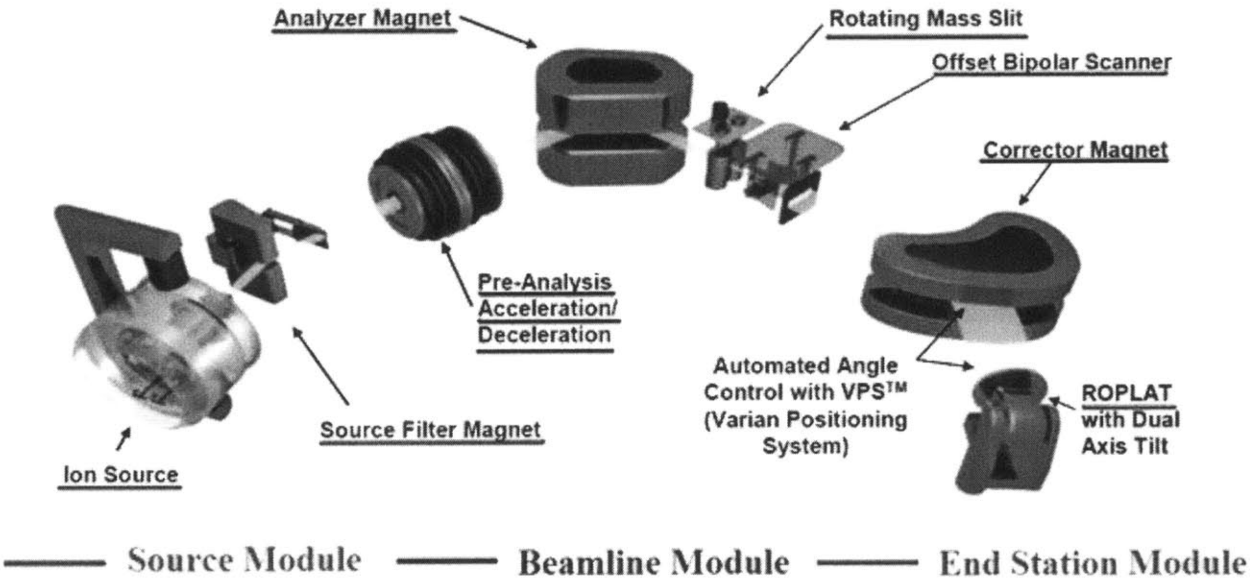


FIG. 2.4 - VIISTA 810XE: *Basic components and their localization.*

2.2 The Source (Or Terminal) Module

The terminal module is where ions are created using either a dual filament Bernas ion source or the IHC alternate source. Ions produced in the source are extracted by an electrode mounted on the manipulator assembly and formed into a beam. The extracted ion beam travels through the filter magnet where the majority of undesired ions are removed. The filtered ion beam then passes through a resolving aperture that further reduces the number of unwanted ions. The filtered and resolved ion beam then enters the acceleration tube where it is accelerated or decelerated to final beam energy.

The main structure of the terminal module, which includes the terminal enclosure safety system, supports the terminal power distribution assembly, terminal control modules, source rough pump, source and filter turbo pumps, process gas box, ion source and bushing, filter magnet, resolving aperture, and acceleration tube. The terminal enclosure safety system is interlocked to prevent access during normal implanter operation. If any doors are open or maintenance service panels removed, the high voltage power and hazardous gas flow is shut off via the interlock system. The VIISta 810XE uses either high pressure or Safe Delivery System process gases. Boron trifluoride, arsine, and phosphine are the standard process gases supported by Varian Semiconductor Equipment Associates (VSEA).

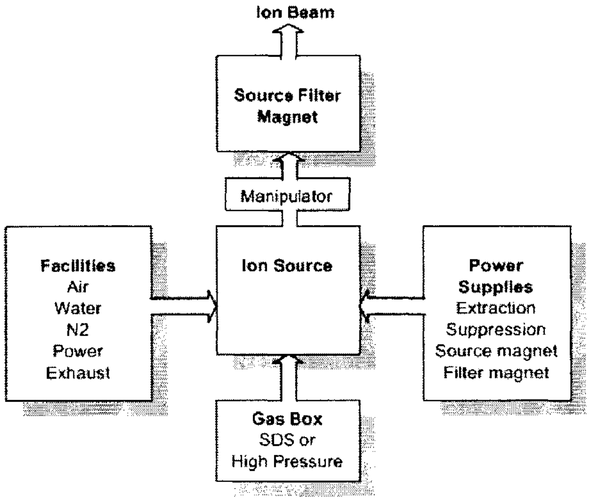


FIG. 2.5 - VIISTA 810: *Main sections.*

The Figure 2.5 diagrams the main sections of the Terminal Module. In the high voltage terminal, the most important part is the ***source chamber***, since it is here that the beam is both extracted from the ion source and pre-analyzed before transmission into the beam line. To achieve this, the source chamber houses not only the ion source and extraction system but also the source filter magnet and its resolving system. The latter has a modest resolving power sufficient to prevent most undesired ions from ever leaving the source chamber. The source chamber has two distinct vacuum regions, the extraction and filter magnet regions. Each has its own turbo pump (300 L/s and 700 L/s respectively); the ion beam is transmitted from the extraction region through a 1 cm diameter aperture. This differential pumping arrangement is sufficient to allow the pressure in the filter magnet region to run at 1 to 2 decades lower than in the extraction region during normal operation, reducing the gas load into the beamline.

The ***ion source*** provides the real ionization, the process where a neutral atom or molecule is converted to an ion by removing or adding electrons; Arsenic (As), Boron (B), and Phosphorus (P) are elements that are found in the Arsine, Boron Trifluoride, and Phosphine gases commonly used in implantation. The VIISTA 810XE implanter generates ions by using a dual filament design; this can be an ICH source or a Bernas source: both rely on a piece of heated tungsten to emit electrons (*See Appendix A for a detailed description*).

From the ***gas box***, the process gas is supplied from either gas-bottles, or from a solid material which is vaporized. The flow of gas supplied to the arc chamber is adjustable for efficient ionization. Too much gas causes inefficient ionization and source arcing problems. Not enough gas also causes inefficient ionization and can result in reduced filament life.A vaporizer option is another source of gas for the implanter. The vaporizer is a vessel that is loaded with elements in their solid form. Heaters within the vaporizer heat the solid to the point of vaporization producing the process gas. The vaporizer temperature controls the amount of gas supplied from the vaporizer.

The ***source filter*** is a dipole magnet that bends the desired beam by 25 degrees immediately after extraction; its design ensures minimal effect on the beam other than deflection. Specifically, the beam is not brought to a focus at the resolving aperture (situated at the exit of the source box and just before the beam enters the acceleration module). This allows undesired ions to be removed at low power densities, thereby reducing erosion and contamination by sputtering. Since the filter magnet performs no optical function other than deflection, the output from the source chamber is similar to a conventional design (with the beam still appearing to come from a source aperture) except that the majority of the undesired beam has been removed.

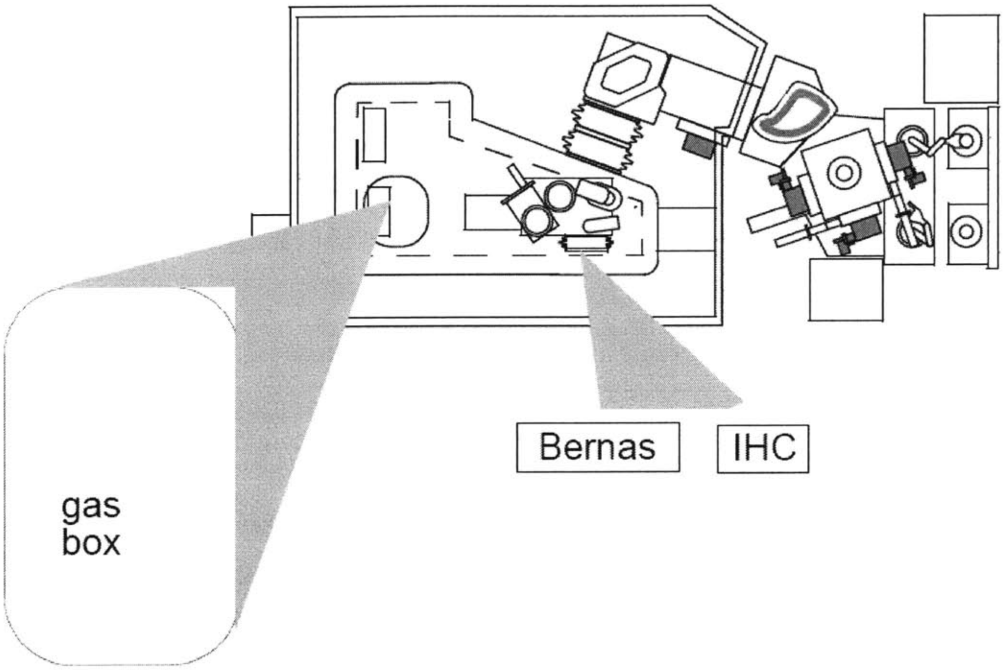


FIG. 2.6 - VIISTA 810: *Gas box, Bernas and IHC location.*

2.3 The Beamline Module

The main structure of the beamline module, as summarized in Figure 2.7, supports the analyzer magnet, scan power supplies, rotary mass slit, scan plate assembly, setup cup assembly, corrector magnet, and beamline control modules. The beamline module including most of the corrector magnet is located inside the implanter's outer enclosure safety system. The outer enclosure safety system is interlocked to prevent access during normal implanter operation. If any outer enclosure door is opened, high voltage power is shut off via the interlock system and automatic grounding rods are engaged. The process chamber has a separate support structure and is physically connected to the end station module.

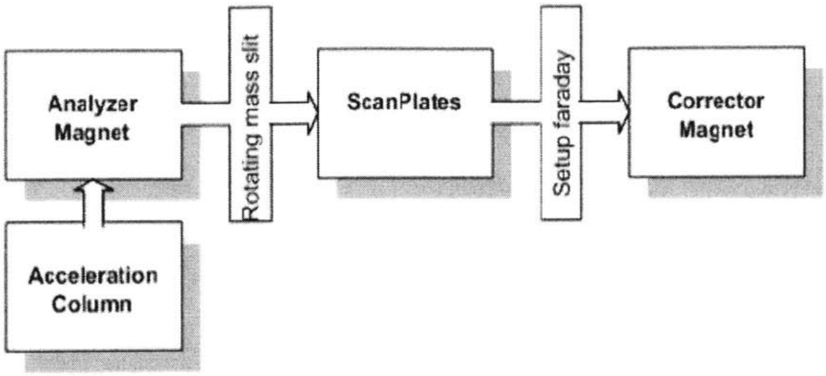


FIG. 2.7 - VIISTA 810: *Beamline diagram.*

The ion beam enters the beamline module after traveling through the ***acceleration tube***; it contains a two gap, three electrode electrostatic lens. The first electrode is at high voltage terminal (source chamber) potential; the final electrode is at ground (wafer) potential. The potential of the intermediate (focus) electrode is maintained by the focus power supply (which resides on the terminal) and is variable from 0 to -120KV with respect to the first electrode. The acceleration column has two purposes: the first is to take the ions from extraction to final energy and the acceleration or deceleration voltage determines this; the second is to ensure that all beams, independent of current or energy, have similar optics as they enter the analyzing magnet. The focus voltage controls this by determining the divergence of the beam and, thereby, the position from which the beam appears to have originated (the virtual object). Generally, the more negative (with respect to the terminal) the focus voltage, the less divergent the beam will be and the further the virtual object point from the analyzing magnet. The focus voltage has no effect on the final energy of the beam leaving the acceleration column. For low energy implants, beams are extracted at a higher energy (typically 40KeV) and decelerated in the column; this allows higher beam currents to be transmitted to the wafer.

Final analysis on the VIISTA 810 occurs after the beam has passed through the acceleration system and is at its final energy.

The ***90 degree analyzer magnet*** is the first component of the beamline module. This electro-magnet creates a strong magnetic field that bends the ion beam 90 degrees to allow only the desired ion species (correct mass) traveling at the correct beam energy (speed) to pass through the magnet. Undesired ions will bend either greater or less than 90 degrees and will not pass through the analyzer magnet.

The analyzed ion beam passing through the 90 degree magnet now enters the rotating ***mass slit*** assembly. The water cooled mass slit, a pair of graphite encased cylinders rotating at high speed (1700 rpm), assures that only desired ions (correct mass and energy) are allowed to pass from the 90 degree magnet to the beam scan area which is the next section of the beamline module. The aperture size of the mass resolving system can be varied: for the majority of beams it is set to 3mm; this gives a resolving power $(M/\Delta M) > 85$ at high currents and substantially higher than this at lower currents. At very low currents ($\approx 10\mu A$) the aperture can be set to 1mm to ensure in stable operation. For low energy beams (which have higher emittance) an aperture size of 5mm is used.

In the ***scan area***, the ions pass between two deflection plates that can allow the beam to pass through without scan (spot mode) or with scan (scan mode). In scan mode, the deflection plates cause the beam to sweep back and forth in the horizontal axis. This method of scanning, called the bipolar electrostatic method, uses varying voltages applied to the plates to attract or deflect the beam and effectively scan it across the surface of the wafer. The scanning system uses a varying (1KHz) electric field to deflect the beam horizontally through an angle typically of ±13.5°, which is sufficient, after angle correction, to produce an uniform 300mm wide beam on target. The applied voltage is bipolar, with each of the scanner plates varying from up to +20KV to -20KV with respect to a reference potential.

The ion beam (in spot mode) passes through the scan area and enters the ***setup cup*** where the beam current is measured. Adjustments are made to the ion source and extraction manipulator until the setup cup beam current specified by the process recipe is achieved. The setup cup now rotates to the out position and the ion beam is allowed to enter into the next electro-magnet.

The ***corrector magnet*** bends the beam 45 degrees so that the beam will enter the process chamber (in the end station module) at 90 degrees to the wafer platen when the x-axis and y-rotate angles are both set to 0 degrees. Additionally, the 45 degree corrector magnet removes any remaining unwanted ions just prior to wafer implant. The corrector magnet and scanning system have been designed so that, independent of scan voltage, the ion trajectories are perpendicular to the implant plane and mutually parallel to better than 0.7°.

2.4 The End Station Module

The main structure of the end station module supports the process chamber, wafer handler chamber, and the load lock chambers. Additionally, there are the tool control and end station racks that contain specific control computers, process chamber and wafer handler control modules, and power supplies.

The ***process (or scan) chamber*** includes several faraday cup systems used during beam uniformity setup and dose integration. Inside the process chamber, a wafer on the platen is moved mechanically in the vertical axis to ensure that, in combination with horizontal beam scan, the entire wafer is implanted uniformly. The vertical scan is accomplished by using a specialized motor to drive the air-bearing shaft up and down with precision. A vertical scan consists of one up and down cycle of the wafer.

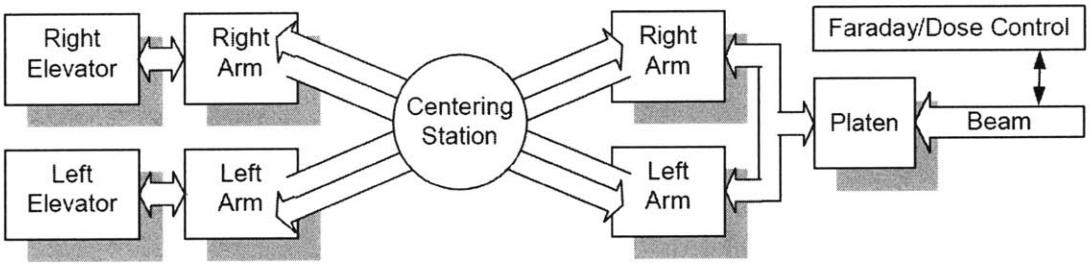


FIG. 2.8 - VIISTA 810: *End Station scheme.*

The VIISta 810XE universal end station uses several mechanical systems to handle wafers, as pictured in Figure 2.8. Major components of the end station operation are the load locks. Each right and left load lock is used to hold a cassette of 25 wafers. The VCS control system includes both automatic and manual door interfacing that allows access to the load lock chambers. A light curtain is used to prevent the load lock doors from closing when either load lock is being accessed.

Each load lock contains an elevator drive, wafer cassette platform (with cassette present sensor), wafer mapping lasers (Class 1 Laser Product) to detect the location of each wafer in the cassette, and load lock isolation valve. To accommodate wafer cassette exchanges, the isolation valve allows the load lock chamber to be pumped from atmosphere to approximately 100 - 200mTorr using a combination of roughing and turbo vacuum pumps before opening to the high vacuum area of the wafer handler.

A left and right wafer handler robot along with a single wafer orient station can be found within this high vacuum wafer handling area [6].

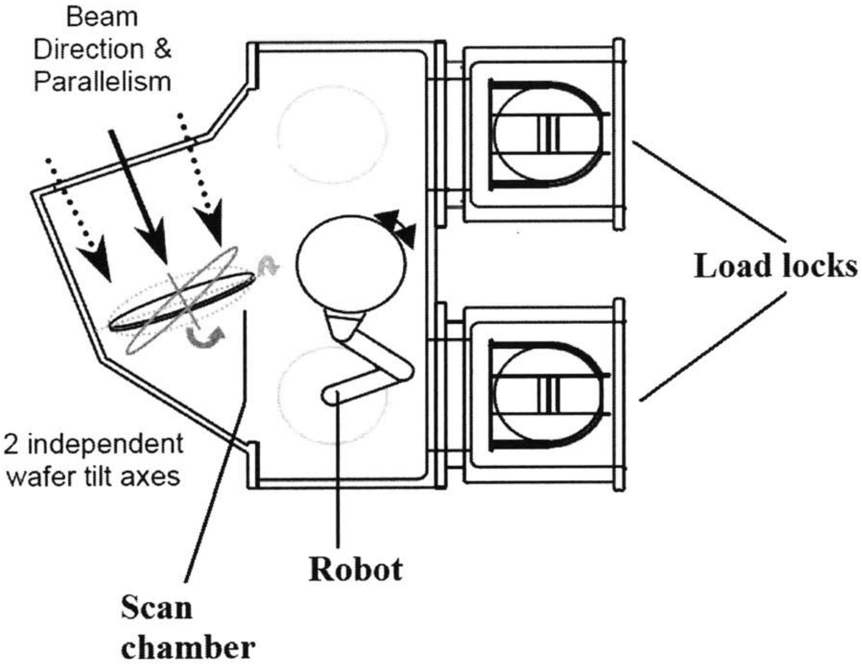


FIG. 2.9 - View of the VIISta end station from above*: on every setup the beam parallelism and direction are measured. Mean beam direction is indicated by the solid arrow, while beam parallelism (spread in angle from the center of the beam to the edge) is indicated by the dotted arrows. Two independent axes(shown in gray) are utilized to tilt the wafer to the desired process angle.*

With the isolation valve open, each wafer is individually removed from the cassette by the wafer handler robot, placed on the orientor, oriented for platen centering and wafer crystal orientation, removed from the orientor by the opposite wafer handler robot and placed on the platen for implant. The implanted wafer is then removed from the platen by the appropriate wafer handler robot and put back in the original cassette. After all wafers from a cassette are implanted, the isolation valve is closed and the load lock is cycled back to atmosphere. After the load lock door opens, the cassette is ready to be removed or exchanged.

The mechanical throughput of the end station for the VIISTA 810XE ion implanter is 400 wph, whereas size specific wafer handler components are available for both 200mm and 300mm wafers.

Precise control over the implant angle is critical to maintaining the uniformity of dopant placement and of device characteristics across the wafer. Beam parallelism is optimized by fine tuning the corrector magnet for the best possible parallelism.

The multi-tilt capability of the end station allows the implant angle to equal the desired implant angle by tilting the wafer to compensate for the beam direction offset, which is also measured on every setup. Measurement and optimization of parallelism, beam direction and implant angle is part of the standard automated beam setup procedure on the VIISta 810XE.

CHAPTER 3

THE VIISTA 810XE: THEORY OF OPERATIONS

The following chapter has to be intended as a short description of the physics at the base of the ion implantation. The entire chapter is drawn by using corporate literature [2, 3, and 5]. The following sections present how the ion beam is extracted, manipulated and used for the wafer implantation.

3.1 Isotopes and Ions: Overview

Atoms with the same atomic number but different atomic mass numbers are called isotopes. The isotopes of an element all have the same number of protons but a different number of neutrons. Isotopes have identical chemical properties, but they can have very different nuclear properties. These properties include possible radioactivity, magnetic properties, and weight.

Boron is commonly used in implantation and has two naturally occurring isotopes: 10B (spoken as B ten) and 11B (spoken as B eleven). 10B has 5 protons and 5 neutrons (5+5=10); its atomic number is 5 and its atomic mass number is 10. 11B has 5 protons and 6 neutrons (5+6=11). The atomic number of 11B is also 5, but its atomic mass number is 11. 11B is used more often for implantation processes because it is four times more abundant than the ^{10}B isotope. However, some processes use ^{10}B because it is lighter and can be implanted more deeply at lower voltage potentials.

Atoms cannot be divided further without changing the basic characteristics of the element except for the limited removal, transfer, or exchange of certain electrons. This exception is what allows controlling the atom.

The Boron ^{10}B, for instance, has 5 protons, 5 neutrons, and 5 electrons. The electrons orbit in two shells around the nucleus. The first (inner) shell has two electrons and the second (outer) shell has three. If the atom gains or loses an electron it becomes an ion. In the diagram of the two Boron ^{10}B ions (Figure 3.1), one Boron atoms has gained an electron. With 5 protons and 6 electrons, it has a net negative charge and has become a negative ion. The second Boron atom has lost an electron and has become a positive ion. With only 4 electrons, it has a net positive charge.
VIISta implanters use positive ions in the implantation process.

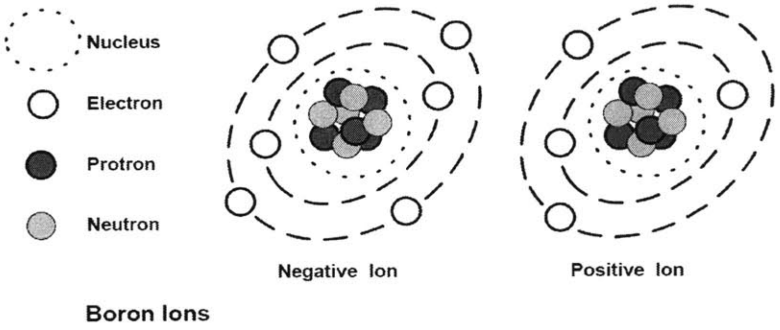


FIG. 3.1 – Negative and positive ions.

