Low Energy Ion Beam Accelerator for Material Damage Studies

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Abstract – Mono-atomic and multiple charges atomic ion beam is extracted from the Electron cyclotron resonance (E.C.R) ion source at 20 kV extraction potential, which is then accelerated uniformly up to 300 keV and then it impinges on the target. The accelerator consists of ion source and its power supply housed in a high voltage dome. The electrical power to the dome is supplied through 350KV/5VA DC isolation transformer. The ion beam extracted from the ion source then passes through a high current uniformly gradient acceleration column and then focused on the target. Vacuum of the order of 10^{-7} mbar is maintained inside the beam line by two turbo-molecular pumps. He^+ ion beam current of 5 mA is focused on 25 mm diameter at the target. This high current ion beam at the target will be used to study displacement per atom (DPA) with energetic beam, surface modification and change in other physical and thermo dynamical properties of the material with energetic ion beam.

1. Introduction

The sub-systems of the accelerator (Fig. 1) include Ion source, high voltage power supplies, high voltage deck, beam line and vacuum systems. Mono-atomic and multiple charge ion beam is extracted from the Ion source passes through the uniformly gradient acceleration column and then impinges on the target. The maximum beam energy in the accelerator for monatomic ions is 320 keV

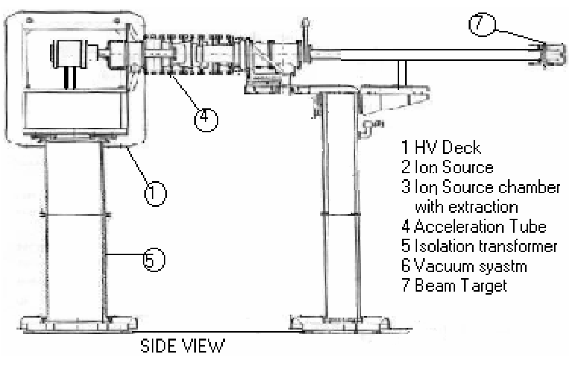

Fig. 1. Side view of accelerator

2. Design Parameter of Accelerator

Beam energy maximum	320 KeV
Beam current at the target He	5 mA
Beam spot at target (mm)	10 mm
Ion source	ECR type
Extraction voltage	20 kV
High Voltage power supply	300 kV/10 mA
D.C Isolation transformer	350 kV/5 kVA
Vacuum pump	400 lps

3. Ion Source

Electron Cyclotron Resonance (ECR) ion source is used as an Ion beam source and its operation principle is, when electrons move in a magnetic field they gyrate around the magnetic field lines due to the Lorentz force. The gyration frequency is called the cyclotron frequency f_{cyc}. If microwave radiation of the same frequency propagates into such a region, the electrons are resonantly accelerated or decelerated (depending on the phase of their transversal velocity component with respect to the electric field vector) when the electron cyclotron resonance condition is fulfilled:

$$f_{hf}=f_{cyc}=(e/m)\times B.$$

Here, e and m denote the charge and mass of the electron, respectively. The plasma electrons are confined in a superposition of an axial magnetic field component and the radial magnetic field of a multipole magnet. This result in a *minimum-B-structure* because the magnetic field has a minimum in the middle of the structure and from there increases in all directions. Therefore, a closed surface is created where the electron cyclotron resonance condition is fulfilled. Electrons passing through that surface can be accelerated resonantly. Furthermore, a high mirror ratio of the magnetic field leads to long confinement times for the plasma electrons. They can pass the resonance region very often, gain high energies and ionize plasma atoms and ions into high charge states via successive single ionization. The ions in the plasma are not accelerated due to their large mass and remain thermal. Therefore they are not confined by the magnetic field but by the space charge potential of the electrons. This magnetic confinement, however, is not perfect and electrons can leave the plasma, for example in axial direction. Since the plasma tends to stay neutral, ions will follow the electrons. By using suitable extraction geometry and by applying a high voltage, the ions can be extracted from the ion source.

