BEAM PROFILING AND MEASUREMENT AT MIBL

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Abstract

Michigan Ion Beam Laboratory (MIBL) is equipped with a 1.7 MV tandem particle accelerator and a 400 kV ion implanter. Ion beams can be produced from a variety of ion sources and delivered to different beamlines. Precise beam profiling and current measurements are critical aspects of everyday activity in the laboratory and influence the success of each experiment. The paper will present the devices used at MIBL to precisely determine the parameters of the ion beams in order to produce successful proton irradiations and ion implantations.

INTRODUCTION

The Michigan Ion Beam Laboratory (MIBL) is located in Ann Arbor and is a part of the Department of Nuclear Engineering and Radiological Sciences at the University of Michigan. The laboratory is equipped with a 1.7 MV Tandetron accelerator, a 400 kV ion implanter and an ion beam assisted deposition system (IBAD). The accelerator is a solid-state gas insulated, high frequency device, capable of operation between 0.4 and 1.7 MV (Fig. 1).

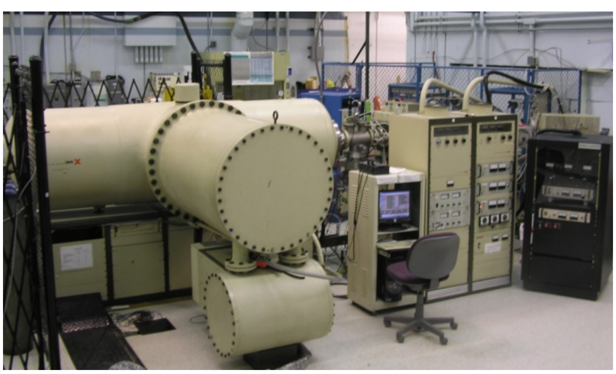

Figure 1: 1.7 MV Tandetron accelerator.

Various beams can be produced, starting with protons (up to 300 μA) and continuing with D^+, He^+, C^+, O^+, N^+, heavier ions like Fe^+ and Ni^+ and many others. The Tandetron can operate with three types of sources: a Torvis by (NEC) [1] that reliably delivers proton and deuterium beams, a duoplasmatron 358 source (HVEE) [2] used mainly for Alfa particles for surface analysis and a sputtering source PS120 (Peabody Scientific) [3] used to produce heavy ions. The Tandetron has two beamlines; a 15^0 beamline for ion beam modification (implantation, and ion mixing) and radiation damage, and a 30^0 beamline for ion beam analysis, each terminated with a target chamber. Both beamlines contain a quadrupole triplet for focusing, an analyzing magnet, a raster-scanner and a steerer. The 15^0 beamline and the chamber are equipped with cryopumps that can routinely achieve pressures in the 10^{-9} Torr range. Beyond the main chamber on the 15^0 beamline there is an electrically isolated irradiation sub-chamber. A temperature controlled sample stage can be attached next for radiation damage experiments (between 50 and 600 °C). The 30^0 beamline contains an aperture system, a Faraday cup for charge collection, a beam viewer, a translation two-axis goniometer and detectors for backscattering and glancing angle measurements. It is turbo-pumped and equipped for rapid sample turn-around. Rutherford backscattering spectroscopy (RBS), nuclear reaction analysis (NRA), elastic recoil detection (ERD), and ion channelling are conducted in this chamber. All the control and monitor software programs for the proton irradiation and the Torvis source are written in Labview from National Instruments (NI) and were developed at MIBL

The 400 kV NEC is an air-insulated ion implanter (Fig. 2). The ion source Model 921 made by Danfysik [4] is designed for production of high current and high brightness ion beams. It is capable of ionizing materials that have low vapor pressure, and can produce ions by sputtering solid targets or by ionizing gases.

Figure: 2 NEC's 400 kV ion implanter.

The implanter can provide beams from most elements in the periodic table, with energies between 10 and 400 kV and with beam currents ranging from several microamperes to more than a milliampere (in some cases). Beam fluencies of up to 10^{20} atoms/cm^2 could be achieved in an area of a square inch in a few hours. Double ionization states for some elements (Ar^{2+}, O^{2+}, etc) allow for implants at energies of up to 800 kV. The target chamber and beam line operating pressure is in the 10^{-8} Torr range. A rotating carousel permits simultaneous loading of twelve 2-inch wafers, five 4-inch wafers or four 6-inch wafers for sequential implantation. The target chamber (3) is equipped with a 4-point Faraday cup system that allows for precise beam monitoring and dose measurements.

BEAM PROFILE MONITORS

Proton Irradiations

In the case of proton irradiations, the beam is raster scanned over an area that encompasses the samples to be irradiated and over a set of slits (apertures) that is used to monitor the current (Fig. 3). If the beam is not centered, (as determined by reading the amount of current detected on the 4-slits set) the beam can be corrected accordingly using the Tandetron's steerers.

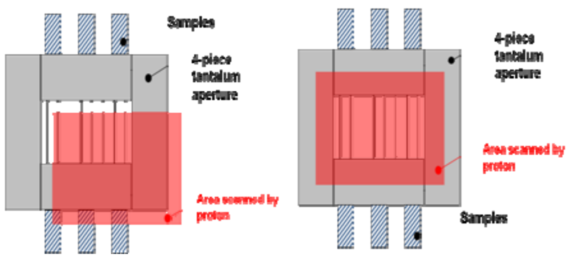

Figure 3: Beam alignment procedure.