The ease or difficulty a particular atom has in gaining or losing an electron depends on its valence ring. Electrons orbit the nucleus of the atom in shells. With the exception of the Hydrogen (H) and Helium (He) atoms, which have only 1 and 2 electrons respectively, all atoms have an inner shell with 2 electrons and from 1 to 6 additional orbiting shells. Each additional shell contains from 1 to 32 electrons. The outermost shell is called the valence ring. The valence ring, Figure 3.2, always likes to have 8 electrons.

- Atoms with 8 electrons in the valence ring are the most stable atoms. They don't want more electrons and they are better able to keep other atoms or processes from stealing one of their electrons. Inert gases and insulators are in this category.
- Atoms with 4 electrons in the valence ring are less stable atoms. They can gain electrons from atoms with fewer valence electrons and they can lose electrons to atoms with more valence electrons. Semiconductors like silicon are in this category.

- Atoms with 1 electron in the valence ring are unstable. Atoms looking to fill their valence ring with more electrons can steal this electron easily. Atoms in this category are considered good conductors.

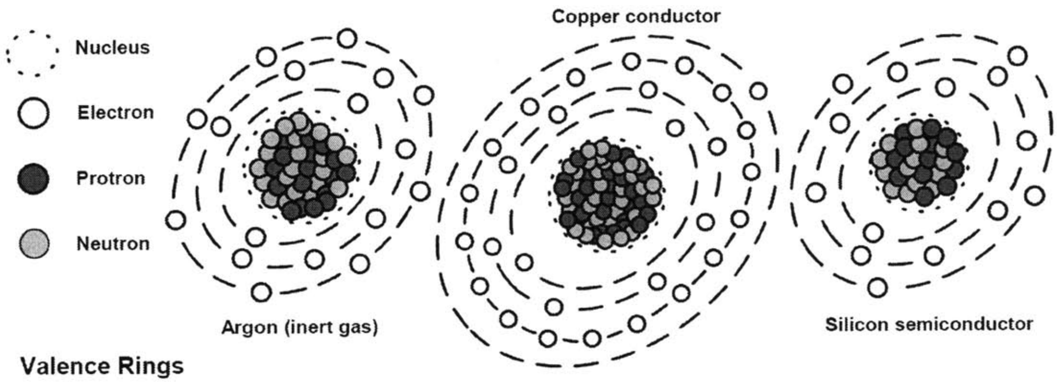


FIG. 3.2 – Valence rings .

The more electrons there are in an atom's valence ring the easier it is for the atom to take an electron. The fewer electrons in an atom's valence ring the easier it is for the atom to lose an electron. An atom with 7 valence electrons can take an electron from an atom with 2 valence electrons more easily than an atom with 5 valence electrons can take an electron from an atom with 3 valence electrons.

3.2 The Beam: Generating and Control

An electrically neutral atom is extremely difficult to control. An atom that has lost an electron (a positive ion) has a net positive charge and can be attracted to and accelerated by negative electrostatic charges. The same positive ion can be repelled and decelerated by positive electrostatic charges. Magnetic fields can manipulate beams of these positive ions by compressing the beam, expanding the beam, and shifting the position and direction of the beam. An implanter, therefore, creates an ion beam and manipulates it to achieve the desired goal of implanting the atoms into a substrate at a desired depth and concentration. Arsenic (As), Boron (B), and

Phosphorus (P) are elements that are found in the Arsine, Boron Trifluoride, and Phosphine gases commonly used in implantation.

Implanters generate ions, manipulate the ions in a controlled environment, and implant the ions into a substrate to a specified depth and concentration. Ionization is the process where a neutral atom or molecule is converted to an ion by removing or adding electrons. The VIISTA 810XE implanter generates ions in a dual filament Bernas source (*See Appendix A*).

3.2.1 The Ionization Process

The four requirements for establishing and maintaining a stable arc (plasma) are: current through the filament, arc voltage, process gas pressure, and a magnetic field [5], Figure 3.3.

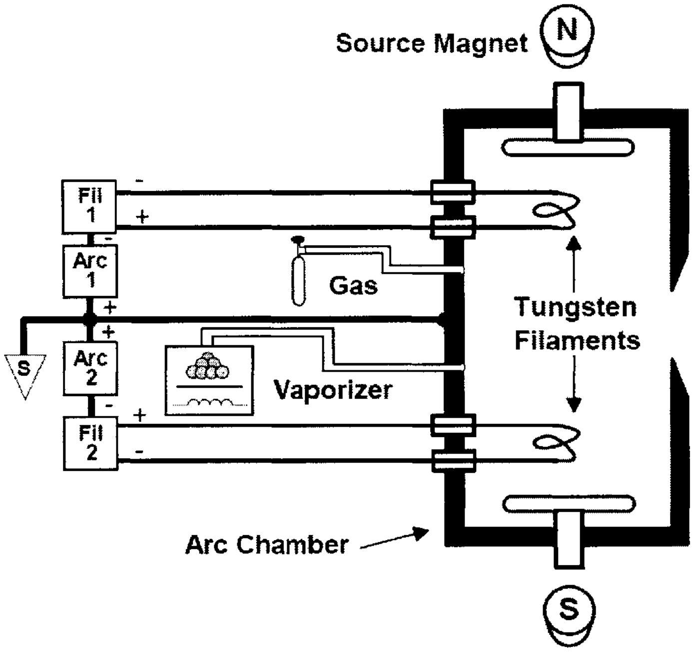


FIG. 3.3 – Stable arc scheme.

The filament is the main supply of free electrons for the ionization process. The filament operates on the principle of thermionic emission, similar to a light bulb in our homes. A light bulb has a filament within a vacuum and when the switch is turned on, electrical current flows into one side and out the other. The filament heats up and glows, giving off free electrons. The number of available free electrons is related to the amount of current applied to the filament. In an implanter, the ion bombardment and sputtering within the source causes the filament to deteriorate over time and therefore requires occasional replacement.

The IHC filament works much the same way as the Bernas source filament. In the IHC source the cathode is isolated from and indirectly heated by the filament. The cathode is made of tungsten and is biased with a higher voltage. It covers the filament and isolates the filament from ion bombardment.

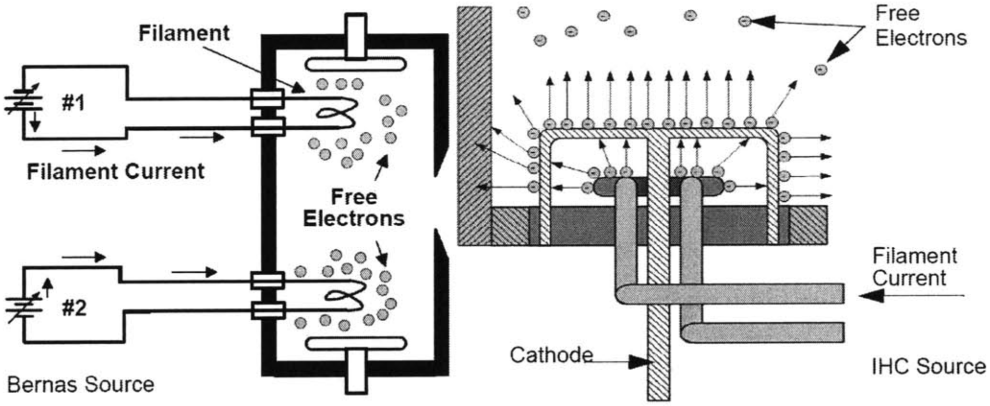


FIG. 3.4 – IHC scheme.

The arc voltage power supplies are connected between the filaments and the wall of the arc chamber. The power supply is wired so that the wall of the arc chamber is more positive electrically than the filaments Figure 3.5.

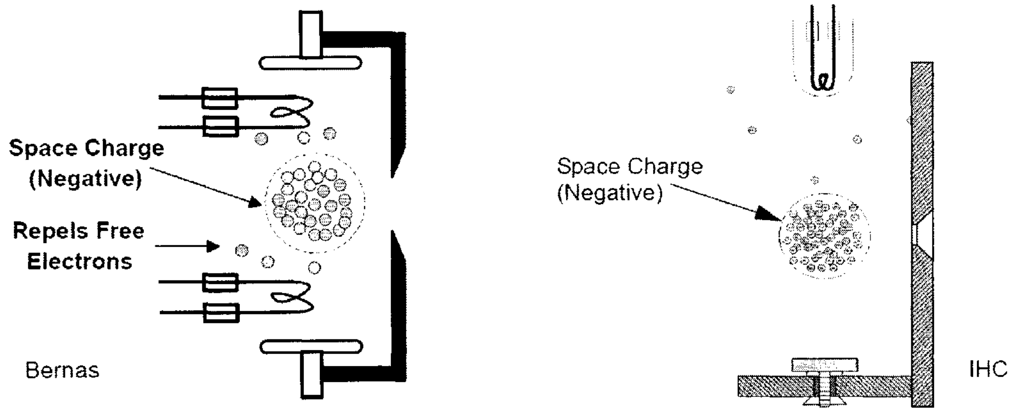


FIG. 3.5 – Bernas / IHC.

The positive charge on the arc chamber wall begins to pull the freed electrons away from the filaments. As electrons flow to the arc chamber wall, the wall becomes less and less positive. Eventually, electrons will not be attracted to the arc chamber wall causing electrons to build up around the filaments as a negative space charge. If this process is allowed to continue, the space charge will inhibit electron output from the filaments.

The process gas is supplied from either gas bottles, or from a solid material which is vaporized. The flow of gas supplied from bottles to the arc chamber is adjustable for efficient ionization. Too much gas causes inefficient ionization and source arcing problems. Not enough gas also causes inefficient ionization and can result in reduced filament life. A vaporizer option is another source of gas for the implanter. The vaporizer is a vessel that is loaded with elements in their solid form. Heaters within the vaporizer heat the solid to the point of vaporization producing the process gas. The vaporizer temperature controls the amount of gas supplied from the vaporizer.

The introduction of a gas into the source arc chamber begins the *ionization process*. Electrons freed from the filament (high-energy primary-electrons) are attracted to the arc chamber wall. On the way to the wall a primary electron may strike a gas atom freeing a valence electron (lower-energy secondary-electron) from it, and thereby producing a positive ion. When a primary electron strikes a gas atom it is deflected in another direction and loses some of its energy. If it loses too much energy, it cannot cause valence electrons to be ejected from the atoms that it collides with.

Initially, there is a small current of primary electrons (arc current) colliding with atoms, producing ions, and eventually reaching the arc chamber wall. As this process continues, the primary electrons around the filaments begin to reduce in number. This allows more electrons to be emitted from the filaments. As ionization continues, the charge within the arc chamber becomes more positive. At some point, for every primary electron emitted by the filaments, one electron will strike the arc chamber wall producing a plasma.

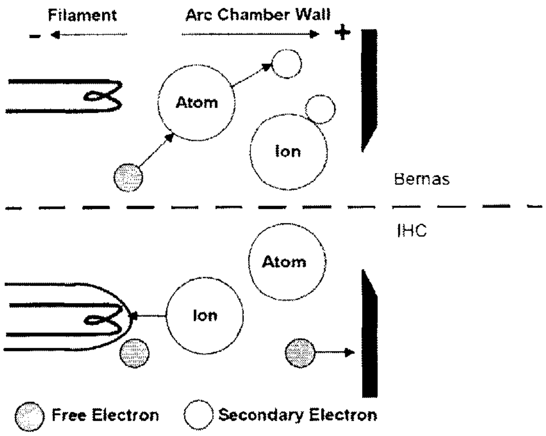


FIG. 3.6 – Plasma Generation.

Plasma is a body of atomic particles (neutrals, positive and negative ions, and various atomic combinations) that has an overall neutral charge. An arc is said to be struck when a plasma is created. As positive ions are extracted from the plasma and arc chamber, more ions are created. Increasing the ion extraction rate increases the ionization rate. Once maximum filament current is reached, an increase in ion extraction rate will cause loss of the plasma.

With a positive arc voltage, enough filament current, and proper process-gas pressure, an arc will be struck and ions produced, but unfortunately this process does not produce the necessary amount of ions for implantation. A *source electro-magnet* allows producing an alternating magnetic field within the arc chamber which improves the efficiency of ionization greatly increasing the amount of ions produced in the chamber. The source magnetic field can be shown as lines drawn through the arc chamber. The lines are referred to as magnetic lines of flux. When more current is sent through the source magnet, the field becomes stronger and the quantity of the lines of flux in the field increases. This is shown in the Figure 3.7 by adding more lines. The term used to describe this is "to increase the flux density".

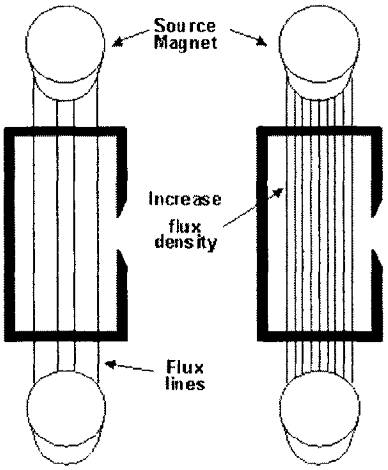


FIG. 3.7 – Magnetic Lines.

Primary electrons are affected by the alternating magnetic field and density of flux lines. As the electron approaches a line of flux it is pulled toward it. Since the electron has energy from its attraction toward the arc chamber wall, the electron spirals along the line of flux, Figure 3.8, toward the positive arc chamber wall. This increases the length of the path from the filament to the wall and therefore increases the chance of a collision with a gas molecule producing an ion.

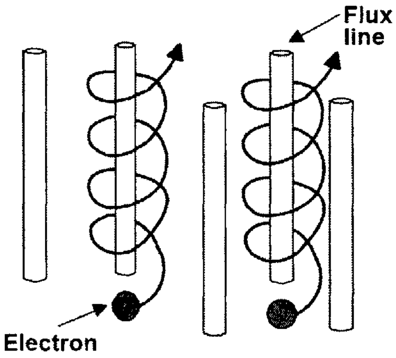


FIG. 3.8 – Magnetic Flux.

To further improve the efficiency of ionization, two floating repellers are used in the source. They are mounted in insulators so that they 'float' or are not electrically connected to any part of the source. Initially they have no charge; however, the primary electrons gather on their surface quickly giving them a negative charge. This has the effect of "repelling" or turning around the electrons spiralling along the lines of flux toward the arc chamber wall.

The electrons then travel in the opposite direction toward the filament. The filament, also being negatively charged, causes the electron to turn around again and head back along the line of flux toward the repeller. This reversing path of motion will continue until the electron collides with a gas atom or another electron changing its direction.

The source magnetic field is adjustable so that ionization can be optimized. If the source field is set too low, the path of the electron will be shortened, collisions will be minimized, and ions will be generated less efficiently. If the source field is set too high; the path of the electron becomes so long that the electron doesn't have enough energy to knock another electron from the valence shell of the gas atom when it collides with it.

All of the elements that are in the arc chamber during the ionization process become a part of the process. The bottled gas Boron Trifluoride is used as an example of the major ion species (there are more) generated during the ionization process, as shown in Figure 3.9.

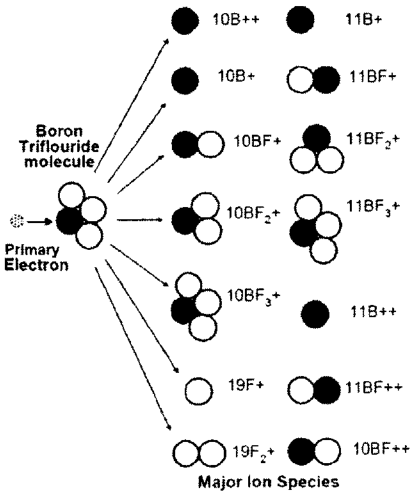


FIG. 3.9 – Boron Trifluoride ion species.

The smallest single division that the gas Boron Trifluoride can be broken down to is a molecule formed by one Boron atom combining with three Fluorine atoms. During the ionization process, the effect of particle charges and collisions will cause this molecule to break up (disassociate) into the ion species shown. These are only the major species, there are more.

3.2.2 Extracting Ions from the Arc Chamber

A *power supply* is wired between the arc chamber and the extraction electrode. The supply establishes up to a negative 70,000 volt difference in potential to attract the positive ions. The mechanical design of the apertures (holes) in the arc chamber and extraction electrode as well as the large difference in potential; provide a means of pulling ions out of the source.

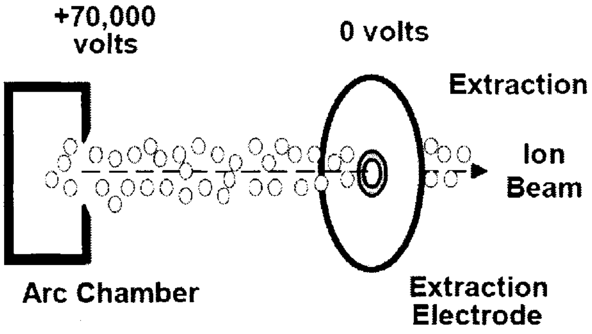


FIG. 3.10 – Ion Generation.

The diagram in Figure 3.11 shows two straight and parallel plates with a 5 volt difference in potential. At any point between plates A and B, as we move further from A, the potential difference from plate B is not as high. If we put dashed lines equally spaced between the plates to show potential, we can assign values to these points. Plate B has 0 volts potential difference. Line 1 has 1 volt potential and line 4 has 4 volts potential difference. If an ion was traveling between plates B and A, by the time it got to line 4 it would have four times the energy it had at line 1.

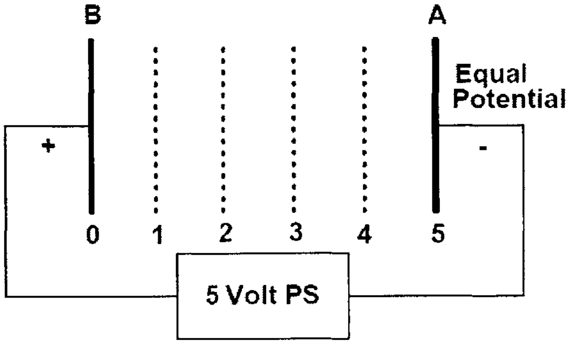


FIG. 3.11 – Diagram of difference in potential.

Now if we curve plate B: close to plate B the equal potential lines curve with the plate, whereas close to plate A the equal potential lines are straight. Lines in the middle of the plates will vary in curvature; the lines closer to B will be curved more than the lines closer to A. The equal potential lines affect the velocity of the ions. The velocity has two components; speed and direction. The ion is accelerated (gains speed) as it is pulled through the field and, the direction is affected by the curvature of the equal potential lines, as shown in Figure 3.12.

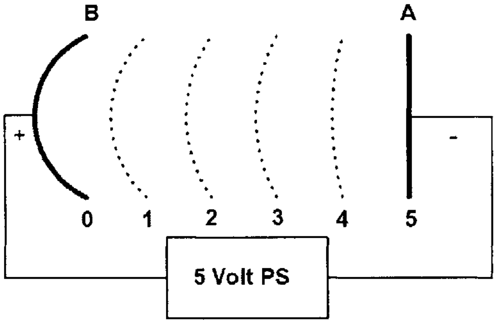


FIG. 3.12 – Curvature of equal potential line.

The aperture in the arc chamber and the aperture through the extraction electrode were designed to set up a specific pattern of equal potential lines. These equal potential lines bend into the arc chamber and extract positive ions from inside the chamber. Ions inside the chamber are traveling in different directions at different speeds (different velocities). The potential pull them from the chamber and changes the direction to steer them through the extraction electrode. In summary, the electro-static field affects the ion-beam in a manner analogous to the effect of a glass lens on a light-beam and is often referred to as an isometric lens.

Now, in order to understand the concept of how the ion is affected by the equal potential lines, we can refer to a very simplistic analogy. We can imagine going outside on a stormy day with extremely strong winds; the wind is blowing across and down the street and we look across the street at our neighbors house and walk directly towards the house. Even though we start out moving toward the house, we will end up somewhere downwind of our neighbors house. This is because the force of the wind has affected the direction (force) of our travel.

There are two forces that will affect the direction of the positively charged ion: the original direction of the ion and the attraction of the strongest point of negative charge influencing the ion at the moment. The two key phrases are "strongest point" and "at that moment". In Figure 3.13 and 3.14, we show equal potential lines by drawing four or five lines between our different potentials. There are actually an infinite numbers of these lines in the gap. Between each of these tiny equal potentials, and because the equal potentials are curved, the ion is directed towards an imaginary straight line between the arc chamber aperture and the aperture in the *extraction electrode*.

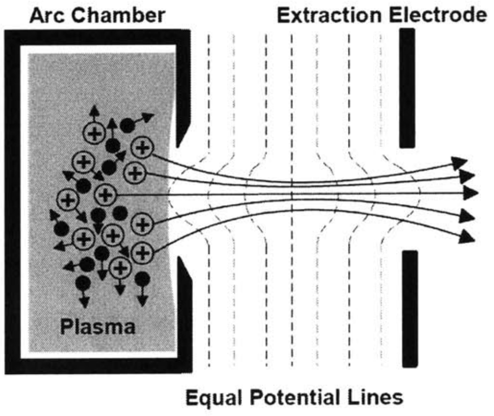


FIG. 3.13 – Equal potential lines.

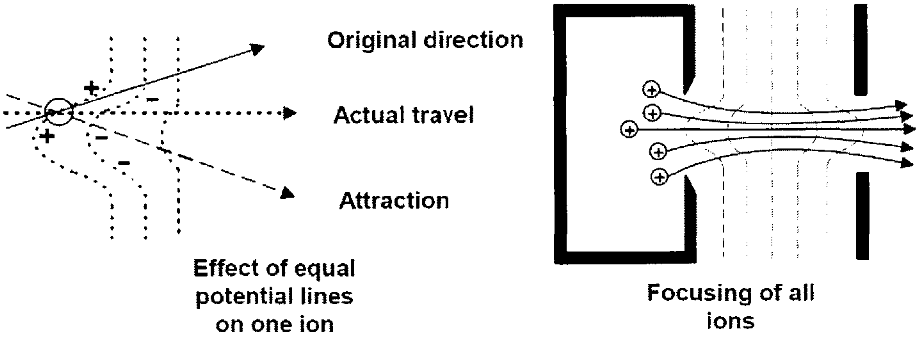


FIG. 3.14 – Equal potential lines.

The extraction electrode can be moved left and right (x), up and down (Y), and towards and away from the arc chamber (Z). The function of moving this electrode is called *beam steering* and is done by the *extraction manipulator.* This is normally done automatically under software control. Beam steering will optimize the electrical lens for different gases and conditions in the implanter.