Fig. 2. E.C.R Ion source

The ion source consists of microwave system, plasma chamber, magnets and extraction system. The plasma is produced inside the plasma chamber, which is surrounded by the permanent magnets system. Two ring magnets produce axial magnetic mirror and a hexapole magnet produces radial magnetic field. The microwave system consists of 2.45 GHz magnetron which can deliver 300 Watts power in the continuous mode. The microwave is transported through a rectangular hollow wave guide to power circulator. A three port circulator with the dummy load is used to protect the magnetron from the reflected power. The microwave systems consists further of a combination of a high-voltage and high-vacuum window and a cross bar transition from rectangular wave guide to coaxial line with the gas inlet at the dead end of the transition.

At the end of the coaxial line a slow-wave structure (helical antenna) is connected which will radiate circularly polarized microwaves in axial direction. The electrons in the plasma gain energy with the applied microwave power due to the electron-cyclotron-resonance and multiply charged ions are produced by successive single ionization process. The ions will be extracted by applying a positive high voltage to the Ion source with respect to the puller electrode.

The extraction system of the source consists of a spherical extraction aperture with 8 mm hole and a puller electrode with 10 mm hole. The puller electrode can either be operated at ground potential or biased/floating potential. The distance between the extraction and puller electrode can be varied. The puller electrode has pierce geometry to suppress the widening of the ion beam caused by the space charge effect.

ECR Ion Source will be operated on 300 KV high voltage platform. Its operation and control has to be performed by taking proper electrical isolation. The microwave power fed to the ion source can be controlled by controlling the voltage and current of the magnetron power supply. Ion source has a gas fed system, which uses needle valve to control the flow of the gas.

The micro controller based control system has been designed for controlling the speed and position of the stepper motor. The stepper motor can be placed on the voltage, current and gas fed control knob. By controlling the speed/position of the stepper motor the voltage, current and gas flow control can be done. The control signals to stepper motor are given through fiber optic cable to provide high voltage isolation. The block diagram illustrating this is as shown below.

4. High voltage power supply

The high voltage power supply is connected to the deck. Ion beam is extracted at 20 keV it is then uniformly accelerated to 300 keV in the acceleration tube with 300 kV/10 mA power supply. The power supply has fine stability, regulation and very low ripple. It can be operated in constant current and constant voltage mode.

5. Beamline and vacuum system

The beam line consists of 300kV acceleration tube and drift tube in which the beam travels and impinges on the target inside the target assembly. Vacuum of the order of 10^{-7} mbar is maintained inside the beamline by two 400 lps turbo-molecular pump.

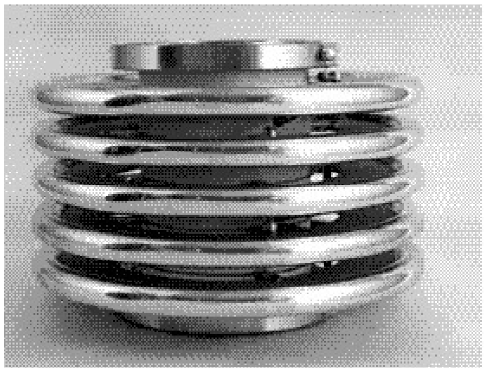

Fig. 3. Single section Acceleration tube

The acceleration tube consists of four sections and each section is a metal bonded assembly with no organic compounds in vacuum volume (Fig. 3). The tube is fully bakable up to 200 °C for contaminant free and ultra high vacuum operation. Each section is conservatively rated at 75KV (1 atm) in air and 200KV in SF6 (2 atm). A multiple series of resistors string in air is used to distribute the electrostatic potential uniformly along the tube. The holding voltage of tube is 300 KV in air.

6. Target Assembly

The target is kept perpendicular to the beam inside the target chamber. It is a metallic substrate on which the ion beam is deposited to study ion implantation and the effect of energetic ion beam causing material damage and displacement per atom (DPA).

References

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