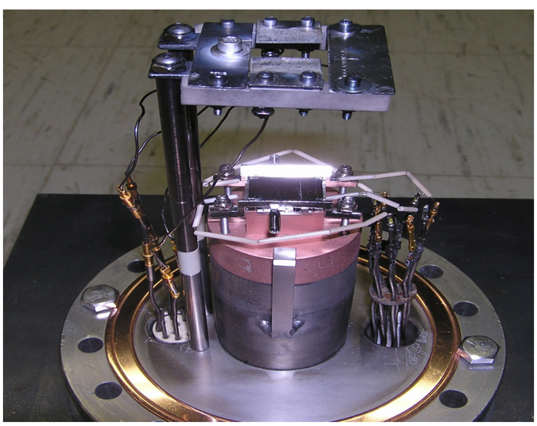

Figure 4: Actual irradiation stage.

This way we ensure that the stage (Fig. 4) where the samples are loaded is uniformly exposed to the beam

The Full-Width-Half-Maximum Profile

If the beam is not ~3 mm or less in diameter during the scanning process, there will be places on the sides of the irradiated area that will "see" less beam. The beam will spend less time on the edges than in the center of the stage, resulting a non-uniform irradiated set of samples. The beam profile gives the beam's spatial characteristics (shape and size) and determines its quality. The Beam Profile Monitor (BPM) outputs the signal to an oscilloscope. The X and Y profile of the beam as displayed on the oscilloscope resemble a Gaussian curve (Fig. 5).

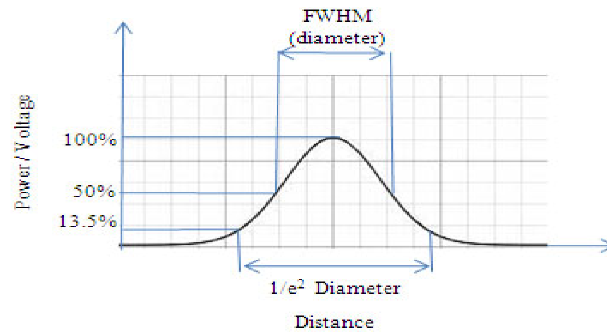

Figure 5: Typical Gaussian curve.

The Full-Width-Half Max (FWHM) specifies where the power drops to one half the maximum and represents the beam's "calculated" diameter. As the edge of the beam is not perfectly defined we generally agree that the beam's diameter is measured between two points that contain a selected percentage of the meaningful energy – and in the case of a Gaussian this is at the $(1/e^2)$*diameter. This is where the beam contains 4-sigma of the energy distribution and the beam power is at this point 13.5% of the power at maximum height.

Measuring the Beam Size

The FWHM is used in determining the width of the beam according to the BPM manufacturer's characteristics. The BPM is located close to the target (about 75 cm away) as a minimum beam is of crucial importance for the success of the irradiation experiments. MIBL is equipped with two BPMs – one on the Tandem and one on the Implanter. They were both manufactured by NEC [1]. The BPMs are model number BPM80 and BPM 82 respectively with controllers model S55A (Fig. 6 and 7).

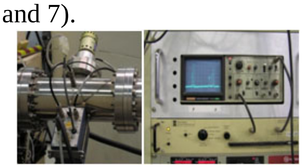

Figure 6: BPM and controller of the Tandetron.

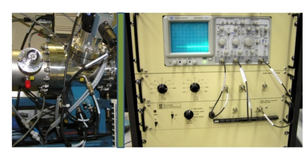

Figure 7: BPM and controller of the Implanter.

These BPMs consist of a helical tungsten wire that is driven horizontally and vertically across the beam at a frequency of about 19 cps. The position is electronically monitored and the secondary electrons generated by the interaction with the beam are collected, the charge amplified and displayed on an oscilloscope. The main advantages of this BPM setup are: long term stability and reproducibility, low current detection (~1 nA) and the capability to quantify and center the beam in the beamline. This is done by setting some reference points on the oscilloscope screen and knowing the relationship between the divisions on the screen and the location and size of the beam, the beam is steered in the correct location.

Measuring the Beam Size

If the two peaks (X and Y) correspond to the fiduciary marks of the BPM, by measuring the FWHM of the peaks (set identical for a circular beam) one can determine the diameter of the beam in the X and Y direction (Fig. 8). In the case depicted in Fig. 8, the FWHM is about 1.5 small units (one unit = 2 mm) on the scope, giving a beam diameter of ~3 mm and guaranteeing a successful irradiation. After the beam is centered and focused, is raster scanned (Fig. 9) to cover the desired area.

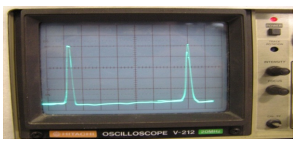

Figure 8: X and Y displays of the beam.

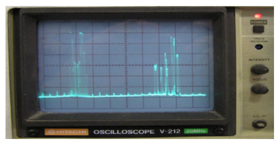

Figure 9: Beam during scanning.

A similar procedure is applied to the implanter to determine the beam's characteristics.

SUMMARY

Michigan Ion Beam Laboratory is a user's facility that can perform a wide range of services in the surface analysis, ion beam irradiation and ion implantation fields. It can produce a wide variety of ion beams with energies varying form 10 keV to 3.4 MeV and higher (for higher charge states). Beam measurements are a prerequisite part of a successful experiment. At MIBL this is guaranteed by a set of BPMs and current measurements performed before and during the runs.

REFERENCES

[1] National Electrostatic Corporation (NEC), http://www.pelletron.com.
[2] High Voltage Engineering Europa (HVEE), http://www.highvolteng.com.
[3] Peabody Scientific: http://www.peabodyscientific.com.
[4] Danfysik: http://www.danfysik.com