The extraction electrode has two components; the suppression electrode and the ground electrode: the suppression electrode is closest to the arc chamber and is mounted to the ground electrode on insulators; the arc chamber is up to 70 kV more positive than the ground electrode. The suppression electrode is up to 40 kV more negative than the ground electrode.

As mentioned earlier, ions are not the only particles coming out of the aperture in the arc chamber. The ionization process is only about 20% efficient, which means that 80% of the gas molecules will not be ionized. Because the gas is put into the arc chamber under pressure the extra gas is forced out of the aperture in the chamber. Most of these gas molecules are immediately pumped out by the vacuum system. Some wind up in the region between the suppression and ground electrodes, and beyond. The ions in this region have been accelerated by as much as 70 kV and have a great deal of energy. Neutral gas molecules in this region have migrated here and have no accelerated energy. Secondary electrons are generated by collisions between ions and gas molecules.

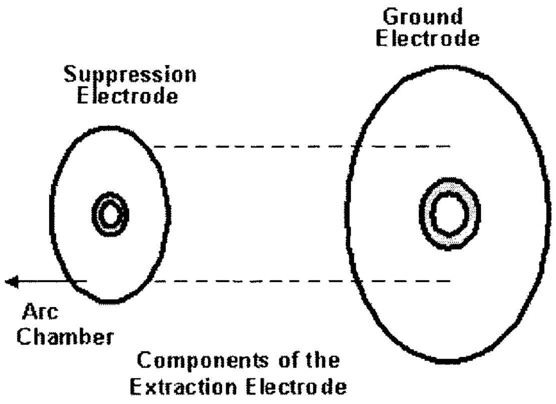


Fig. 3.15 – Extraction Electrode.

These negatively charged secondary electrons are immediately drawn toward the positive potential of the source and arc chamber. These light weight electrons will gain tremendous energy, being accelerated by up to 70 kV toward the source. If they were allowed to continue and collide with the metals in the source dangerous x-rays would be generated. To prevent this, the suppression electrode is put in the path of their acceleration. Before the electron can gain energy, it senses the negative voltage of the suppression electrode relative to the ground electrode. The electron is repelled by the suppression electrode and the strongest positive attraction it senses is from the ions in the beam. The electrons join the ion beam and pass through the ground electrode.

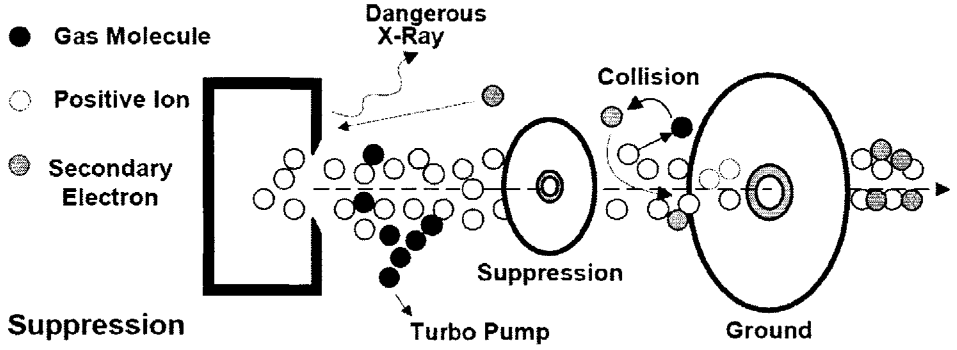


FIG. 3.16 – Prevention of x-ray generation.

The secondary electrons become a valuable asset to the beam. The positive ions repel each other and would force the beam to separate. The positive ions and negative secondary electrons are attracted to each other and form a loose bond that helps to hold the beam together. This effect is called "space charge".

As discussed earlier the source produces many different types of ions. The *source filter magnet* is used to remove the majority of the unwanted ions prior to acceleration. This reduces the risk of energy contamination. An additional benefit of the source filter magnet is the reduction of particles generation from downstream components. By locating the magnet prior to acceleration and analysis, the majority of unwanted species are removed early on and therefore there is less chance of creating particles in the vicinity of the process chamber.

The field created by the *filter magnet* pulls the positive ions toward the right. The heavier ions are not affected as much by the field and therefore do not make it through the hole in the source filter resolving aperture. The dashed line, in Figure 3.17, shows the path of the desired ions with the magnet turned on. The solid line shows the path the ion beam would take if the magnet was turned off. A more detailed explanation of how a positively charged particle is affected within a magnetic field will be discussed later in our description of analysis.

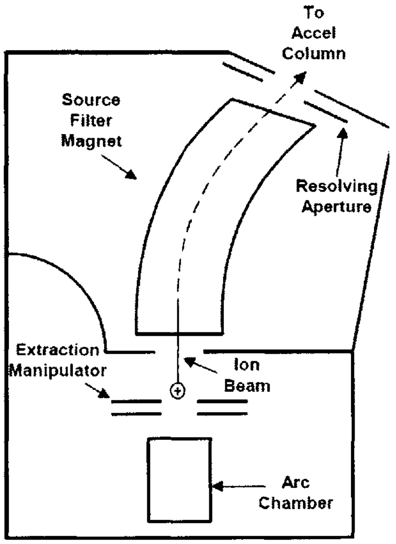


FIG. 3.17 – Ion path.

3.2.3 Accelerating the Ions

Acceleration gives the ion the required energy (final beam energy) to penetrate the wafer to the specified depth of implant. The earlier discussion on extraction explained in detail two concepts that are important in understanding acceleration. The first concept is the effect of a high voltage difference in potential on a positive ion. The second concept is the focusing effect of the equal potential lines created by the difference in potential.

In Figure 3.18 we can see a simplified diagram of an *acceleration tube* (or *column*). The acceleration tube is composed of electrodes (graphite electrodes) separated by insulation rings. The potential across the acceleration tube in a VIISta 810XE is variable from 0 kV to 200 kV. The difference in the potential is divided equally between the two electrodes. The lines of potential are shown as dotted lines.

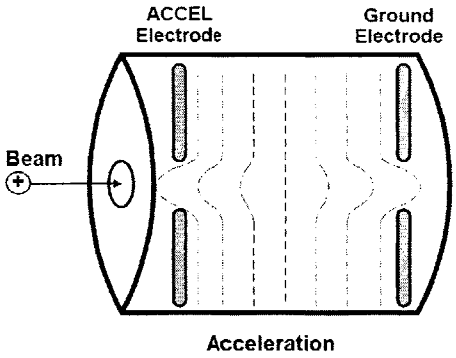


FIG. 3.18 – Acceleration tube diagram.

At the entrance and exit of the tube the equal potential lines are curved and they become less curved the closer to the center of the tube. In our earlier discussion we talked about how these curves in the potential lines focus the beam towards the central axis of the beam. As the positively charged ions reach each equal potential line it is attracted towards the next more negative equal potential line. As the ions travel from one equal potential line to the next they gain energy based on the amount of potential difference between the lines and the charge of the ion. For clarity there are very few equal potential lines shown. In reality the distance between these lines of force is extremely small. When the ions leave the acceleration tube they will have gained energy equal to the product of the voltage applied to the tube and the charge of the ion. For example, the maximum energy for P+ is 270 keV. This energy is created by the sum of (extraction voltage [70 kV] + acceleration column voltage [200 kV]). In this case, the Terminal voltage is 200 kV above end-station earth-ground and the Source and Gas Box are 70 kV above the Terminal ground.

In order to keep the beam tightly focused a separate negative electrode is placed inside the acceleration tube. The potential on this electrode is variable from 0 kV to -125 kV. It will initially be set based on the extraction and acceleration voltages, and then it will be tuned for maximum beam current.

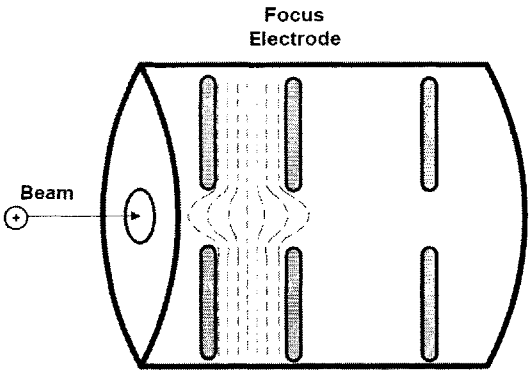


FIG. 3.19 – Focus Electrode.

A set of lines of potential are developed between the entrance of the tube and the focus electrode similarly to what we just discussed. By varying the voltage, the strength of the field will change. As the strength changes, so will the shape of the lines (focus lens) which provides the desired focusing effect. The focus lens is particularly important when acceleration voltage is set to 0 (drift mode) or when the Accel PS is in de-energized (low energy) mode.

3.2.4 Filtering the Beam

When we ionize gas in the source using Boron Trifluoride as many as 14 other major ion species may be created. Using the source filter magnet we are able to remove the majority of the unwanted species; however, we want to accurately select only one ion. The analyzer magnet gives us the ability to select only the desired one and reject the others.

We have discussed how positively charged ions can be controlled by both electric and magnetic fields. An explanation of how negatively charged particles (primary electrons) are affected by the magnetic lines of flux generated by the source magnet was given in the ionization section. Positively charged ions are similarly affected except they are turned in the opposite direction. Since secondary (space charge) electrons are embedded in the ion beam, these electrons are also affected by magnet fields. As a result the space charge must be reconstituted throughout the beamline.

Figure 3.20 shows a uniform field magnet commonly used on implanters for analyzing ions. Uniform field means that the flux density (magnetic field strength) is equal on the core between the poles. The flux density is controlled by the current flowing through the magnet coils. Increasing the current increases the flux density and makes the magnetic field more powerful. Magnetic fields flow from the north poles to the south poles, as indicated by the arrows.

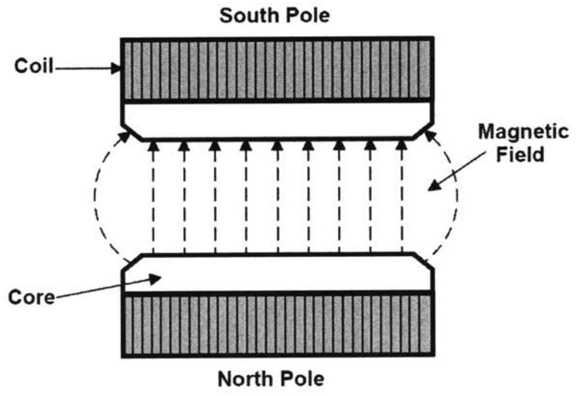


FIG. 3.20 – Uniform field magnet.

The charge (single or double) of a positively charged ion is determined by the number of electrons that it has lost. An ion that has lost one electron is considered single charged, one that has lost two electrons is called double charged. Doubly charged ions will gain twice the energy that singly charged ions will when being extracted or accelerated.

3.2.5. Analyzing the Beam

The path of any ion entering the analyzer magnet will be bent by the magnetic field. Lighter ions will bend more than heavier ions, as shown in Figure 3.21. The net effect is to fan out all of the different ion species. Selecting the correct magnet current will direct the selected ion species through the rotating mass slit. The rotating mass slit is an adjustable aperture spinning at 1700 RPM. This helps to prevent the ions close in atomic weight from traveling down the beamline. Heavier ions will not be turned enough to go through the mass slit; lighter ions will be turned beyond the mass slit. The selected ion species is directed through the slit and continues down the beamline.

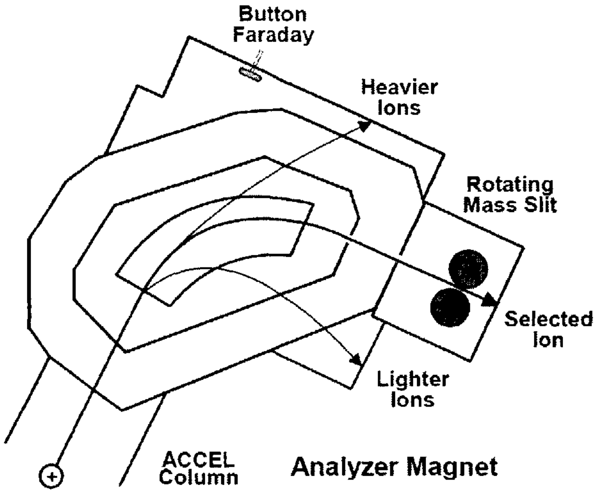


FIG. 3.21 – Ion path inside the analyzer magnet.

The basic equation used to calculate the correct magnet current is:

$$I = K\sqrt{\frac{mV}{a}}$$

Where:

I = current

K = constant. This is calculated for each species by the implanter prior to production.

m = mass of the species

V = total voltage applied to the ion

a = charge of ion (1, 2, or 3 for single, double, or triple charge)

3.2.6 Scanning the Beam

The deflection plates sweep the beam back and forth on the surface of the wafer distributing an even layer of ions into the wafer. There are many different techniques for scanning a beam across a wafer. We will discuss bipolar electrostatic scanning on the horizontal axis. In order to understand this technique we need to recall two basic principles discussed earlier: like charges repel each other and unlike charges attract each other and the greater the difference in charge the stronger they repel or attract.

For bipolar scanning two plates are used both of which have variable power supplies attached to them. If both of the plates, and were at 0 volts potential, the positively charged beam would have an equal attraction towards both plates. The beam would travel in a straight line between the plates. Once the beam is beyond the influence of the deflection plates it will continue in the same direction.

If a variable plate was set to a negative 1000 volts the positive beam would be attracted to the negative potential. The beam would be pulled in the direction of the variable plate. The greater the voltage the further the beam will move. Conversely, if a positive voltage is applied to the opposite plate, the beam would be repelled or pushed away from that plate, as in Figure 3.22. By placing opposite potentials on the two plates, the plates can work together to scan the beam horizontally.

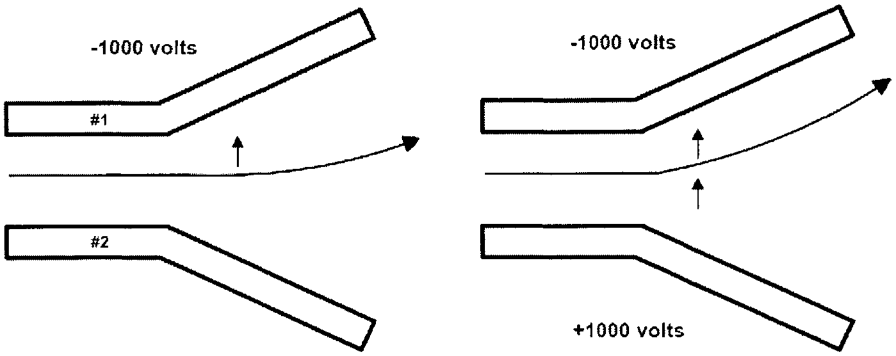


FIG. 3.22 – Differences on the beam path with different charges on the plates.

The variable plates in the VIISta 810XE are connected to power supplies that can change from -20 kV to +20 kV very quickly. Typically the supplies can be varied from positive to negative and back 1000 times each second (1 khz). The beam will be deflected from right to left each time the power supplies cycle. This is called scanning or sweeping the beam. A highly accurate control board is used to provide the signal to drive the deflector plates. The specific signals developed will vary based on the energy of the beam as well as the mass of the specie being used. Small changes can be made to the control signals to maintain horizontal uniformity of the beam.

3.2.7 Angle Correction

The purpose of *corrector magnet* is to adjust the direction of the beam so that it strikes all points on the surface of the wafer at 90 degrees when the wafer is in the normal position. For this discussion, normal position is defined as 0 degrees tilt.

The scanned (deflected) beam coming from the scan plates enters the corrector magnet at different angles. The scanned beam is swept continuously back and forth across the entrance to the corrector magnet. For clarity there are three points of entry shown in Figure 3.23; there are actually an infinite number of entry points across the scan of the beam.

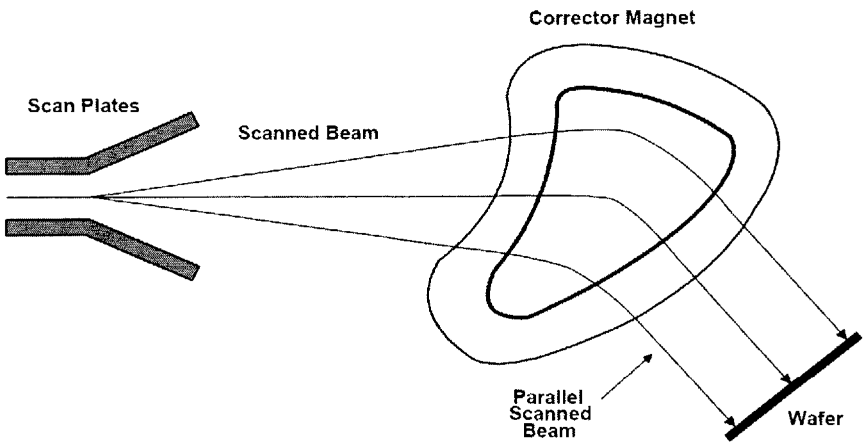


FIG. 3.23 – Scan plates and corrector magnet diagram.

In order for the ion beam to strike the wafer at an equal angle, it must exit the corrector magnet parallel across the scan. This parallelism is what ensures that the angle the beam will be implanted on the wafer is equal and therefore the effects of channeling are minimized. The VIISta 810XE beamline and corrector magnet are designed to bend the ion-beam to the right, and into the process (target) chamber where it impacts the silicon wafer.

Looking at the three lines drawn showing the beam entering the magnet, we can see that the amount of correction needed will be different from one side to the other. The beam entering the left side of the magnet will need to be bent further than the beam entering the right side of the magnet. The beam entering the middle of the magnet will need to be bent less than the left and more than the right. From our discussion about the analyzer magnet we know we can affect the direction of the beam using magnetic force. Using the Left Hand Rule, we can determine that the north pole of the magnet is on the bottom and south pole is on the top. The only key factor remaining is: how do we bend the beam different amounts across the horizontal scan?

The answer to the question is in the physical design of the corrector magnet. Looking at the illustration 3.23 we can see that the poles of the magnet are tear drop shaped. This shape causes the beam entering at the left side of the magnet to travel a longer distance through the magnetic field than the beam entering at the right side. The longer the beam stays inside the field the more it is affected. Therefore, the beam is bent different amounts as it is scanned from left to right and exits the magnet parallel across the entire scan. As we discussed earlier, the amount of current through the magnet will determine the field strength. Additionally, the energy of the beam as well as the mass of the species selected will effect the field strength needed. The current through the coils will therefore be adjusted for the specific gas and energy being used.

3.3. Implantation

With the beam horizontally sweeping and entering the *process chamber* at a constant angle, Figure 3.24, it must be uniformly implanted on the wafer. Several steps are taken for this to be accomplished.

The wafer is moved mechanically up and down through the beam to equally implant the ions across the entire wafer surface.

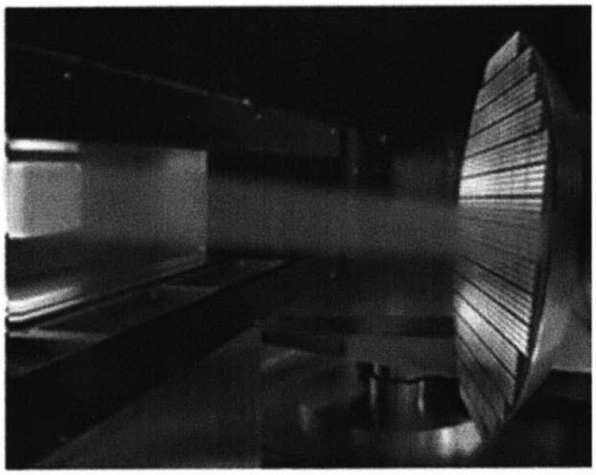


FIG. 3.24 -End Station: *inside the scan chamber.*

The *air bearing* is the mechanism that scans the wafer vertically. The air bearing is a shaft that rides on a cushion of air inside a cylinder. At the bottom of the shaft, in atmosphere, a specialized motor drives the shaft up and down with extreme precision. At the top of the shaft, in vacuum, the platen holds the wafer as it is scanned vertically through the beam. A vertical scan is one complete pass of the wafer up then down.

With horizontal and vertical scanning we can now distribute the beam across the entire surface of the wafer. The next concern is distributing the ions uniformly across the surface of the wafer. To understand how this is accomplished we need to understand several terms: dose, Faraday cup, and in situ. Dose is the measured accumulated beam that has been implanted into a wafer. A Faraday cup is a device used to measure the dose. In situ means "in the original place" or more simply put the place of origin.

3.3.1 The Dose Controller

The dose controller monitors and controls implant uniformity. Nonuniform results are usually caused by nonlinear problems in the deflector plate and the corrector magnet. Before beginning the implant, the *profiler Faraday* measures the horizontal uniformity. Corrections in the horizontal plane can be calculated on the controller and sent to the deflector plates.

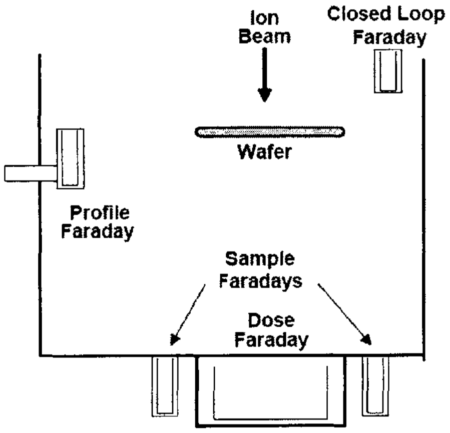


FIG. 3.25 – Process Chamber diagram

During each horizontal scan the dose is measured by the closed loop Faraday. This Faraday, mounted at the exit of the corrector magnet, can sense when the beam current fluctuates. If the beam current changes during implant, corrections need to be made to maintain the uniformity vertically across the wafer. The linear motor which drives the air bearing has an accurate positioning system which is fed into the dose controller. The dose controller maintains a table of the dose received during each scan of the beam. It can change the speed of the vertical scan to compensate for any deviation is detects. The dose controller has the ability to make corrections to the deflector plates as well as the linear motor with extreme accuracy.

3.3.2 Wafer Handling

There are several mechanical systems used by the end station to handle the wafers. These components are responsible for cleanly picking up, moving, setting down, and orienting wafers to be implanted. After being implanted the wafers are transferred back to the slot they came from. The elevators are used to hold cassettes of wafers and to provide an interface to go from atmosphere to vacuum. Wafers are brought in and out of the elevator by robot arms, Figure 3.26. The arms can load a wafer from any slot in the cassette, place it on the centering station, pick it up again and place it out on the wafer platen. After the wafer is implanted the robotic arm reverses the process and returns the wafer to the slot it came from.

