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Summer Student Project at ISOLDE

Solid State Physics Group

The GLM ion implantation chamber: Automating and optimising collections of radioactive ions

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Abstract

This report details the progress made in automating the General Low Mass (GLM) Ion Implantation Chamber at the ISOLDE facility, CERN. The primary focus was on developing control systems for the vacuum infrastructure, sample transport mechanism, and auxiliary components to enhance operational safety and efficiency. Python scripts were successfully implemented to communicate with and control Pfeiffer vacuum pumps and gauges via an RS-485 interface. The sample transport system, driven by stepper motors, was integrated and tested. Furthermore, the existing graphical user interface was assessed for future integration. Challenges were identified with the current relay board for valve control, prompting a plan for its repair or replacement. The work conducted establishes a foundational software framework for the future fully automated and safe operation of the implantation chamber, significantly reducing the need for manual intervention and potential radiation exposure.

Keywords: ISOLDE, Ion Implantation Chamber, Automation.

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1 Introduction

The European Organization for Nuclear Research (CERN) is a premier hub for scientific innovation, where cutting-edge experiments continually push the boundaries of human knowledge. The ISOLDE facility, dedicated to producing a wide variety of radioactive ion beams for research in nuclear physics, materials science [Catherall et al. 2017], biology and medicine, provides a unique environment for such advancements. This project was conducted as part of the ISOLDE summer student program, contributing to the upgrade and automation of the experimental equipment within the General Low Mass (GLM) beam line.

The ion implantation chamber (IIC) is used to implant radioactive isotopes into samples. Therefore, it is usually installed at the GLM area of the ISOLDE hall, which is classified as a controlled zone, allowing the safe implantation and handling of radionuclides.

The IIC operates in an environment where minimizing radiological exposure to users is paramount. The automation of the chamber's components, such as the vacuum system, stepper motors, and the vacuum valves, reduces the need for manual intervention and thus, reduces the operators' exposure to radiological harm.

Also, the development of dedicated control scripts for pumps and gauges, significantly improves the system's reliability and performance. The implementation of the load-lock mechanism, in addition to the sample transport and positioning automation, reduces downtime, enabling faster sample changes and more precise implantation.

Moreover, the integration of user-friendly automation features, such as computer-controlled stepper motors and a graphical user interface, simplifies the operation of the IIC. This reduces the risk of user error and lowers the technical barrier for researchers, allowing them to focus on scientific outcomes rather than complex manual procedures. And enhanced documentation and testing protocols further ensure that future maintenance and upgrades can be performed seamlessly, extending the chamber's lifespan and adaptability.

Therefore the objectives of this project were:

1.1 Objectives

- To study the components and operational workflow of the IIC.
- To automate the control of the vacuum system, stepper motors, and vacuum valves.
- To improve documentation and testing procedures for future maintenance.

2 Ion Implantation Chamber

The general design of the ion implantation chamber is shown in Figure 1. The system consists of two main sections: a loading chamber and an implantation chamber, forming a load-lock configuration. These are connected by a specially designed gate valve that maintains its position in case of a power loss or pressure failure.

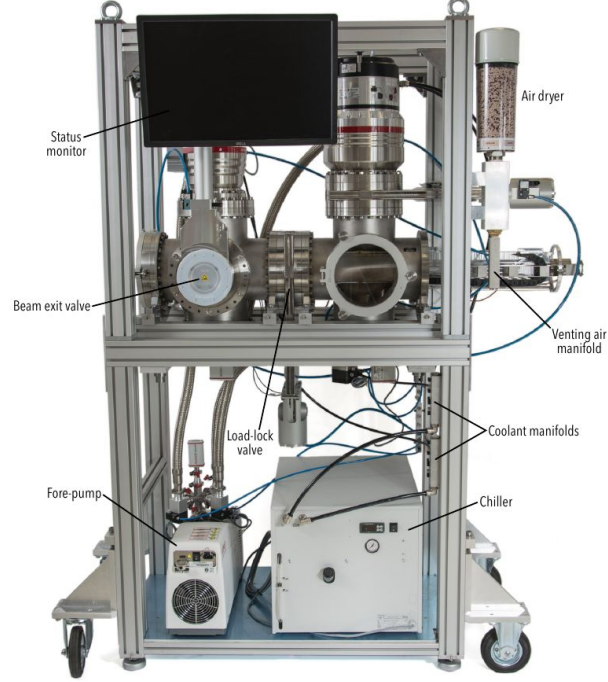


Figure 1: General layout of the ion implantation chamber, sample transport system is opened [Nagl 2014].

The implantation chamber is equipped with a quick-access door for ease of maintenance, especially the exchange of contaminated collimators. And the sample loading chamber is fitted with a similar quick-access door for the loading and unloading samples. Each part of the chamber is evacuated by a turbomolecular pump. The sample loading part's evacuation system was designed to yield a pressure below 10^{-6} mbar in less than 10 min after closing the quick access door. The implantation sub-chamber is designed to be kept at a pressure below 10^{-6} mbar for the entire duration of its operation. Both turbopumps are connected to a dry multi-stage roots pump acting as fore-pump. The two turbopumps are cooled using a closed cycle cooling system based on a chiller mounted on the lower level of the supporting frame, as can be seen in the Figure 1. The chamber is ventilated using cleaned air. To reduce condensation of air moisture on the chamber's interior parts during ventilation, an air dryer reduces the humidity level of the incoming air. An additional particle filter removes dust. Three valves control ventilation of the sample loading chamber as well as ventilation of the implantation chamber's and the sample loading chamber's turbopumps. Pressure levels of the fore-vacuum network and the two sub-chambers are measured using three vacuum gauges integrated into the electronics circuit of the two turbopumps and the fore pump. They are directly fed to the computer via

the RS-485 connection.

