Cryogenic Penning Ion Trap in 4K environment

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Introduction

The cryogenic Penning Ion trap (PIT) facility at VECC has a specially designed cryostat where the trap along with its detection electronics will remain immersed in the liquid helium filled bore of a 5T superconducting cryo-magnet dewar. Detailed descriptions of the magnet and mechanical assembly for immersing the trap assembly were described in [1, 2]. The PIT facility was operated at room temperature and at 77K and an electron cloud was successfully trapped and detected using detection circuit developed at VECC [3]. However, the operation of the PIT in cryogenic environment requires special components like non-magnetic, multipin, vacuum feedthroughs for applying low DC voltages to Penning trap electrodes, high voltage lines for ion generation and RF ports for trap electron excitation and detection. This multipin feedthrough has to sustain high vacuum environment in a region surrounded by liquid helium in the bore of a 5Tsuperconducting magnet. Since the bore of the magnet has limited space, the feed-though pins required for different purposes have to be accommodated within very small dimension. Recently, a cryogenic feed-through was indigenously developed and performance test at 4K showed that it satisfied all required criteria [4]. The detection electronics developed by VECC was based on RF resonance absorption method. For detection of trapped electrons, a narrowband detection circuit, consisting of a high Quality factor helical resonator and a Low Noise Amplifier (LNA), indigenously built at VECC were used. In this amplifier design, active devices based on the GaAs technology have been used for its capability to operate at cryogenic temperatures and high magnetic field of around 5 Tesla [5].

Operation in cryogenic environment

Recently the complete PIT components were put together, the trap assembly along with detection circuit were put in a vacuum vessel shown in Fig.1. Ultra high vacuum (~ 10^{-9} mbar) was achieved in the chamber by month long pumping where the setup had been routinely warmed upto 80 °C. Once the ultimate vacuum was achieved, the trap chamber was disconnected from pump by pinching off the connecting tube and the chamber was immediately inserted in the liquid helium bath. After dipping the system, about a week was given for cryo-pumping and thermalization and then trapping operation was started. In order to achieve the required vacuum condition through cryo-pumping, special precautions were taken as described in the following section.

Fig. 1: Trap assembly with detection circuit inserted in vacuum chamber

Vacuum preparation

The Penning trap assembly has to be pumped only by cryo-pumping inside the liquid helium bath, because there is no arrangement to connect any external pump to the system. In order to prepare the system, the chamber was initially cleaned in an ultrasonic bath thoroughly. The connecting tube between the pump and the trap chamber was pinched off when the pressure gauge near the pump showed ultra-high vacuum (~ 10^{-9} mbar) after about a month of pumping. The pressure inside the chamber that was connected to the pump by a narrow tube was expected to be ~10^{-6} mbar at that time. However, after pinch off, the pressure inside the trap chamber was expected to be ~10^{-3} mbar within about 10 minutes that was sufficient to dip the trap assembly in the liquid helium bath. Inside the liquid helium bath, ultra-high vacuum was achieved through cryo-pumping by the adsorption of gas molecules to the liquid helium cooled walls of the chamber. It has been learned through trials that initial ultra-high vacuum (~10^{-9} mbar) was necessary for efficient cryo-pumping. Higher pressure resulted in larger number of gas molecules which were not efficiently adsorbed to the wall even at 4K as the walls became saturated after formation of a few mono-layers of adsorbed gas molecules. The achievement of ultra-high vacuum in 4K was confirmed through the successful emission of a field emission electron gun inside the chamber.

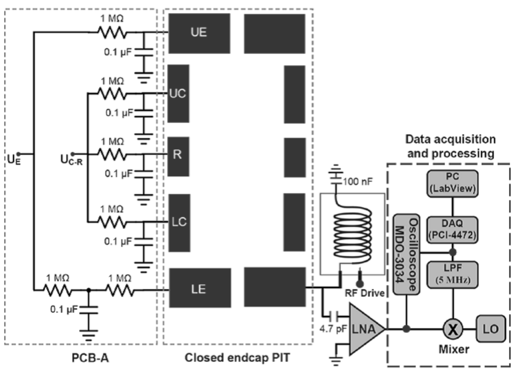

Fig. 2: Schematic detection circuit for trapped electrons at 4K

In the case of poor vacuum inside the trap chamber, the field emission tip sparked at around 100 V. Even after immersion in liquid helium, it was necessary to wait around a week to obtain ultra-high vacuum as cryo-pumping is a very slow process. Electrons were generated by field emission process at 1000V and then the trapping experiment was initiated.

Detection electronics testing at 4K

A schematic drawing of the resonant detection circuit comprising indigenously developed helical resonator and LNA is shown in Fig 2. The frequency response of the detection circuit when it is connected to the trap electrode at 4K is shown in Fig. 3. The Q-factor was measured by exciting the resonator with a -30 dBm signal about the resonance region and studying the response with frequency. It was found that the Q-factor improved from 96 at room temperature to 263 at 4K.

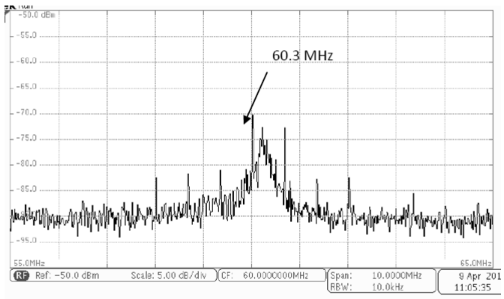

Fig. 3: Frequency response of detection circuit at 4K

Variation of trap parameters for detection of signal of trapped electrons at 4K is under process.

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References

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