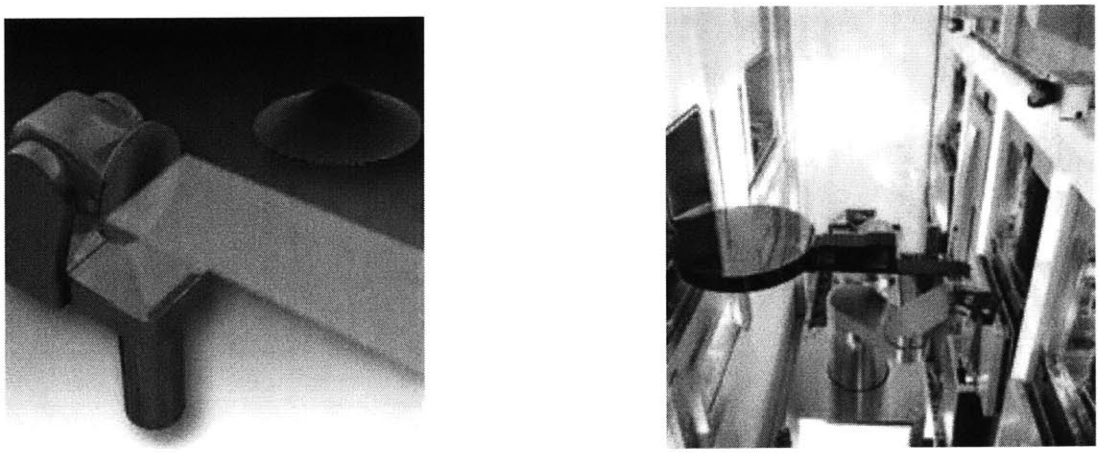


***FIG. 3.26 - Wafer Handling**: platen (left) and robotic arm (right).*

The centering station is used to orient the wafer before going to the platen. It first locates the notch or flat on the wafer and then aligns it so that it will be at the desired twist angle when it is placed on the platen. The twist angle is set in the recipe and is used to minimize any channeling of the ions as they are implanted into the silicon structure of the wafer. Additionally, the centering station determines the exact orientation of the wafer so that the robotic arm will place it precisely on the platen.

The platen is the device that holds the wafer during the implant. Once the wafer is placed on the platen by the robotic arm, the platen electrostatically clamps the wafer and rotates into the implant position. The x-axis motor is used to rotate the platen from the load to implant position. It can also be used to set the actual angle that the beam will hit the wafer. A second motor, the y-axis motor, is mounted on the bottom of the air bearing and can be used to tilt the platen during implants.

CHAPTER 4

THE FLOW LINE SHIPMENT PROGRAM

This chapter describes the revolution that Varian Semiconductor Equipment is pursuing with the Flow Line Shipment Program. After a brief discussion about the current manufacturing process, we present the intent of such a project, describing in different sections the benefits that both Varian and its customers can achieve by changing the manufacturing system.

4.1 The Actual Manufacturing Process

The current manufacturing process at Varian contemplates the following main steps for the production of the entire family of ion implanters:

- reception of the outsourced components;
- assembly and preliminary test of the three main modules by using:
  - terminal module flow line;
  - beamline flow line;
  - universal end station flow line;
- final assembly and test in the *clean room* area;
- disassembly and storage of the ion implanter in modules;
- shipment of the ion implanter to the customer;
- reassembly and test of the modules in the field.

To manufacture the ion implanters, Varian uses three dedicated flow lines in which several different components, outsourced to manufacturers all over the world, are assembled together. The production system is based on the modular manufacturing cell in which subassembly cells and the final assembly cell (the clean room) are linked by a pull system. The operations and processes are grouped according to the manufacturing sequence that is needed to make each module of the ion implanter. In each flow line the cells provide both subassembly and test operations in sequence. This arrangement is designed for flexibility, since the ion implanter demand is variable during the year. Moreover customers require hundreds of different customizations for their ion implanters: different number or size for the turbo pumps, for instance, or different components for particular and dedicated implantations. All these aspects require the manufacturing structure mentioned, to guarantee the right flexibility.

Each flow line is dedicated to one particular functional section of the ion implanter, in order to test the components through a step by step process. Since some checks and tests can be performed only by running the real beam, the implanter has to be assembled in a special room, where cleanliness can be achieved at a higher level than in the flow line. Moreover the so called "clean room" guarantees the highest level of safety for the employees, since the equipments used in this area allow to control toxic gases and exhausts and manage the high voltage necessary to the implanter.

Upon positive verification of the correct assembly through a series of vacuum and electronic checks, the implanter is subjected to hundreds of scan cycles with real beam and wafers, in order to verify the reliability of the machine and the accuracy of the result.

When the technicians state that the ion implanter is ready for the shipment, the machine is disassembled again in three main modules, which are cleaned and packed in special boxes for shipment and reassembly at a customer fab.

4.2 The Company Revolution

Managers and engineers are trying to lead the company to an important revolution in terms of manufacturing process, and this revolution is known as "Flow Line Shipment" at Varian. What everyone knows inside the company is the fact that the *clean room* represents a step in the manufacturing process, in which all the modules of the ion implanter are assembled together for the final tests; this step guarantees the achievement of the standard quality and reliability that customers expect from Varian, but, in terms of delivery time, it represents a large delay and consumes substantial resources.

What every company intends to do is reducing the cycle time without compromising the quality of its products, in order to optimize and increase the annual production; this is exactly what management at Varian wants to achieve. The ambitious project needs to review the entire production system, since every step in the chain needs to be adjusted and modified; in fact the pursued intent is to eliminate the clean room area in order to be able to ship all the components of the ion implanter directly from the flow line to the customer, without the actual necessary step of the final assembly. Of course the engineers are implementing several tests to be done directly in the flow line, even though at this step it is impossible to run the real ion beam. The challenge is to identify and implement additional tests and procedures to enable successful assembly at the customer site only.

Several teams together are currently reviewing supplier testing, module test, final assembly and final test procedures to determine the most efficient and effective way to achieve quality system shipments and efficient system installations for the customers, without assembling the entire ion implanter in the factory. Analyzing the actual manufacturing process, it has been found that:

- many final tests are redundant or can be performed at an earlier stage of manufacturing: the air bearing burst test and the vacuum and leak tests are some examples;
- assembly and disassembly of tools in final test can contribute to defects during installation;
- many alignments are currently made to run the real beam in the clean room for test purposes, but these are useless for the delivery of the equipment to the customer; in fact the ion implanter is disassembled after the final test and shipped to the field and, consequently, some of those alignments have to be performed again to the customer. An example is the alignment performed to assemble the beamline with the terminal module.

The Flow Line Shipment Project is conceived to guarantee that all factory testing is done earlier in the manufacturing cycle and all field assembly and testing is performed by experienced proven staff, following the sequent *Field Installation Plan*:

- on-site manager/coordinator;
- senior/experienced mechanics;
- senior/experienced technicians;
- manufacturing engineers;
- quality engineers;
- engineering onsite support if needed;
- fast response for parts.

For pursuing this kind of revolution, Varian is adopting a methodology that can be summarized in the following main points [8]:

- review internal and field failure data;
    - identify where additional testing and spare parts are required;
- develop internal protocols and test plans;
- adopt zero defect goal for all point-to-point transactions for the shipments;
- develop metrics to validate and measure success;
    - establish flowline tests to replace current methods;
    - verification of modified testing procedures;
- strategic initiative to improve quality of shipments from the Flow Line;
    - eliminate weaknesses and fully utilize strengths;
- transition plan for the actual production to the Flow Line Shipment;
- additional, more comprehensive supplier certification procedures.

4.3 Flow Line Shipment: Benefits for the Company

The most important benefits that Varian Semiconductor Equipment can achieve, by introducing the flow line shipment, are:

- lead time;
- gross margin;
- reutilization of the production area.

Varian's expectation from the project we mentioned so far, is to cut down a huge amount of production hours per tool, by eliminating the clean room area. The flow line shipment will affect positively the ***lead time***, which is the period between a customer's order and delivery of the final product. Manufacturers are always looking for ways to improve the lead time on their products, since it can mean the difference between making the sale and watching a competitor sign the contract.

In many markets, in fact, the ability to deliver sooner will win business away from competitors with similar product features, quality and price. Shorter lead time increases flexibility, reduces the need for inventory buffers and lowers obsolescence risk.

There is a direct relationship between lead time, inventory investment, and customer service. Reducing lead time can increase customer service with the same inventory investment or allow to reduce inventory with no decrease in service. Or even better, with a significant lead time reduction, a company can reduce inventory and improve customer service at the same time.

Late delivery not only invariably means that there is more waste than necessary, but also usually results in expediting, excess inventory on hand to cover against untimely production, excessive overtime, low resource utilization, and high costs. But how can superior delivery improve profitability for Varian?

There are two aspects to superior delivery: the first involves keeping delivery commitments, or delivering product to customers, internal or external, when promised; the second involves keeping lead times, or the time between receipt of a production requirement and its delivery, at a minimum. Of the two aspects of delivery, short lead times provide the most leverage. Varian Semiconductor Equipment can use lead-times that are shorter than the competition's to generate large increases in profitability. First, the manufacturer can use the short lead times to generate increased sales, both in industrial and consumer marketplaces. Second the company can use the short lead times to drive down its costs [9].

Shortened lead times can also result in drastically reduced manufacturing costs. The best way to understand the relationship between short lead times and low costs is to break lead time up into its segments: set up time, process time, queue time, and move time. During the process time segment of lead-time, a company is transforming components or raw material and bringing them closer to their final shippable state. Only during the process time segment is a company adding value. If a manufacturer has inventory in house and is not adding value to it, it is incurring cost. Therefore, each lead-time segment, other than process time, costs money. Table 4.1 highlights these costs:

LEAD TIME	**GREATER COST FROM**
Set Up Time	• Increased overhead • Decreased machine utilization • Decreased labor productivity • Forcing increased queue time
Queue Time	▪ Lost opportunity cost of capital ▪ Greater quality problems ▪ Obsolescence ▪ Greater space requirements ▪ Taxes
Move Time	➢ Increased material handling

TABLE 4.1 – Lead Time components and costs.

Set up time increases costs due to the cost of the people and equipment to perform the set up. Set up time also results in lost machine utilization; typically when a machine is in a set up condition, it is not manufacturing product. When too many machines are in a set up condition, operator productivity decreases. Finally, when a machine is being set up, work is usually queuing up in front of it, building inventory.

Queue time increases costs because material waiting in queue ties up investment dollars that could otherwise be put to more productive use. Also, material waiting in queue ages, often deteriorates, runs the risk of becoming obsolete, consumes valuable floor space, and is often subject to tax.

Move times increase cost because the act of moving product requires people, equipment, and floor space for clear passageway. Like queue time, move time also adds inventory carrying and obsolescence costs. In addition, moving product increases the risk of damage.

It should be clear that reducing lead times could increase sales and trim costs. However, smart manufacturers only spend precious time and resources on activities with large payback. How much benefit can be gained from aggressively shortening lead times? It is impossible to state how much shortened lead times increase sales.

Much depends on the marketplaces in which individual companies are active. However, it is safe to say that the more competitive the industry, the more shortened lead times will help. In competitive industries, short lead times will differentiate a company from its competitors, leading to increased sales. If Varian can cut the largely wasteful time product spends sitting or moving, it can also reduce work in process inventory. In many environments, reductions in work in process can have an immediate and significant impact on costs and profitability.

Since a better lead time drives down the manufacturing costs, with the Flow Line Shipment Varian is trying to improve its ***gross margin***, which reveals how much a company earns taking into consideration the costs that it incurs for producing its products and/or services. VSEA Inc., in particular, has the business objective of increasing its gross margin, which could enable it to have more money to spend on other business operations, such as research, development or marketing.

The other important result that can be obtained from the Flow Line Shipment is the ***reutilization of the space*** currently dedicated to the clean room. The wide surface can be converted into warehouse space and area for demonstrative tests for customers, without facing the current concern about the necessity of a new building, considering the growth of the ion implanters demand.

4.4 Flow Line Shipment: Benefits for the Customers

The Flow Line Shipment program translates into quicker time to the first production wafer for the customers, enabling them to achieve a higher rate of return on their capital investment through a quicker time to volume production. Varian's advanced flow line manufacturing process, with the use of emulation software, permits full system level testing at the modular manufacturing cell.

This means that no additional time is lost for customer personnel to travel to and from VSEA to complete Factory Acceptance Testing, thereby eliminating travel expenses, while installation time remains unchanged.

The Flow Line Shipment Program not only has the expected customer benefits of faster equipment installations and quicker time to volume production, but also will meet the customers' needs for:

- lower cost of ownership;
- improved high quality assembly performance;
- faster time to market.

Since assembly and disassembly of tools in Final Test could contribute to defects during installation, shipments from the Flow Line allow to contain them and to increase the quality of the product, toward the final goal of zero defect production. Inferior quality for a company usually results in extra inspection, sort and rework activities, excess inventory on hand to cover quality losses, production delays due to missing components, low resource utilization, and inevitably in higher costs of the final product for the customers. Moreover, the reduction of the hours required to perform redundant tests inside the clean room can be redirected to increase the time dedicated to particular and crucial tests in the flow line; the flow line shipment can allow, in fact, Varian to increase, for instance, the time dedicated to the test for the mechanical throughput of the end station, by increasing the cycle test and the argon beam run time into button faraday during the flow line test.

Time to market (TTM), the length of time it takes from a product being conceived until its being available for sale, is one of the most important aspects for each company; VSEA with its new shipment program can contribute to a faster TTM for its customers. A rapid time-to-market is important for the competitive success of many companies for the following reasons:

- Competitive advantage of getting to market sooner;
- Premium prices early in life cycle;
- Faster breakeven on development investment and lower financial risk;
- Longer market life cycle; and
- Greater overall profits and higher return on investment.

Achieving the reduction of lead time at Varian allows faster equipment installations, which enables VSEA customers to release the implanters more quickly into volume production, getting to the market in time and therefore improving their profits. Research, in fact, show that on average, for every month a product is late to market, it will lose 10% of its gross profit potential [7].

CHAPTER 5

PROBLEM STATEMENT

The following sections describe the problem faced in this thesis. An overview introduces the context of the project; section 5.2 reviews the current final assembly process inside the clean room area in order to understand how Varian performs this important step. Finally, section 5.3 presents an overview about the idea to solve the problem and section 5.4 details the project plan and the time line followed to understand, analyze and address the issue.

5.1 Problem Overview

The ambitious Flow Line Shipment project requires review of the entire production system, since every step in the chain needs to be adjusted and modified; in fact the pursued intent is to eliminate the clean room area in order to be able to ship all the components of the ion implanter directly from the flow line to the customer, without the actual step of the final assembly.

Among software, electrical and mechanical concerns in pursuing the revolution that we mentioned before, our work examines one of numerous mechanical problems that Varian is facing inside the Flow Line Shipment project. In a manufacturing process in which the final assembly of such a sophisticated machine is a step that has to be avoid and in order to reduce the cycle time and the delivery time to the customer, the correct alignment of subassembly components becomes a critical aspect and needs to be checked before the shipment, since assembly errors or out of specifications components from suppliers, may lead to huge delays and reworks. This last aspect cannot be ignored, since if adjustments and modifications can always and quite easily be accomplished in the flow line without conspicuous waste of time, the same cannot be said in the field, where customers want to install their equipment, thousands of miles away from the factory. Varian has not faced these challenges before, since the final assembly in the clean room could point out eventual problems which could be solved in the flow line or, generally, directly in the Varian clean room itself.

5.2 The Actual Assembly Process

The terminal module and the beam line module are assembled together through the acceleration column which links the source chamber inside the terminal with the analyzer magnet of the beam line (Figure 5.1).

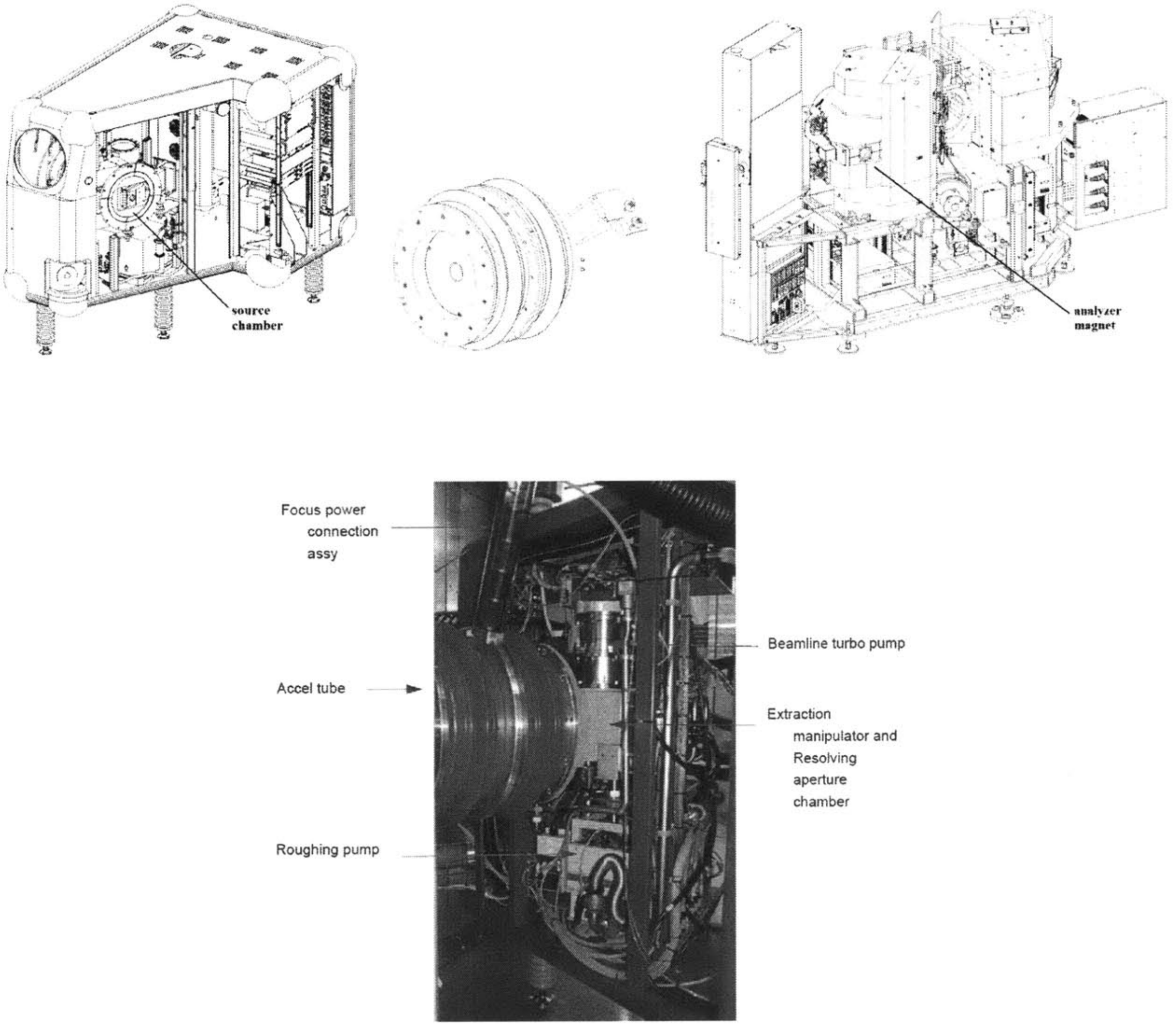


FIG. 5.1 – Components of the Ion Implanter: *from the left we can see the terminal module with the source chamber, the acceleration column and the beamline module.*

Technicians at Varian follow a rigorous procedure to lay down the ion implanter for the final assembly in the field and in the clean room. This procedure locates the heavier beamline module firstly and the adjustable terminal module second. The schematic procedure to lay down the modules are summarized in the following steps [10]:

1. *BEAMLINE LAY DOWN*

a) Gather tools and fixtures;
b) Prepare module for moving from flowline;
c) Move beamline assembly;
d) Locate laydown and alignment marks on fab floors: the position of the feet is constrained by an aluminum floor in which there are holes which locate this position at its nominal value (see Figure 5.2).

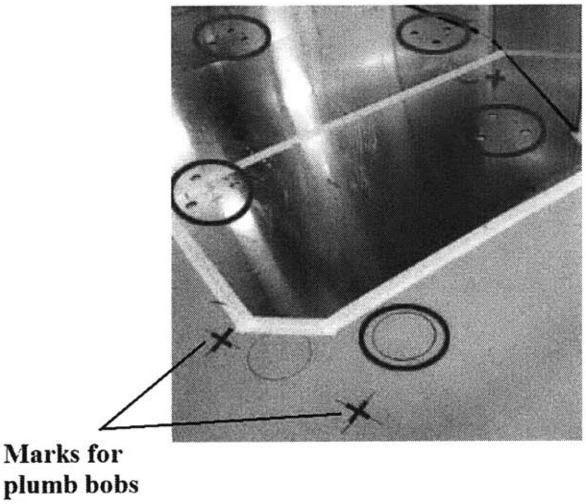


FIG. 5.2 – The Aluminum Floor: *inside the enclosure marks and holes locate the position of the beamline.*

e) Place beamline module on the aluminum floor;
f) Level corrector magnet;
g) Align with floor markings as shown in Figure 5.3;

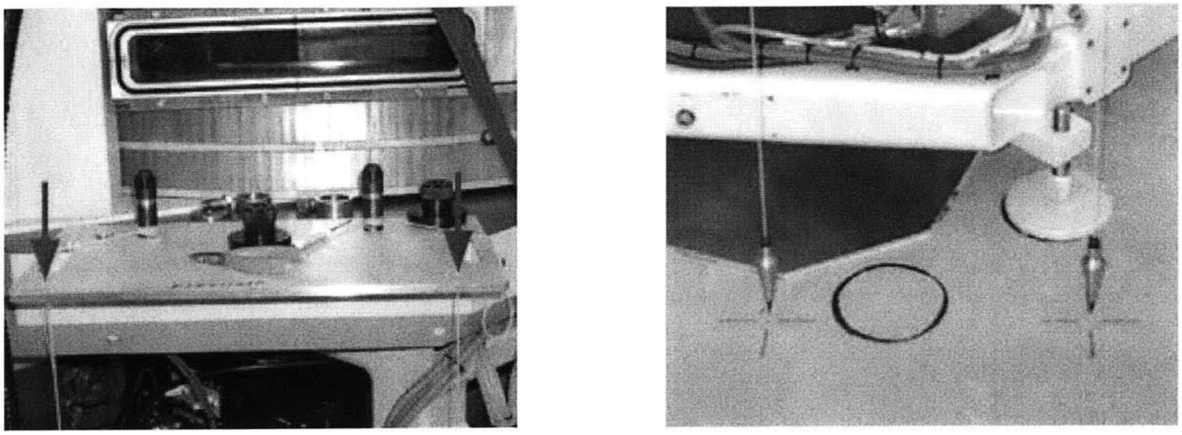


FIG. 5.3– Beamline Alignment: *from the left we have the alignment plate with plumb bob locations and floor marks with plumb bobs.*

h) Find height of corrector magnet waveguides;
i) Recheck alignment and level;
j) Perform laser alignment between the analyzer and corrector magnet to achieve the correct orientation of the two parts;
k) Recheck laser alignment;
l) Remove and return fixtures.