A drawing of the ion implantation chamber, created in FreeCAD [FreeCAD Community 2025] and integrated in the drawing of the GLM’s whole setup is presented in Figure 2.

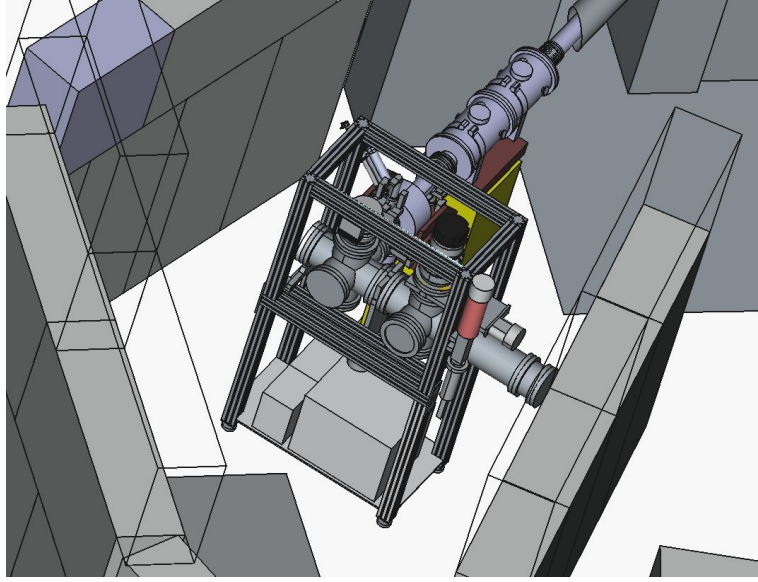


Figure 2: The ion implantation chamber drawing, created in FreeCAD, and integrated into the drawing of the GLM’s whole setup.

3 Vacuum System Automation

The initial phase of the automation process focused on the vacuum system. Control scripts were developed in Python utilizing the PySerial library [Liechti et al. 2025] to establish communication via the RS-485 serial interface. The Pfeiffer vacuum protocol was studied and implemented to interface with the pumps and gauges.

The system’s components, as illustrated in the circuit diagram (Figure 3), are all controlled through the serial communication port. A set of five dedicated Python classes was written to manage the different hardware elements:

- `TC400.py` and `TC1200.py` for the control of the turbomolecular pumps.
- `ACP28.py` for the control of the fore-pump, which required handling its specific protocol variant.
- `MPT200.py` and `RPT200.py` for reading data from the vacuum gauges.

Communication with each device was successfully verified through terminal output tests. The scripts correctly interpreted the Pfeiffer protocol, enabling precise control and status monitoring of the entire vacuum system, which is a fundamental prerequisite for automated operation sequences.

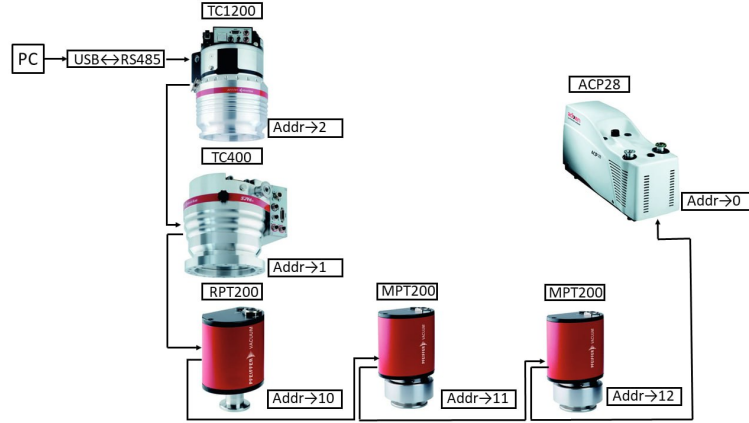


Figure 3: Circuit diagram of the vacuum system.

4 Stepper Motor Control

The transport of samples between the loading and implantation parts of the chamber, as well as sample positioning during implantations, is based on an assembly of two linear stages and a tilt mechanism, which are controlled by stepper motors. The hardware of the transport system consist of 5 microcontrollers, which can be used for both rotation and translation motion, and connect it each motor in question. The software is developed in this manner: 2 in-house drivers (NVUsB and NVMotor) are written in-house, requiring only libusb, which is an open source and publicly available library to communicate between the PC and the microcontrollers. The graphics user interface (GUI) currently available uses Qt6 and the 2 mentioned drivers, serves as a platform for users to control the motors with ease and without any technical or computational knowledge. Communication tests between the GUI, the drivers, and the motor controllers were performed successfully, confirming the functionality of the sample transport system.

5 Vacuum Valve Control

The control of the normally closed vacuum valves, which are activated by applying a 24 V DC signal, is intended to be managed through a relay board. The operational usability of the existing I²C-based relay board was tested. However, it was determined that the board is not functioning correctly. Further analysis is required to diagnose the fault, and a plan must be developed to either repair the current board or replace it with a functional relay module to complete the automation of the valve system.

6 Conclusions

Significant progress was made towards bringing the GLM Ion Implantation Chamber into an operational state. The vacuum system, including its control software and the associated chiller, was successfully implemented and tested using Python. The sample transport system and its stepper motors were also verified to be functional, with its control framework established in C++ and accessible via a Python binding (PyBind11). A challenge was identified with the controller board for the vacuum valves, which will need to be resolved. Future work will focus on integrating these independent subsystems into a unified control interface, potentially using PyQt5 or Qt6, to enable fully automated and safe operation of the chamber.

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