2. TERMINAL MODULE LAY DOWN

a) Locate the equipment;
b) **Position terminal and set insulator feet height:**
  i. **pull terminal onto aluminum floor and maneuver it into position;**
  ii. **use a pry bar, if necessary, for small adjustments;**
  iii. **locate each insulator over its matching bolt pattern marked on floor as shown in Figure 5.4;**
  iv. **preset and adjust the insulator foot heights;**
c) Return tools and fixtures.

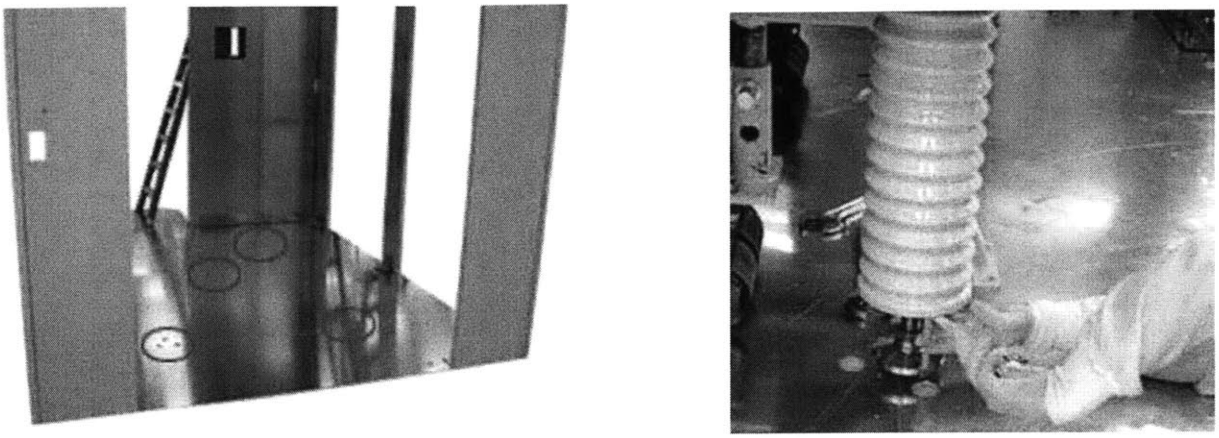


FIG. 5.4 – The Enclosure: *lay down areas on the left and sloped foot on the right.*

3. ACCELERATION COLUMN INSTALLATION

a) Purge and inspect the acceleration column;

b) Install and prepare coupling;

c) Join acceleration column to source chamber;

   i. Adjust the height of the acceleration column by cranking the cart handle;

   ii. Rotate the column to align the pins on the column with the holes on the outside of the source;

   iii. Install and tighten the screws with the pattern shown in Figure 5.5;

   iv. Make any adjustments required per the source to analyzer alignment procedure;

d) Join acceleration column to analyzer magnet;

e) Checks;

f) Remove or adjust alignment fixture.

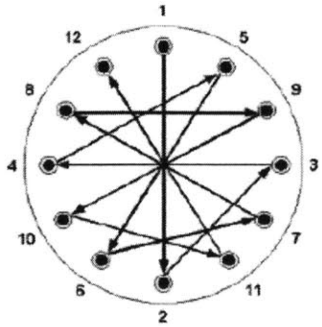


FIG. 5.5 – Acceleration Column-Source Chamber Assembly: *alterating star pattern.*

5.3 The Idea

The last third step requires one to adjust the orientation and position of the source chamber inside the terminal to assure the correct alignment between the terminal and the beamline module through the acceleration column and, only when the assembly cannot be achieved by doing that, technicians move slightly the terminal frame. Eventual further adjustments of the terminal position inside the enclosure might result in to a sloping position of the insulators (legs of the terminal module), as shown previously.

Inside the Varian clean room, the mechanical assembly can be checked and eventual problems solved, but in the Flow Line Shipment context this represents a big issue, since out of specification parts, due to production errors for instance, may produce misalignments which make the final assembly impossible.

In the context mentioned so far, it is pretty clear that at Varian technicians and engineers are interested to find a way to easily check the correct alignments of their subassemblies, in order to be sure to quickly solve eventual problems before the shipment to the field of the entire machine.

Looking at the whole problem, our task is to get the right orientation of the source chamber in relation to the position of the feet that may vary their displacement to match the marks on the field floor.

The idea is to realize a fixture which could relate the position and orientation of the source chamber with the position of the feet of the terminal module. Firstly, our intent is to check if the position of the feet are inside the project tolerances for the terminal module, and secondly we want our fixture to locate exactly the source chamber with respect to these feet. Our idea would allow technicians in the flow line to check if the source chamber can be rightly positioned and oriented with respect to the feet, in order to make appropriate adjustments to the subassembly, before shipping the terminal module to the field. Obviously the same will be done in the future for the beamline module; by doing so Varian could verify if its components can be assembled without mechanical problems to the customer and without having assembled the ion implanter before.

What our fixture should answer:

- Are the positions of the feet in tolerance?
- Can the source chamber be adjusted in its orientation and position with respect to the feet, in order to match the project requirements for the final assembly?

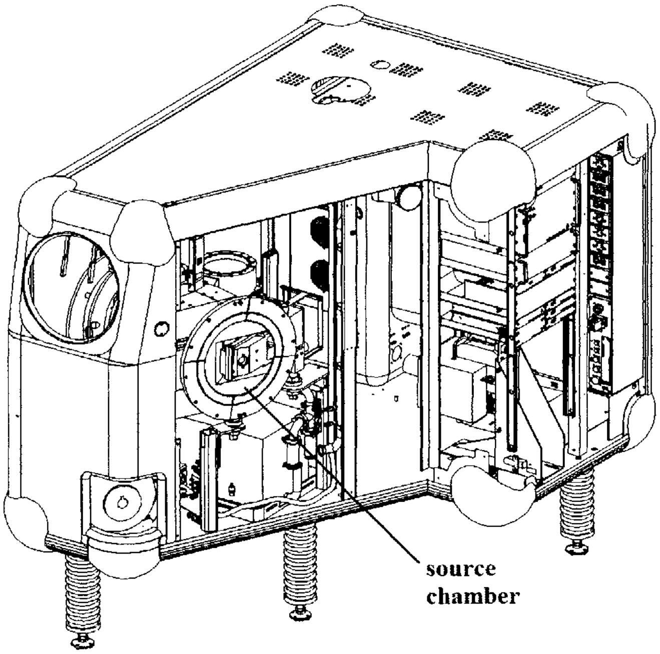


FIG. 5.6 – Terminal Module: *the source chamber links the terminal module with the acceleration column.*

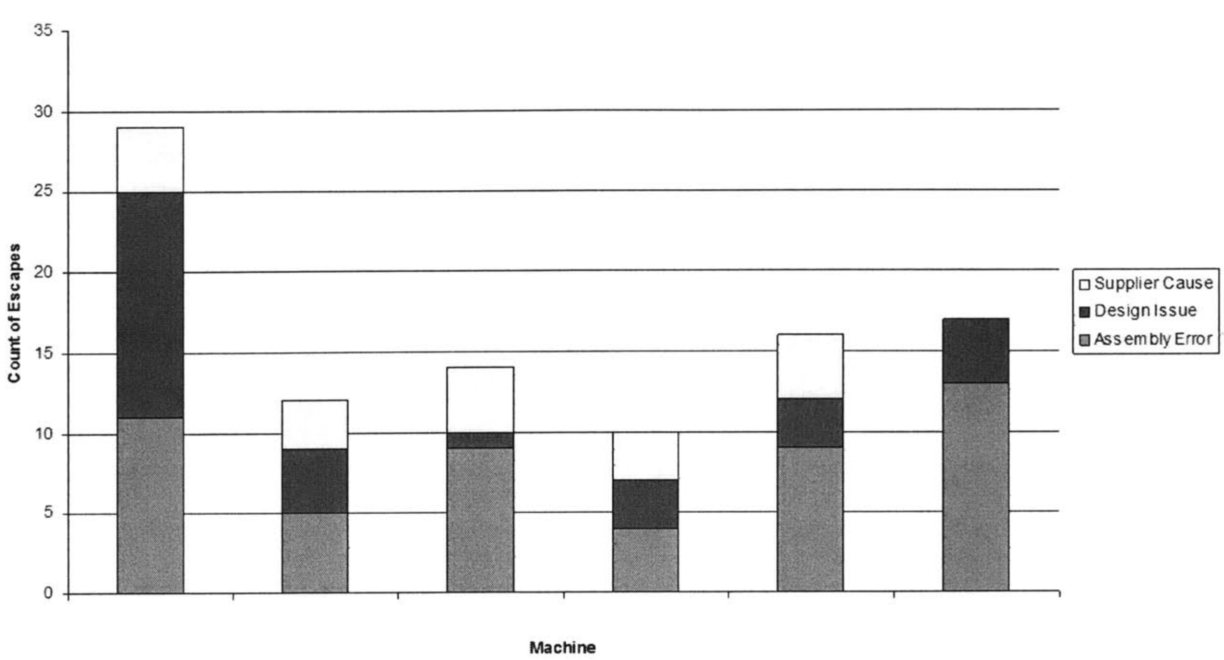


FIG. 5.7 – Counter of Escapes.

As we can see from Figure 5.7 [8], the assembly errors heavily influence the time needed to complete each single machine. The intent of our fixture is to reduce these errors in order to meet the goals (gross margin improvements) set by Varian, which the flowline shipment is a part of.

5.4 Project Plan and Time Line

The planned project tasks and time line used to complete this effort are shown in table 5.1. As of the completion of this thesis (late august), the fixtures are being prototyped and produced.

<table>
<tr><th>Task</th><th colspan="3">Date</th></tr>
<tr><td>Understanding the global manufacturing process by spending one week in each flow line and in the clean room.</td><td><i>May:</i></td><td colspan="2">1st week Terminal Module flow line
2nd week Beam Line flow line
3rd week End Station flow line
4th week Clean Room</td></tr>
<tr><td>Understanding the Flow Line Shipment Project by participating at meetings with technicians, engineers and managers in the mechanical department.</td><td><i>June:</i></td><td colspan="2">1st and 2nd week</td></tr>
<tr><td>Analyzing the mechanical subassembly of the terminal module: procedure and tools.</td><td><i>June:</i></td><td colspan="2">3rd week in the flow line</td></tr>
<tr><td>Analyzing the terminal lay down and the final mechanical assembly: procedure and tools.</td><td><i>June:</i></td><td colspan="2">4th week in the clean room</td></tr>
<tr><td rowspan="2">Fixture designing and feedback collection from the mechanical department</td><td rowspan="2"><i>July</i></td><td><i>Matte Liscaio</i></td><td><i>Simone Guerra</i></td></tr>
<tr><td>Jig Design
(CHAPTER 6)</td><td>Fixture for Source Chamber Alignment
(CHAPTER 7)</td></tr>
<tr><td>Fixture prototyping.</td><td><i>August:</i></td><td colspan="2">1st and 2nd week</td></tr>
<tr><td>Fixture production.</td><td><i>August:</i></td><td colspan="2">3rd week</td></tr>
</table>

TABLE 5.1 – Project Time Line.

CHAPTER 6

JIG DESIGN

The following chapter describes the design process of the fixture starting from a general idea through completion of approved detailed engineering drawings.

6.1 Design Process

There are a multitude of devices used to ensure the objects we build are true and square. These come in many forms and can be a simple straightedge or a complicated trussed assembly that is as much of a project as the object it is used to align. In our case the fixture is in the middle. It is not as simple as a straightedge nor complex as a trussed assembly, but is the outcome of a design process that starts from a need and yield a product easy to build and to use in order to achieve the purpose of its realization. Our specific goal here is to design a fixture to align the Terminal Module and the Beamline through the Accel Column in the easiest possible way.

We can summarize our design process as shown in Figure 6.1. Each of these steps will be discussed in details further.

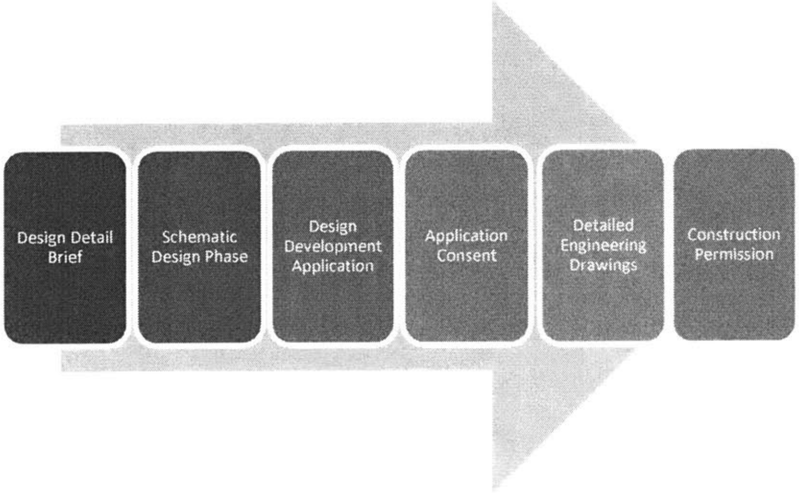


Fig.6.1 *– Design process*

6.2 Schematic Design Phase

After a first stage, as shown in the Figure 6.1 above, where the project is described briefly, the second step is a schematic design phase where the basic idea of the fixture is carried out in a rough 3D model.

Our concept in the early stages of the design process was to grab the legs of the Terminal Module (Insulators), shown in the Figure 6.2 by red arrows, using aluminum tubes trussed with aluminum beams (Figure 6.3).

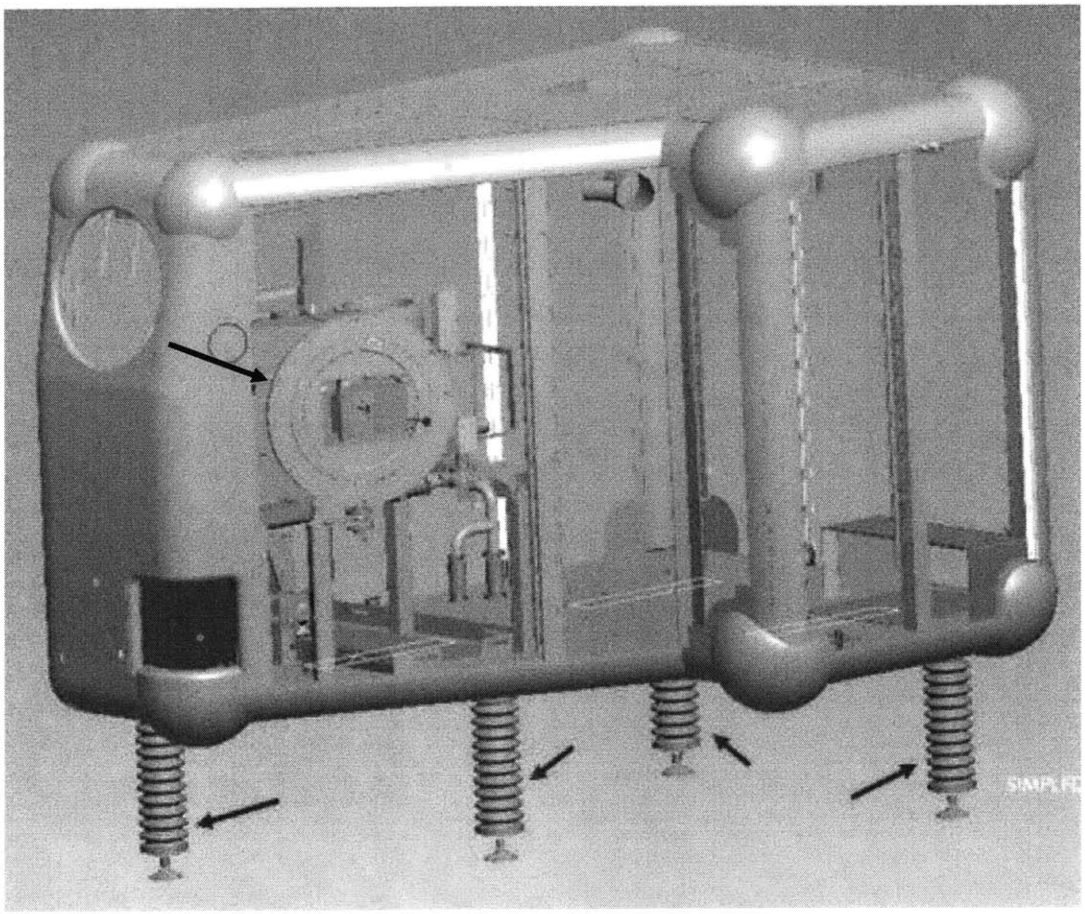


Fig.6.2 *– Terminal insulators*

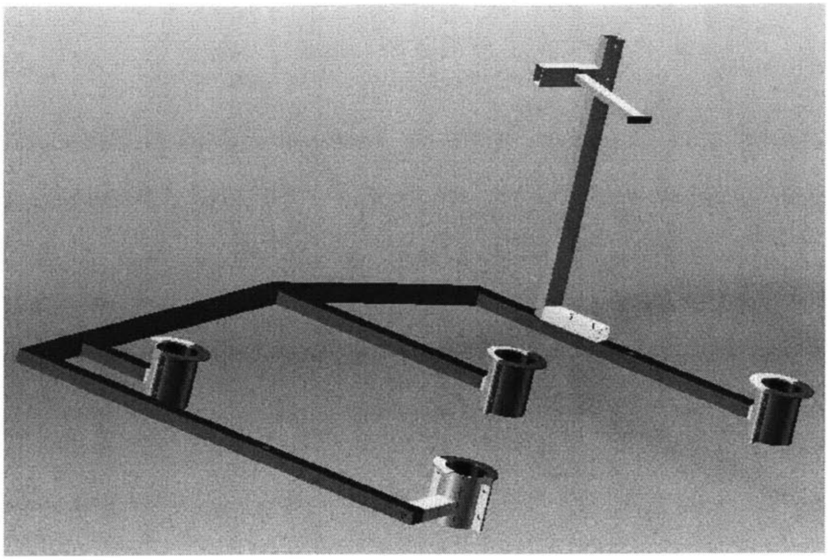


Fig.6.3 – Fixture first release

In this way we could check the position of the legs in relation to the position of the Source Chamber (black arrow, Fig. 6.2). In fact the red and grey tubes could grab the insulators of the terminal module and put them in the nominal position respect to the frame of the terminal and guarantee the perpendicularity of the legs through the flanges at the top of the tubes that grab the insulators, as shown in Fig. 6.4.

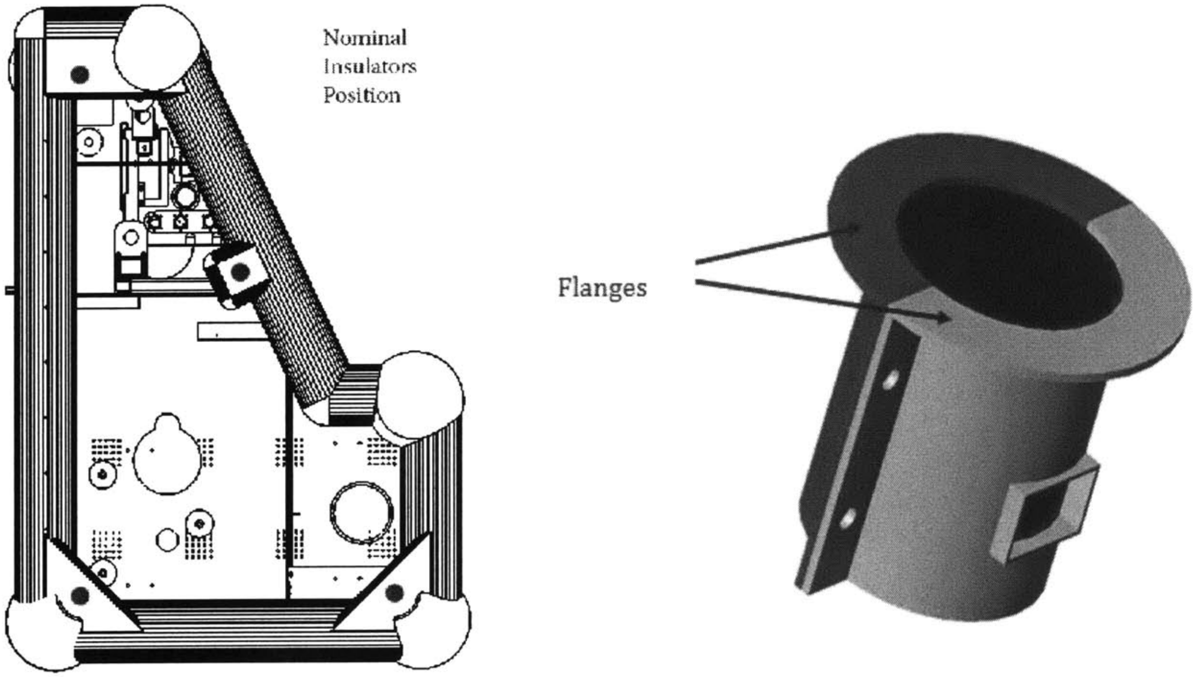


Fig.6.4 – Insulators nominal positions and flanges

The tolerances on the dimension of the insulators and on the position of the holes, where the legs are screwed into, could be absorbed by a layer of rubber stuck inside the tubes.

6.3 Design Development Application/Consent

With this basic idea on how to check the position of the legs, once they are located on the related holes into the frame (red spots in Figure 6.4), we moved forward into the sequent steps of the process design that, as shown in Figure 6.1, consist in the Design Development Application/Consent.

It was at this stage, reviewing the first model assembled together with the Terminal Module that two major concerns came out:

1) The company that is producing the insulators has a very loose tolerances on the dimensions, and this means that even if we could set the head of the legs in the right position this does not automatically result in the bottom of the legs matching with the position of the holes into the field's floor;
2) The solution of grabbing the insulators by flanged tubes is very hard to manufacture.

In fact, suppose we put the feet of the terminal Module onto the related holes into the floor. If, as shown in Figure 6.5, the holes at the head and bottom of the legs are misaligned during the terminal lay down [10], in order to match the holes on the floor, the legs must be slanting as seen in Figure 6.6

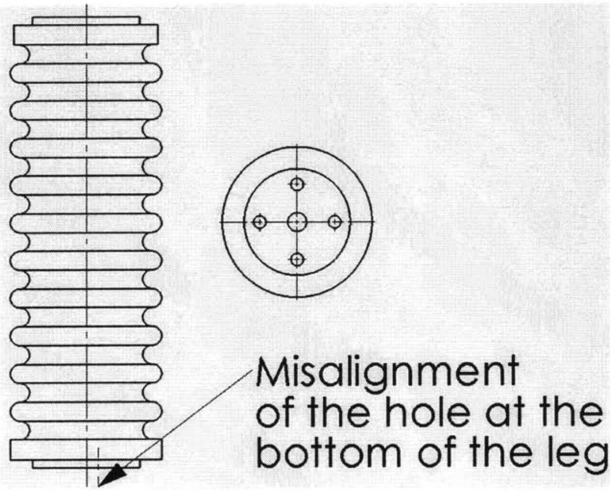


Fig.6.5 – Insulators misalignments

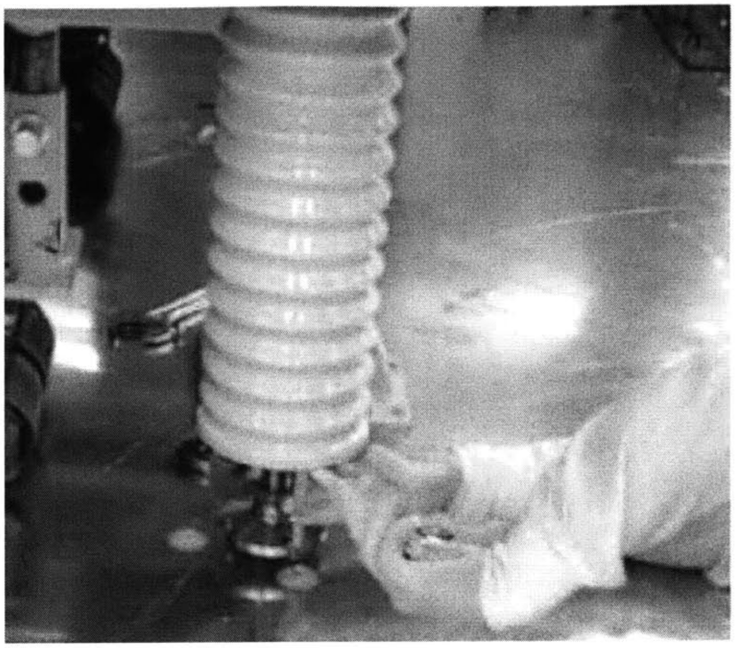


***Fig.6.6** – Insulators slanting*

Thus, even if the source chamber will be perfectly positioned inside the Terminal Module frame, it might turn out to be impossible to automatically assemble together the Terminal and Beamline [11] through the Accel Column without further and time wasting adjustments of the Source Chamber first (inside the Terminal) and of the Terminal itself by moving the insulators until we reach the desired assemblage's position.

Moreover, the fixture has an overall dimension that is around 7 to 8 feet in width and 5 feet in length. With the design that seeks to grab the legs of the Terminal at the top of them, taking into account all the tolerances, the intrinsic manufacture variability in going from the 3D model to the real prototype and the difficulty of welding together the flanged aluminum tubes with the beams that are the framework of the fixture, it becomes almost impossible, with a standard manufacturing process, to realize the fixture itself with the desired precision.

At this stage before passing to the Application Consent and the following Detailed Engineering Drawings we had to change the way we check the position of the insulators using the better understanding of the project gained so far but without change to the solution of checking the position of the source chamber related to the legs that still remained successful.

What we thought at the time was to focus our attention on the position of the holes at the bottom of the insulators where the feet are supposed to be screwed in, as illustrated in Figure 6.7.

Fig.6.7 – Insulator and foot assembly

We see that since the lay down procedure for the Terminal has, as a first step, to put into the right position the feet onto the field's floor, we can determine the position of the feet (through the hole at the bottom of the leg where they are screwed) using the new alignment fixture and, playing with the alignment of the holes in the frame module, (where the legs are connected to the frame), we can adjust the legs. In this way the fixture will give always the right orientation of the source chamber with respect to the position of the feet, and will allow assembling together the Terminal, Beamline and Accel Column without wasting time moving the terminal in the right position. The fixture shown previously now has changed resulting in the design shown in Figure 6.8.

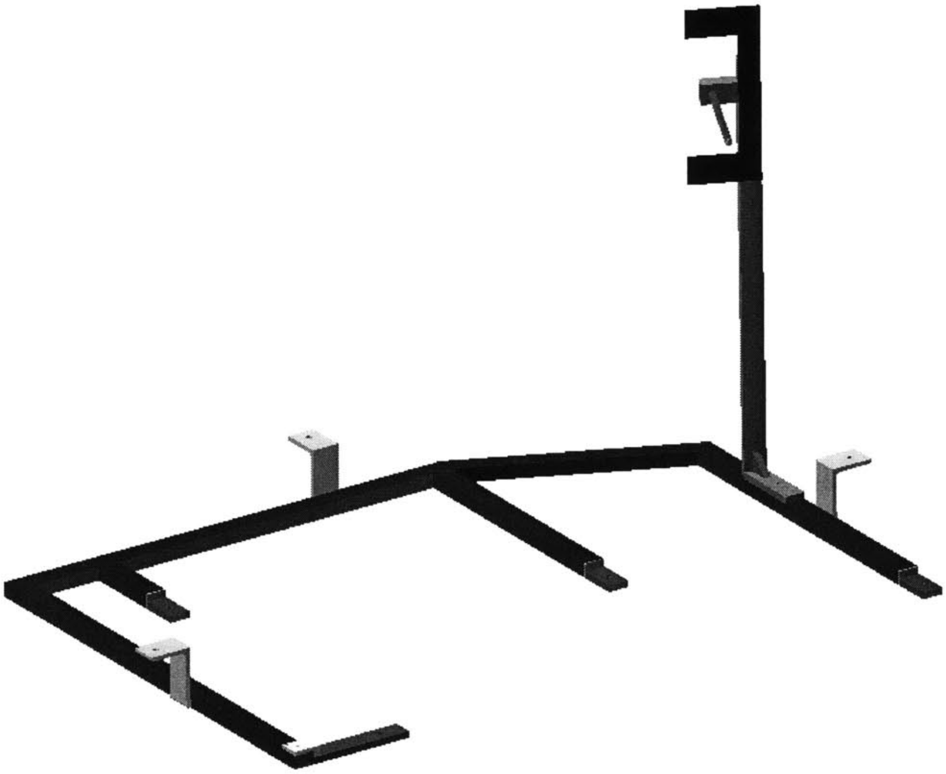


Fig.6.8 *– Second release fixture*

As we can see, the tubes that were grabbing the insulator have been eliminated are replaced by four beams with a hole where will be placed a pin that, when screwed into the bottom part of the legs, will force them to go into the right position once the fixture has been installed. The position of the source chamber will be checked using two lasers, placed on the source chamber and shooting into two targets placed into the black plate at the top of the vertical green aluminum beam as shown in Figure 6.9. While the upper target is a cross, to define the position both in the horizontal and vertical directions, the lower target has just a vertical bar to control only the horizontal alignment of the source chamber.

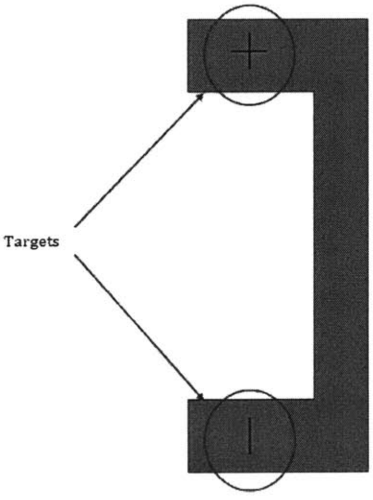


Fig. 6.9 *– Fixture's Target*

With two lasers shooting on this target we can control the vertical and horizontal orientation of the source chamber but we still need to check the position in depth inside the

Terminal frame. For this purpose we can notice a black PVC rod, Figure 6.8, that, going out from the vertical green beam of the fixture, is supposed to touch the surface of the source chamber; this should assure the correct position in depth.

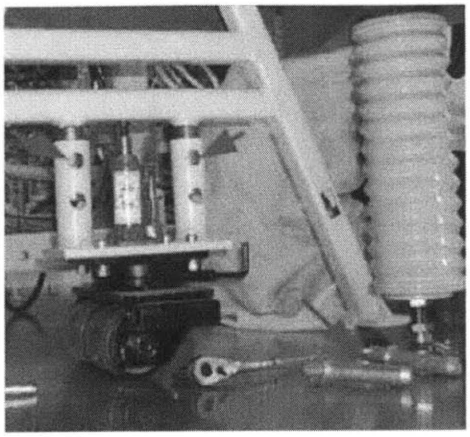


***Fig. 6.10** – Platforms underneath the terminal module*

While the Terminal Module in the flow line is always heightens from the floor with three yellow platforms that allow moving easily the terminal during the working process. The positions of these platforms underneath the terminal are shown in Figure 6.10 – as the yellow outlined box. These deeply influence the design of the fixture, as the fixture must to avoid the platforms leaving the necessary working space for the personal at work on the machine, considering also the space constraint in the flow line itself.

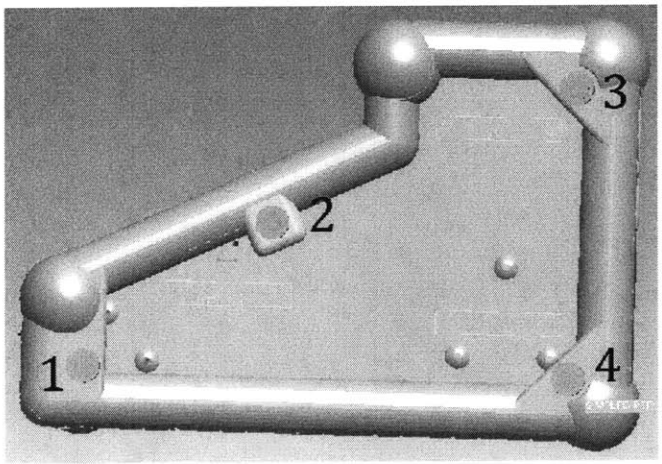


***Fig. 6.11** – Insulator numbers*

If we number the position of the legs as shown in figure 6.11 we can see that we need, for the fourth leg, an extractable beam to check the position of the hole at the bottom of the leg.

Fig. 6.12 – Extractable beam

As in Figure 6.12, the chosen design consists two beams assembled together by two dowel bullet pins that locate the position of the red beam (that carry the hole where will go the pin screwed into the leg of the terminal) and one bolt. When the fixture is positioned underneath the Terminal in the right position the operator will just screw the beam in with a particularly easy operation. Moreover to allow the movement of the fixture into the flow line even under the Terminal, the jig has been provided with three swivel wheels that give a complete range of movement to the jig. The wheels are connected to the fixture through three standard aluminum structural L-angle where have been made threaded holes to allow the operator to move up and down the fixture using a standard wrench at the top of the threaded rod, as illustrated in Figure 6.13.

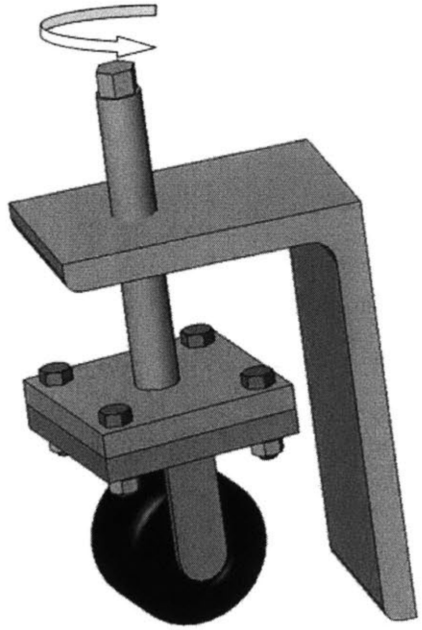


***Fig. 6.13** – Fixture's wheel*

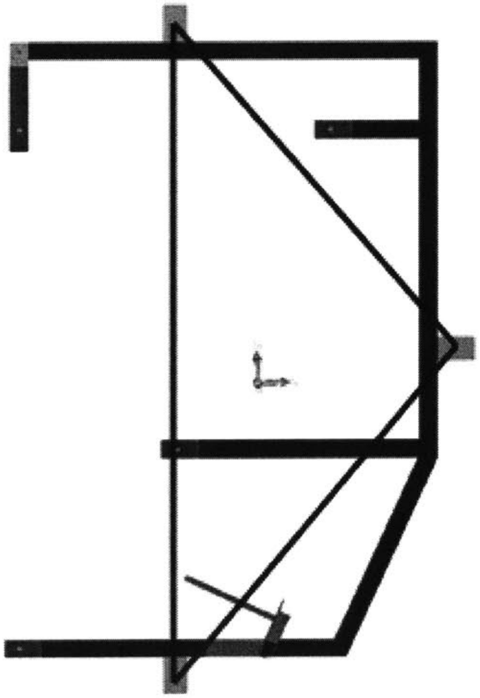
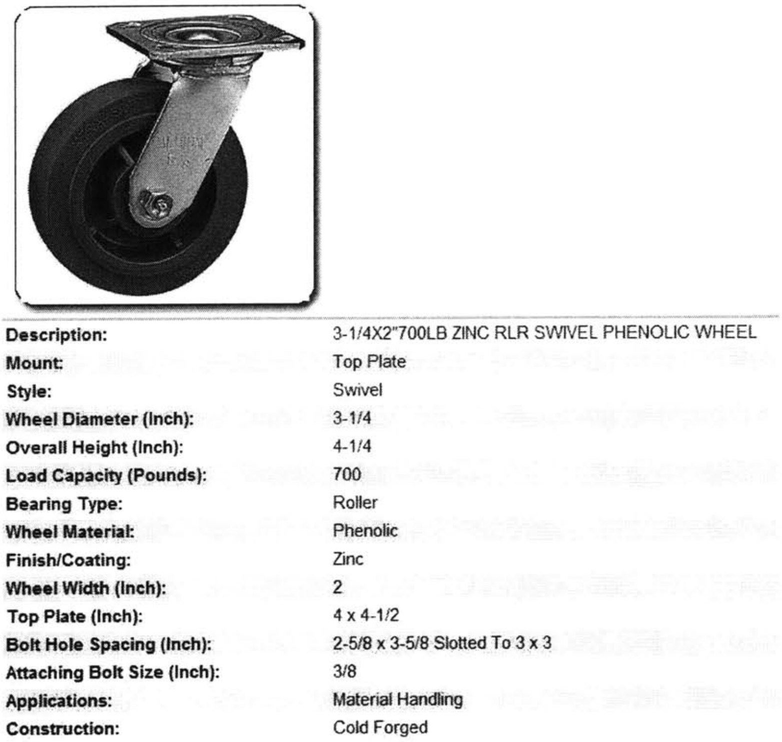


***Fig. 6.14** – Fixture's center of mass*

The stability of the fixture is guaranteed by checking the position of the center of mass [13]. As we can see in Figure 6.14, this is inside the polygon made by linking together the holes on the structural L-angles that support the threaded rod of the wheels. Another detail that has been taken into account, for safety reasons, is the load capacity that the wheels can support. An estimate of the weight of the fixture is around 81 pounds but the wheel chosen can support a load capacity of 700 pounds, as summarized in Figure 6.15, [12].



Description:	3-1/4X2"700LB ZINC RLR SWIVEL PHENOLIC WHEEL
Mount:	Top Plate
Style:	Swivel
Wheel Diameter (Inch):	3-1/4
Overall Height (Inch):	4-1/4
Load Capacity (Pounds):	700
Bearing Type:	Roller
Wheel Material:	Phenolic
Finish/Coating:	Zinc
Wheel Width (Inch):	2
Top Plate (Inch):	4 x 4-1/2
Bolt Hole Spacing (Inch):	2-5/8 x 3-5/8 Slotted To 3 x 3
Attaching Bolt Size (Inch):	3/8
Applications:	Material Handling
Construction:	Cold Forged

***Fig. 6.15** – Wheels description*

The beam supporting the target with the two marks, where the lasers are shooting, is removable; this has been done for two main reasons:

1) To allow an easier storage of the jig while unutilized;
2) To improve the precision, during the building stage of the fixture, of the position of the target at the top of the green vertical beam (as seen in the picture of the jig in Figure 6.8).

In fact, the position of the target, on the jig, is determined by two pins that locate the bar and by one bolt. Whereas the screw hole that locates the bolts will be made in the early stages of the assembly, the positions of the two pins will be established only at the end of the assembly by drilling two holes exactly in the right position in order to compensate for tolerances and misalignment that we might face at the end of the assembly, and thus guarantee the wanted position of the target on the jig as the detailed view of Figure 6.16.

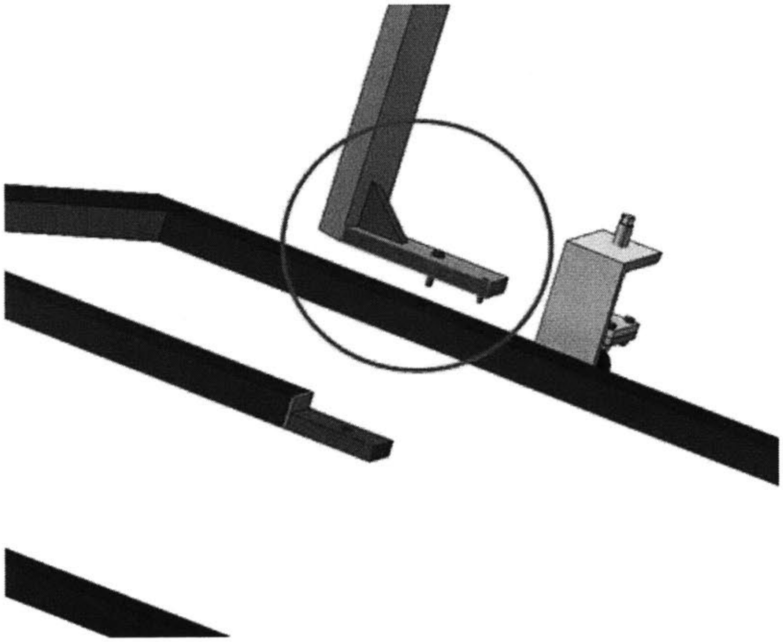


***Fig. 6.16** – Vertical beam assembly*

6.4 Detailed Engineering Drawings

Once the idea has been approved (obtaining consent to go ahead), the next step was the Detailed Engineering Drawings as noted in Figure 6.1. In this stage all of the engineering details were carried out through specific drawings and reviewed with other designers in a multitude of meetings. During this stage have also been made changes in the design itself in order to achieve a better manufacturing process of the fixture.

As seen in Appendix B, the template (first sheet) of the engineering drawings is supported by a Bill of Materials where each components of the jig is presented with the relevant details such as Material, Quantity, Description and even Vendor's Name and Code when needed. The role of the template is to show the overall assembly of the object, in addition to providing the description of each single component through the BOM (Bill of Material); moreover this also shows notes on how to paint the jig and on how to build some details of the fixture itself.

The second sheet of the engineering drawings shows all of the geometric and linear tolerances of the overall assembly. These are needed to:

3) Define the position of the hole where the pins (screwed into the insulators) will be placed;
4) Give the tolerances for the planarity of the beam with the holes where the pins (screwed into the insulators) will be placed;
5) Give detailed information on the tolerances and position of the target in the fixture;
6) Give the position of the main components of the fixture.

Finally, the third and fourth sheets give the details of each single component of the fixture, allowing the operators to build all the part of the fixture. In the design process each single part has been designed with the intent of making the manufacture process as simple as possible, starting from standard part easily available in the market or even available inside the inventory of the company.

Figure 6.17 shows how the fixture should look once installed in the Terminal Module. The red circle highlights an area shown in more detail in figure 6.18.

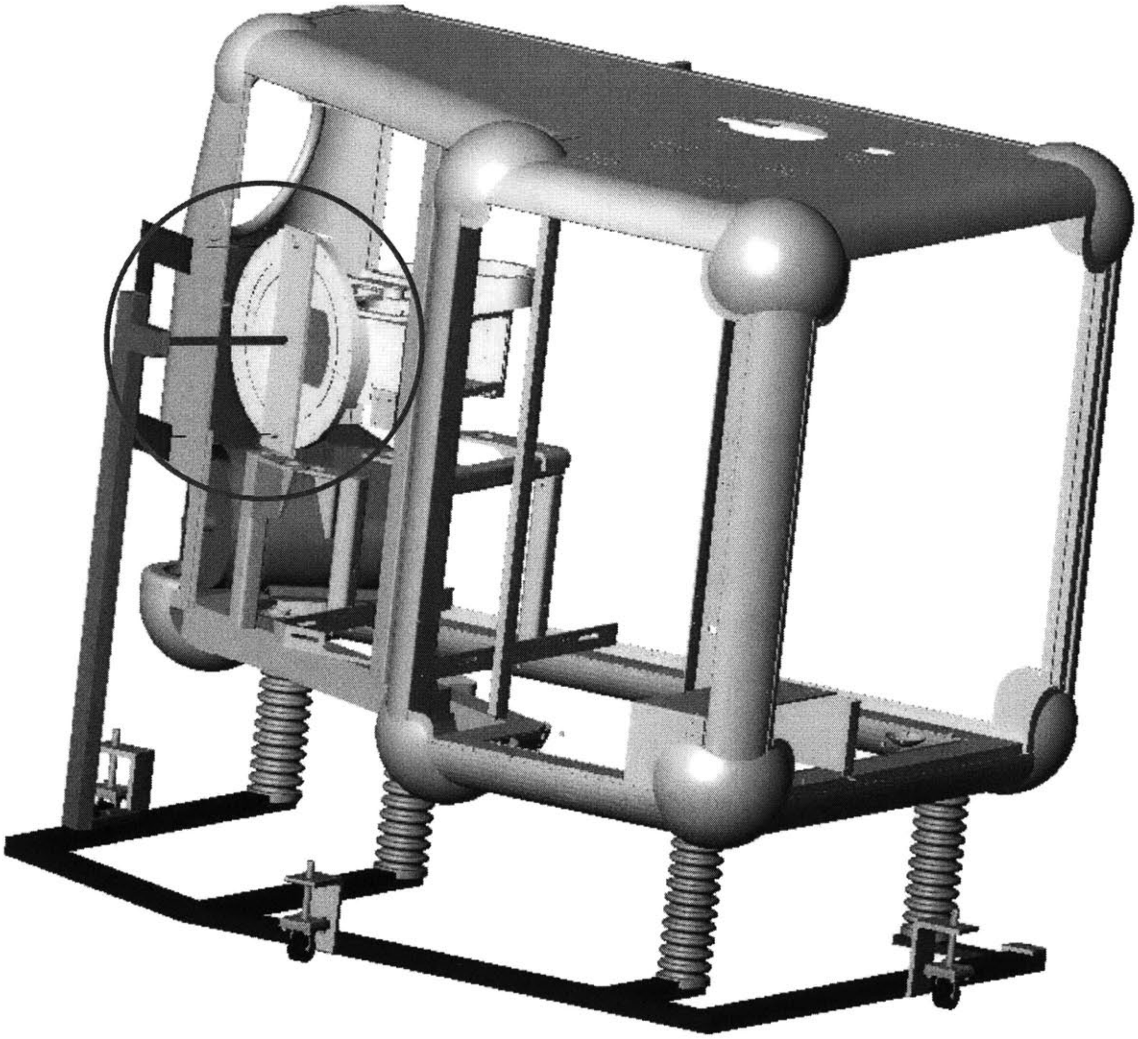


***Fig. 6.17** – Fixture and terminal module assembly*

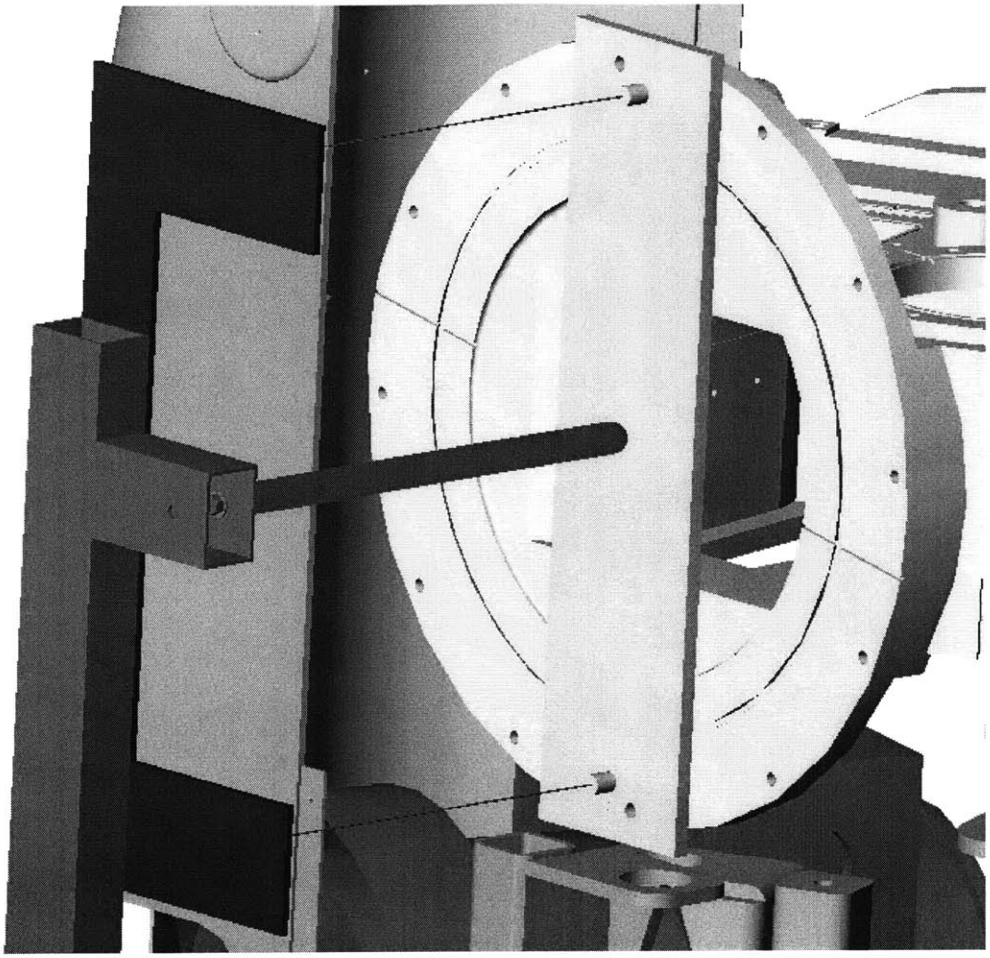


Fig. 6.17 – Detailed view of source chamber alignment

In this figure we can see how the lasers are shooting on the target allowing the operators to easily change the position of the insulators and source chamber in order to be set in their nominal position and ready to be connected with the Accel Column and Beamline.

The last stage of the project was the construction permission; this was granted in perfect time with the starting of the flow line Shipment scheduled for the starting of September 2007.

CHAPTER 7

SUMMARY OF SOURCE CHAMBER ALIGNEMNT

This chapter is a summary of the work of my colleague Simone Guerra for the source chamber alignment. Here will be discussed briefly the problem statement and the final solution. For a complete discussion of the source chamber alignment see Chapter 6 of the thesis of my colleague [14], "A Template Modeling for an Assembly Control – Source Chamber Alignment", Chapter 7.

7.1 PROBLEM STATEMENT

In order to align the terminal module with the beamline through the Accel column, the source chamber inside the terminal must be oriented in the right way. In the previous chapter, it has been shown how to check the position of the feet of the terminal module and how to control the depth of the source chamber inside the terminal frame through a horizontal PVC rod that is supposed to touch the source chamber face, as shown in Figure 6.17. Here the problem is to orient the source chamber (height, left and right) inside the terminal frame.

7.2 PROPOSED SOLUTION

To align the source chamber inside the terminal module and relate its orientation with respect to the feet, we need essentially:

- 2 micro modules lasers;
- a laser bracket;
- a target plate, installed on the fixture for the feet;

- A digital level.

The Figure 7.1 shows the necessary equipment for the correct alignment.

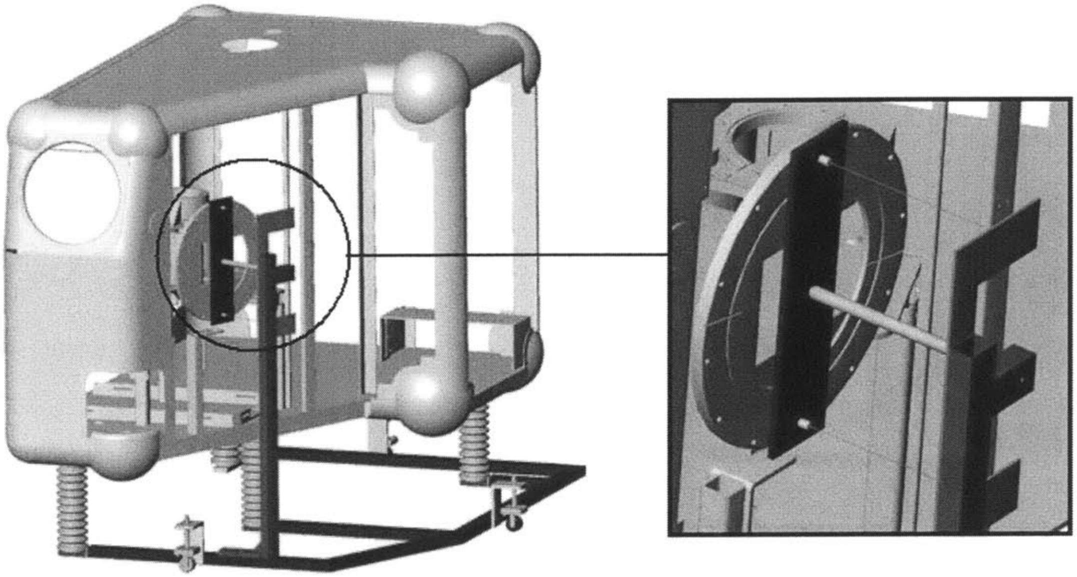


Fig. 7.1 - Source Chamber Alignment: *general and particular view of the fixture*

Class II and fixed focus lasers have been chosen respectively for safety reason and precision in the alignment. The laser bracket is a simple rectangular plate in aluminum, which houses the two lasers. In order to correctly install the fixture on the source chamber, two pins have been considered; the top one matches the top hole of the source chamber, and the other one locates the corresponding slot. Two bolts tighten the fixture on the part, as shown in Figure 7.2.

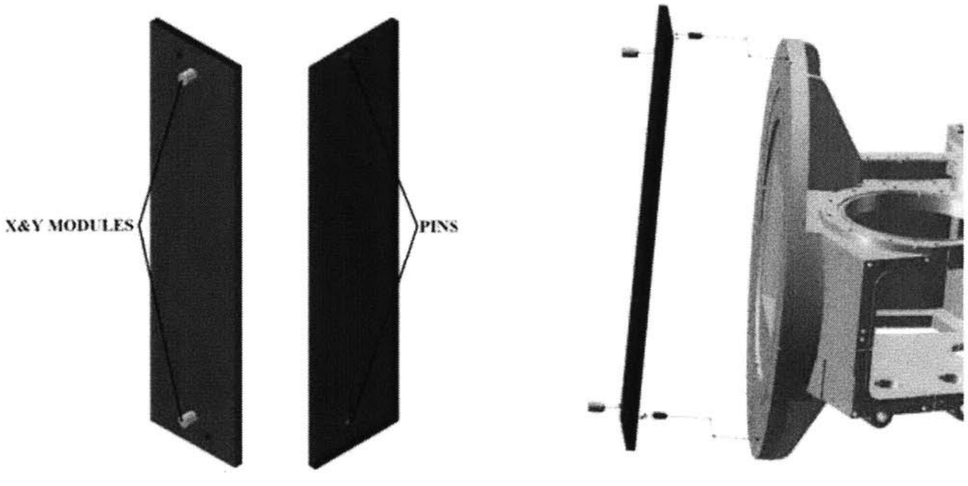


Fig. 7.2 - Laser Bracket

The details of the target plate are shown in Figure 6.9.

CHAPTER 8

CONCLUSIONS

In the ion implantation market, revenue is increasing faster than unit volume because implanters have become more capable but also more expensive. However, both revenue and volume are subject to the severe boom-and-bust cycles that have affected the entire semiconductor capital-equipment industry in the past decade, a pattern that will likely continue. In such a competitive, variable and fast market, companies are always motivated to reduce their lead time and increase their gross margin, by continuously improving their manufacturing processes, in order to be customer-ready and improve profitability.

Managers and engineers are trying to lead Varian Semiconductor Equipment to an important revolution in terms of manufacturing process and this revolution is best known by the name "Flow Line Shipment Program" inside the company. The pursued intent is to eliminate the final assembly area from the production chain in order to be able to ship all of the components of the ion implanter directly from the flow line to the customer, without prior final assembly at the factory. Such an ambitious project needs review of the entire production system, since every step in the chain needs to be adjusted and modified. In particular several additional mechanical, electrical and software tests have to be done directly in the flow line, even if at this step it is impossible to run the real ion beam prior to product shipment.

Among software, electrical and mechanical concerns in pursuing the revolution that we mentioned so far, the thesis examined one of the numerous mechanical issues that Varian is facing inside the Flow Line Shipment project. In a manufacturing process in which the final assembly of a sophisticated machine is a step that has to be avoid and for achieving the results we mentioned before, the correct alignment of subassembly components becomes a critical aspect and needs to be checked before shipment, since assembly errors or out of specification components from suppliers may lead to huge delays and reworks. This last aspect cannot be ignored, since if adjustments and modifications can always and quite easily be accomplished in the flow line without conspicuous waste of time, the same cannot be said in the field, where customers want to install their equipment, thousands miles away from the factory. Varian was never faced these challenges previously, since the final assembly in the Varian "clean room" area could point out eventual problems which could be solved in the flow line or, generally, directly in the clean room itself.

After having introduced the Company, the ion implanter, its theory of operations and the Flow Line Shipment Program, the thesis focused attention on the assembly concerns that Varian is facing inside its project. The thesis, in particular, pointed out a solution to possible misalignments that may affect the final assembly between the source chamber, an important component inside the terminal module and the beamline module, two fundamental sub-assemblies of the ion implanter. Inside the clean room, in fact, the final mechanical assembly can be checked and eventual problems solved, but in the Flow Line Shipment context this represents a big issue, since out of specification components, due to suppliers' production errors for instance, may produce misalignments which make impossible the final assembly.

The thesis was the conclusion of a three month internship that I had with my colleague Simone Guerra at Varian; chapter 7 in this thesis presented one of the two aspects related to the fixture we developed together for the correct alignment of the source chamber inside the terminal module. Whereas I present in detail how to check the position of the feet of the terminal module through a mechanical jig, my colleague developed the procedure to align the source chamber relatively to the same jig and, consequently, to the terminal module.

8.1 Future Directions

The entire work was finalized to build a fixture that allows setting up the terminal module for the alignment with the beamline through the Accel Column directly into the flow line. This makes it possible, without the need to try the assembly with all the components, to simply simulate it with just the terminal module and our fixture. Additional precautions should be taken into account in the future to make the alignment process as smooth as possible and eliminate the necessity for eventual rework due to the impossibility to achieve the desired position of the source chamber, inside the terminal frame, in relation to the positions of the insulators. Our fixture should enable Varian to detect directly in the flowline an eventual impossibility of final assembly, due to parts out of tolerances. However, future work could also make the following improvements in order to keep such eventualities as small as possible:

1) The insulators should have much tighter tolerances. Even if their utility relies on a very convenient price, it must be taken into account that they play a central role in the Terminal/Accel/Beamline assembly issues that Varian is facing right now;
2) Our fixture will guarantee the possibility of finding the correct position of the terminal and source chamber inside a certain range of variability, due to the imprecision of the insulators. Outside this range, with the actual design of the terminal frame it is impossible to proceed in a different way other than to substitute the insulators with better ones. For this purpose Varian could make the holes in the plates that support the rod of the source chamber (Figure A) bigger. In this way the operators could have a better possibility to play with the position of the source chamber and offset eventual major problem that they may face due to insulator dimensions out of tolerance.

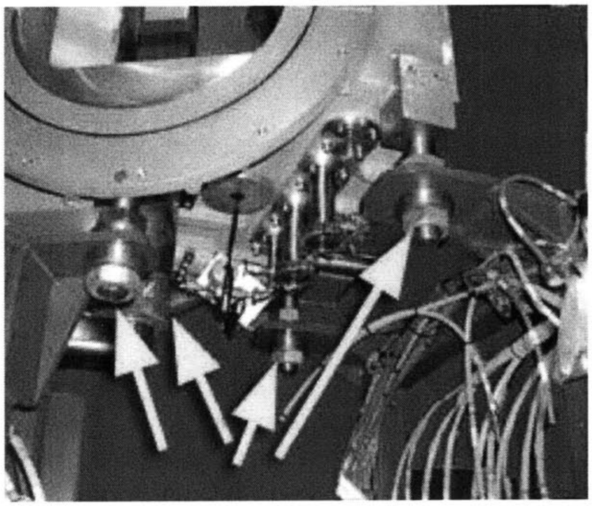


FIG. A – Support Rods.

3) The position of the generator inside the Terminal frame is never checked. For a better confidence on the overall assembly this could be checked in the flowline too, simply adding a fixture that take its position under control or modifying our jig to keep the center of the flange of the generator always in the right position.

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[10] Varian Semiconductor Equipment – *"Terminal Laydown"* – Procedure ID E86114470.

[11] Varian Semiconductor Equipment – *"Beamline Alignment"* – Procedure ID E86120850.

[12] MSC Direct Big Book – http://www.mscdirect.com

[13] Myer Kutz - Mechanical Engineers' Handbook

[14] Simone Guerra – *"A Template Modeling for an Assembly Control – Source Chamber Alignment"*, Chapter 7 - M.I.T.

Thesis Degree, 2007.

APPENDIX A

THE ICH AND BERNAS SOURCES

The indirectly heated cathode (IHC) source has much in common with the more familiar Bernas source. Both sources rely on a piece of heated tungsten to emit electrons. A source magnet and repeller are used in both types of ion source to confine the emitted electrons. Finally, in both sources the emitted electrons collide with atoms (supplied by the gas feed or vaporizer), creating ions, which can be extracted from the source as an ion beam.

The main distinction between an IHC source and a Bernas source is the presence of an additional electrode (the cathode). The cathode performs two main functions – to protect the relatively fragile filament from the harsh environment inside the arc chamber and to serve as the source of electrons needed to create ions inside the arc chamber. It is useful to briefly think through how the Bernas source operates before going on to the IHC source.

The Bernas source (schematic below) works by heating the filament with a current (the filament current). Once the filament is hot, it will emit electrons if a voltage is applied to it, this voltage is the arc voltage. The electrons spiral around the source magnet field, and occasionally collide with atoms introduced into the arc chamber by either the mass flow controller or the vaporizer. The collision results in the creation of an ion. Control of the source is accomplished by changing the filament current – a higher filament current makes the filament hotter, which increases the number of electrons it will emit. We see this as an increase in arc current and extraction current. So when the operator requests more extraction current, the source responds by increasing the filament current.

The IHC source also begins with a filament heated by an electric current (again, the filament current). The job of the hot filament is again to emit electrons when a voltage is applied, however these electrons are used not to create ions but to heat the cathode. Therefore the voltage (called the bias voltage) is applied between the cathode and the filament. The electrons emitted by the filament form an electric current (the bias current) and are accelerated by the bias voltage until the hit the back side of the cathode. There they transfer their energy to the cathode as heat. When the cathode is hot enough, it too will emit electrons if a voltage is applied. This is the arc voltage, and the cathode now serves the purpose of emitting electrons inside the arc chamber, so that they can collide with atoms to make ions. The control mechanism to set the extraction current is still temperature, in this case temperature of the cathode. The way the cathode is made hotter is to increase the bias current. So what we see when the operator requests more extraction current is that the system responds by increasing the bias current. Higher bias current means more electrons emitted by the filament, more energy transferred to the cathode, and a hotter cathode. The hotter cathode will emit more electrons inside the arc chamber, which we see as more arc current and finally more extraction current.

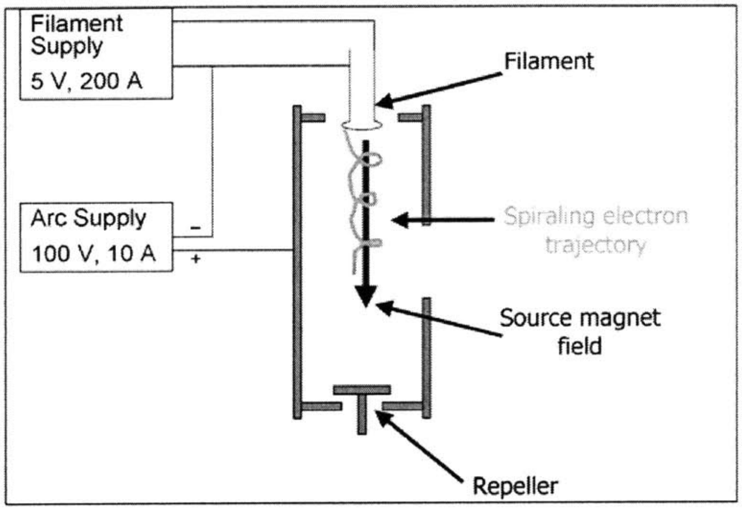


FIG. A1 – The Bernas Source.

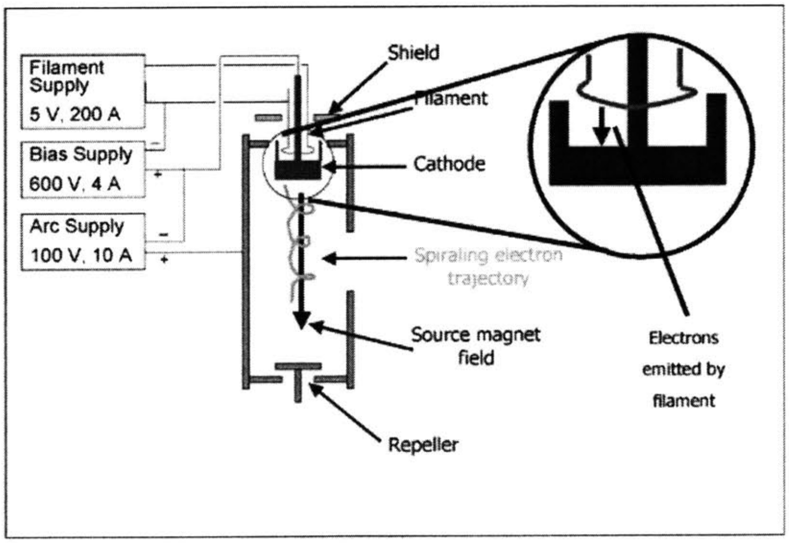
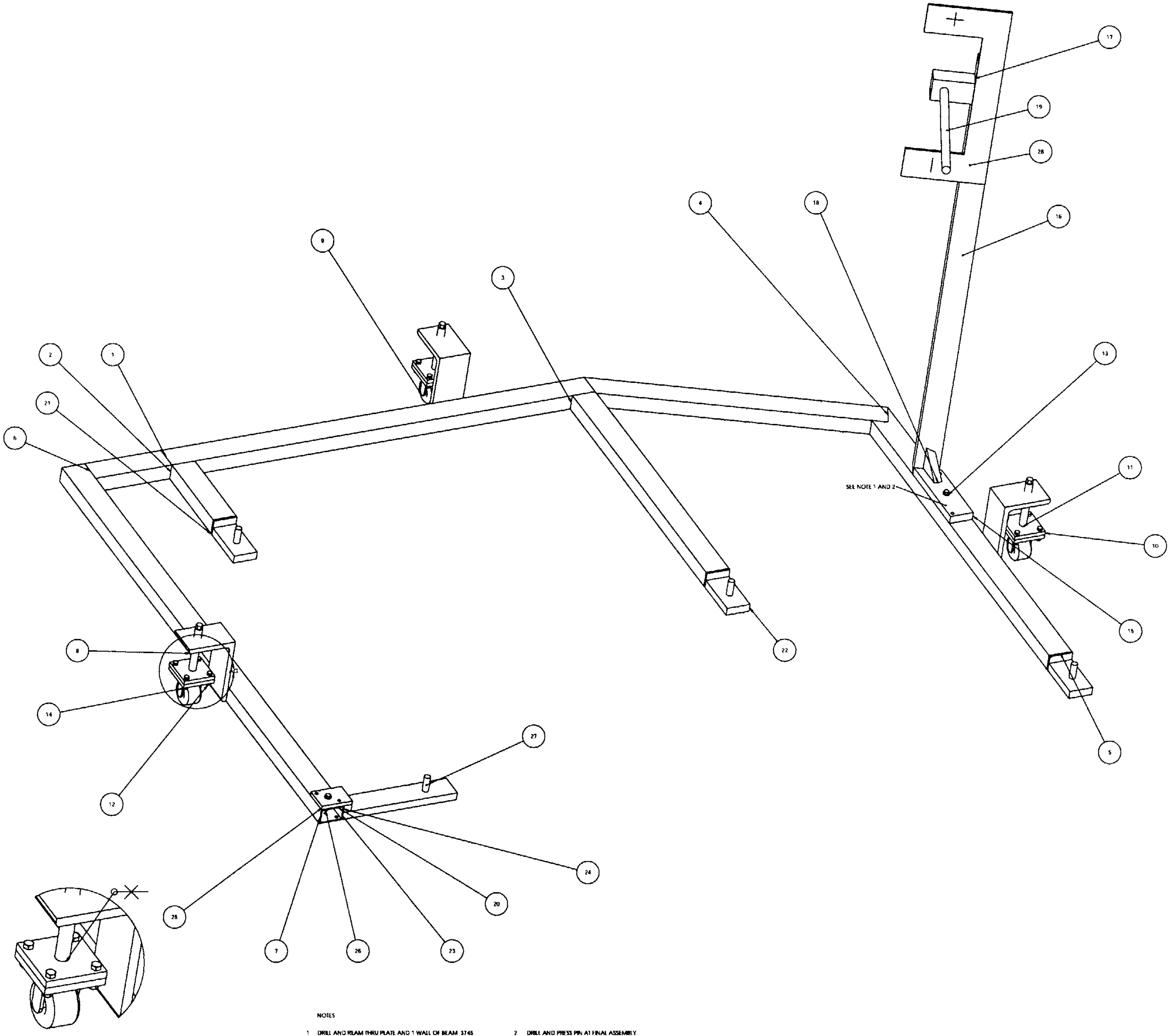


FIG. A2 – The ICH Source.

APPENDIX B

FIXTURE DRAWINGS



ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	QTY.
1	e18292050_01	TUBE, RECT , 2x3x0.125 THK	Aluminum 6061-T6	1
2	e18292050_02	TUBE , RECT , 2x3x0.125 THK	Aluminum 6061-T6	1
3	e18292050_03	TUBE , RECT , 2x3x0.125 THK	Aluminum 6061-T6	1
4	e18292050_04	TUBE , RECT , 2x3x0.125 THK	Aluminum 6061-T6	1
5	e18292050_05	TUBE , RECT , 2x3x0.125 THK	Aluminum 6061-T6	1
6	e18292050_06	TUBE , RECT , 2x3x0.125 THK	Aluminum 6160-T6	1
7	e18292050_07	TUBE , RECT , 2x3x0.125 THK	Aluminum 6160-T6	1
8	e18292050_09	L-ANGLE , STRUCTURAL , 6x8x0.625 THK	ALUMINUM, 6061-T6	3
9	e18292050_10	3-1/4x2" 700LB ZINC RLR SWIVEL PHENOLIC WHEEL , MSC #: 75947432 / Mfr Part #: 16TM03203S		3
10	e18292050_11	PLATE , 1/2 THK	STELL HOT ROLLED	3
11	e18292050_12	ZINC PLATED THREADED ROD , 1 1/2-6	STAINLESS STEEL	3
12	e18292050_13	HEAD HEX BOLT 3/8-16 X 1 1/2 , GRADE 2	CARBON STEEL	13
13	1421201600	FALT WASHER, SCREW SIZE 3/8	STEEL , GRADE 2	15
14	e18292050_14	HEX NUT , 3/8-16	STEEL GRADE-2	12
15	e18292050_08	TUBE , RECT , 2x3x0.125 THK	Aluminum 6160-T6	1
16	e18292050_15	TUBE , RECT , 2x3x0.125 THK	ALUMINUM , 6160-T6	1
17	e18292050_16	TUBE , RECT , 2x3x0.125 THK	ALUMINUM , 6160-T6	1
18	e18292050_17	PLATE , 1" THK	ALUMINUM , 6061-T6	1
19	e18292050_18	ROD , 1" DIAM	RIGID PVC	1
20	e18292050_27	BULLET NOSE DOWEL, CARRLANE VENDOR , PART NOUMBER: CL-3-BND , 3/8 HEAD AND SHANK DIA.		4
21	e18292050_19	PLATE , 1/4 THK	ALUMINUM , 6061-T6	3
22	e18292050_20	SOLID BAR , RECT , 1x3	ALUMINUM , 6061-T6	3
23	e18292050_21	SOLID BAR , RECT, 1x3	ALUMINUM, 6160-T6	1
24	e18292050_22	SOLID BAR , RECT , 1x3	ALUMINUM , 6061-T6	1
25	e18292050_23	PLATE , 1/2 THK	ALUMINUM , 6061-T6	1
26	e18292050_24	HEAD HEX BOLT 3/8-16 X 2 , GRADE 2	CARBON STEEL	2
27	e18292050_25	THREADED ROD, 3/4 DIAM , 3" LENGHT	STAINLESS STEEL	4
28	e18292050_26	PLATE , 1/4 THK	ALUMINUM , 6061-T6	1

NOTES

1 DRILL AND REAM THRU PLATE AND 1 WALL OF BEAM .3745
REAM BEAM FOR CLEARANCE .390
PRESS PIN INTO PLATE TO LEAVE .270 PROTRUDING

2 DRILL AND PRESS PIN AT FINAL ASSEMBLY

3 PAINT YELLOW PER VSEA PAINT SPEC 04453001

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

	NAME	DATE
DRAWN	[illegible]	8-7-2007
CHECKED	[illegible]	
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

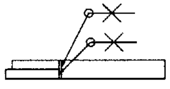
MATERIAL SEE P/L
FINISH PAINT (SEE NOTES)

PROPRIETARY AND CONFIDENTIAL

TITLE:
FIXTURE , BEAM L. , SOURCE CHAMBER

SIZE E
DWG. NO. e18292050
REV

SCALE 1:4
WEIGHT
SHEET 1 OF 4



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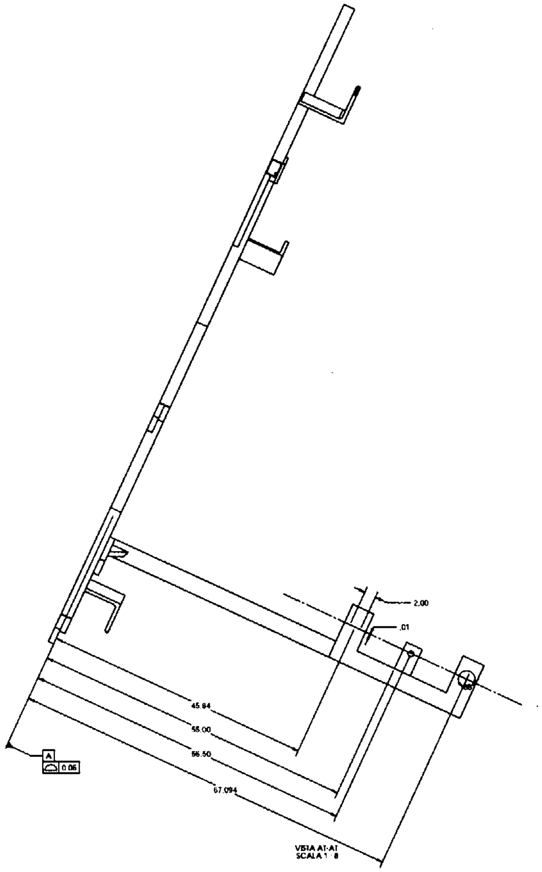

VISTA AT-AT
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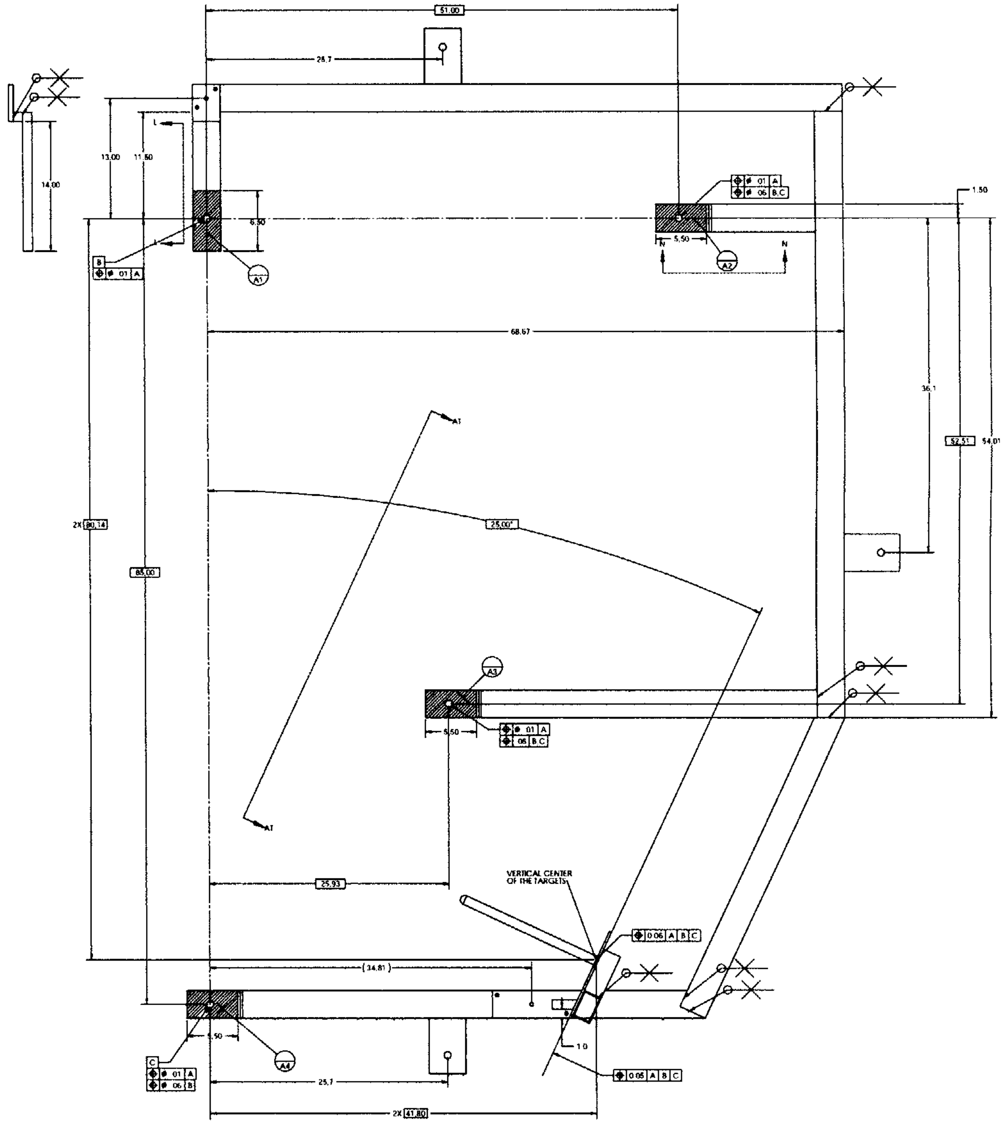

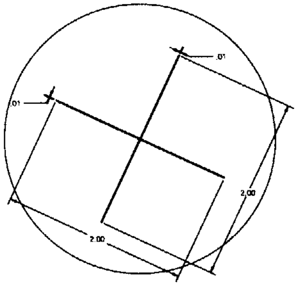

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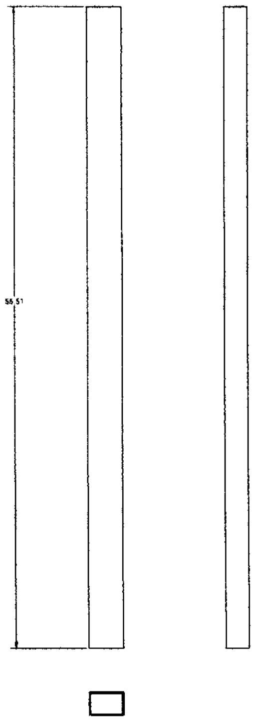
TITLE
FIXTURE , BEAM L. ,
SOURCE CHAMBER

SIZE E | DWG NO e18292050 | REV
SCALE 1:3 | WEIGHT | SHEET 2 OF 4



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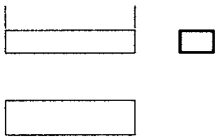

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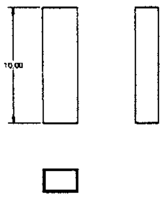

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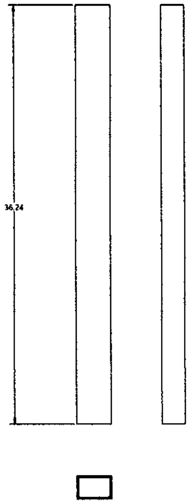

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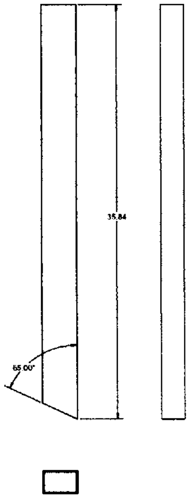

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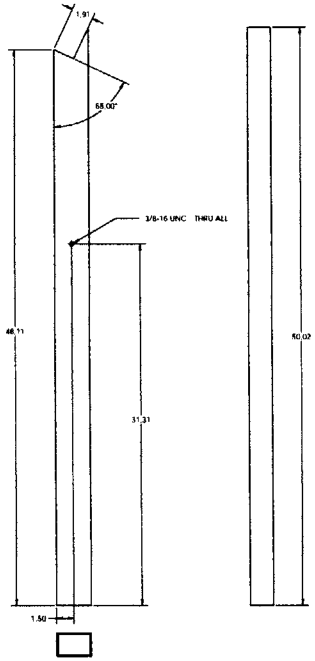

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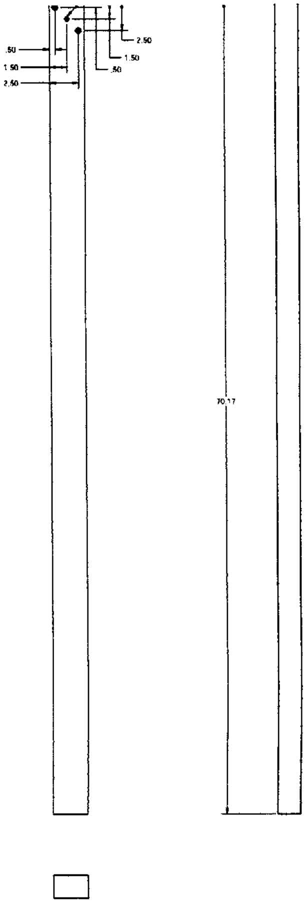

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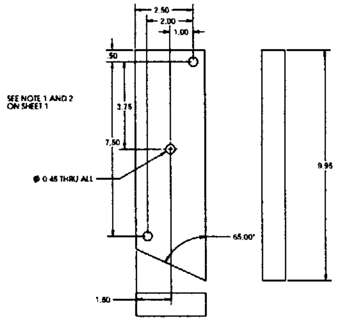

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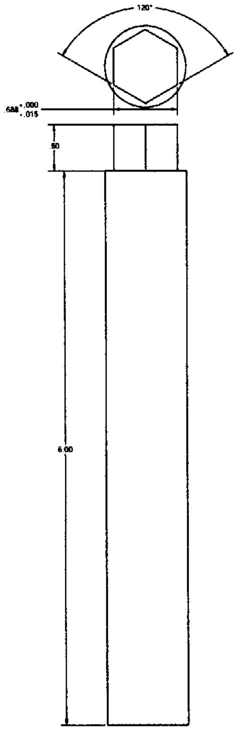

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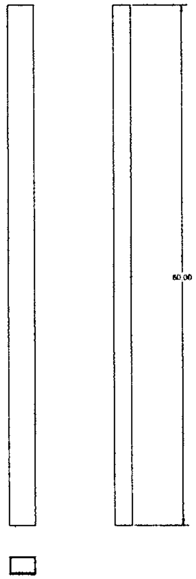

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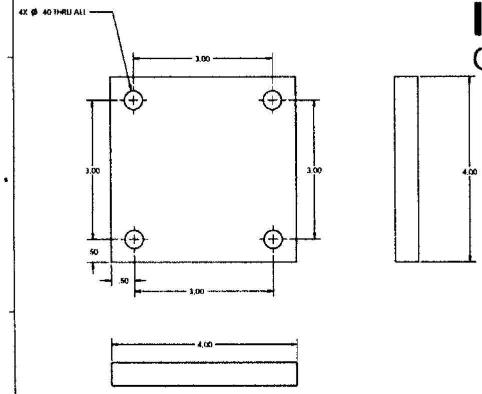

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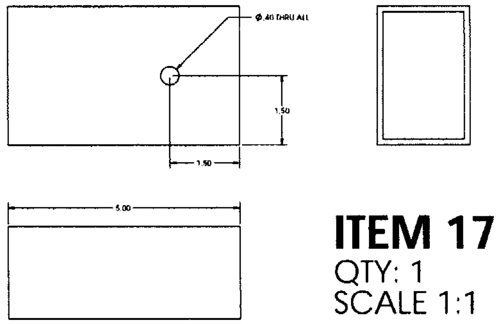

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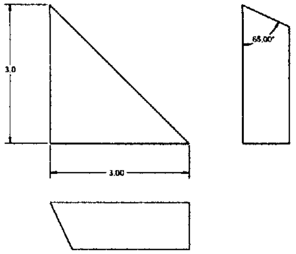
TITLE
FIXTURE , BEAM L.,
SOURCE CHAMBER

SIZE	DWG NO	REV
E	e18292050	

SCALE 1:4 WEIGHT SHEET 3 OF 4



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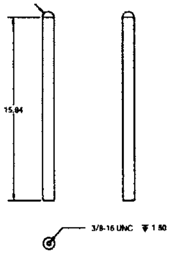

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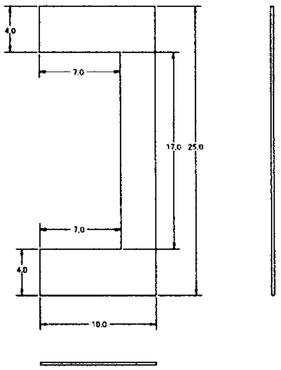

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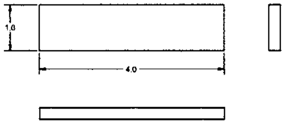

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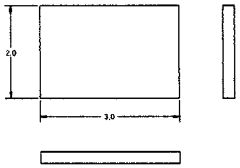

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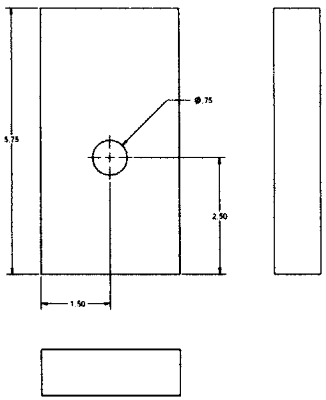

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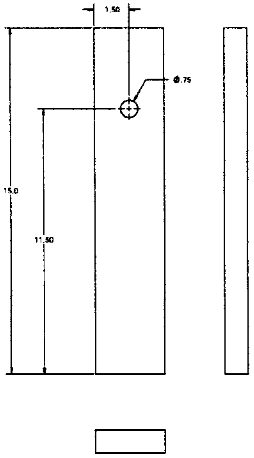

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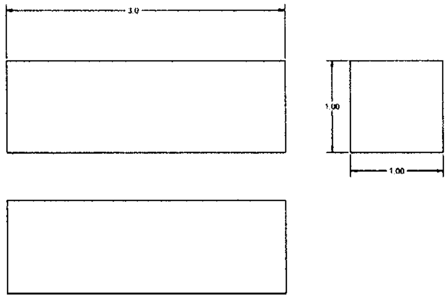

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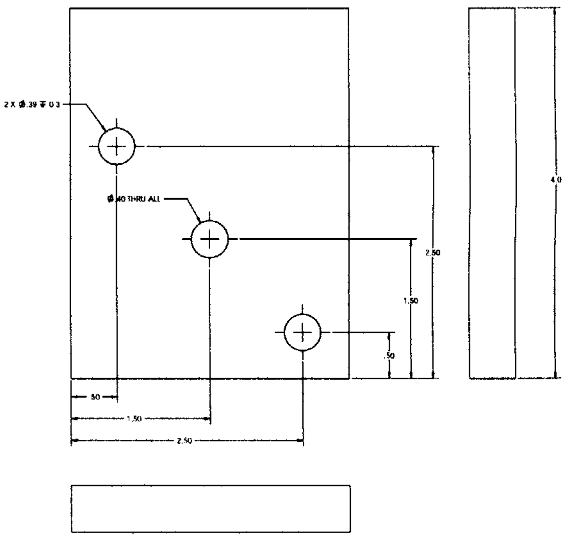

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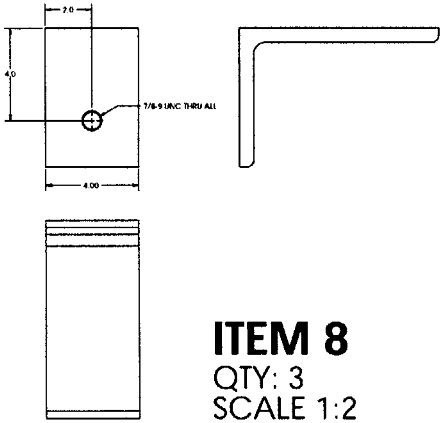

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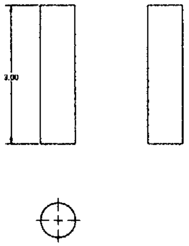

ITEM 27
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TITLE
FIXTURE , BEAM L.,
SOURCE CHAMBER

SIZE E | DWG NO e18292050 | REV
SCALE 1:4 | WEIGHT | SHEET 4 OF 4