A High Magnetic Field Penning Ion trap at Room-Temperature is made operational – A cloud of electrons successfully trapped and detected

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Introduction

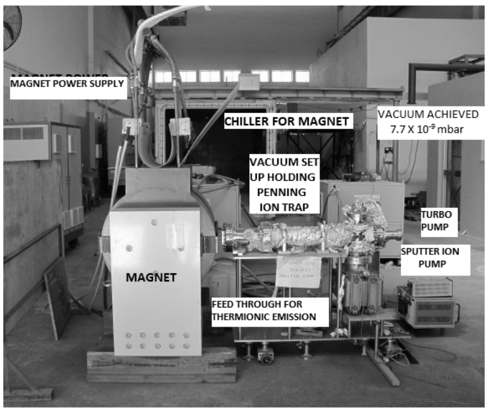
Trapping and cooling of ions provides an alternative way to study the atomic and nuclear properties instead of using ultra-high energy accelerator facilities. In recent years, experiments using trapped charged particles have contributed significantly in the precision measurements of nuclear masses, tests of quantum electrodynamics (QED) and studies on fine and hyperfine structure effects and in search of physics beyond standard model [1,2]. A room temperature Penning Ion Trap (RT-PIT) has been designed and developed for studying nuclear properties using atomic physics techniques based on mass spectrometry and LASER spectroscopy. RT-PIT has been operated successfully and the signal from a trapped cloud of electron has been observed.

RT-PIT setup

The magnet of this RT-PIT facility is an iron core electromagnet having high magnetic field intensity (~1.7T) at the center of a large air gap of 88mm. The uniformity the magnetic field is ~40 ppm over the Good Field Region (GFR) of ϕ2 cm x 1 cm. The weak quadrupolar field is generated by applying electric field to the trap electrodes having a hyperbolic design. The hyperbolic trap electrodes were designed in Atomic and Molecular Physics Division, BARC and fabricated in-house. The components were assembled, the electrical connections for thermionic emission, biasing the electrodes, detection were made before pumping for evacuation started. After several days of conditioning i.e. by baking and cooling subsequently, a vacuum ~ 7.7 $\times 10^{-9}$ mbar was achieved. The entire vacuum assembly was put on rails for precision positioning of trap centre in the GFR region. A description of the RT-PIT is available in [3] and the complete assembly is shown in Fig. 1.

Magnet Operation and Electron generation

The magnet was operated and magnetic field measurements were done using a 3D probe. A current of 585 ampere provided a magnetic field of 1.726 T. As a small field ~ 0.5 T is sufficient for electron trapping, the magnet was operated at 100 ampere current producing a magnetic field of 0.513 T at the center of the dipole magnet. In this Penning trap facility, cloud of electrons is generated using thermionic emission where the filament is heated by passing a constant current of 1.7 A.



VACUUM SET UP HOLD QUADRUPOLAR TRAP. THE SET UP HAS BEEN PUT ON WHEELS FOR MOVING TRAP SET UP IN AND OUT OF MAGNETIC FIED

Fig. 1: RT-PIT facility

Detection of trapped electrons

Trapped electrons are detected using RF resonance absorption method. In this technique, the detection circuit is tuned at a fixed resonance frequency (23.92 MHz). It is weakly excited using an external RF source and the trap potential is swept over a voltage range from 0.3V to 14.5V. At a given dc voltage, the axial frequency of trapped electrons coincides with the resonant frequency of tuned circuit. This results in a dip in the response of the detection circuit due to resonance transfer of energy from the tank circuit to the trapped electrons.

The detection electronics is developed at VECC for detecting the cloud of electrons. The trapped electrons are detected using a narrowband detection circuit shown in Fig. 2, consisting of a high Quality factor helical resonator [4] and a Low Noise Amplifier (LNA) [5] indigenously built at VECC. The output signal of LNA is further amplified using a second stage amplifier from mini-circuits (ZFL-1000LN). The amplified signal is down-converted to dc value using an RF mixer. The down-converted signal is filtered using a low pass filter with a cut-off frequency ~ 10 Hz. A Q ~ 80 is achieved at a resonant frequency of 23.92 MHz.

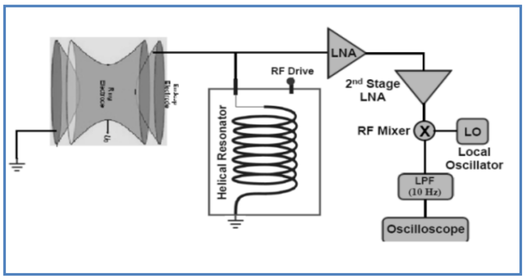


Fig. 2 Schematic PIT Detection circuit

A dip in the response of the detection circuit was observed indicating the transfer of energy from the tank circuit to the trapped electrons as shown in Fig. 3a. The observed dip signal is quite broad. It is also observed that reducing the RF excitation power from 0 dBm to -12 dBm result in lower magnitude of the absorption signal seen in Fig. 3b. This confirmed resonant absorption of energy by the trapped electrons.

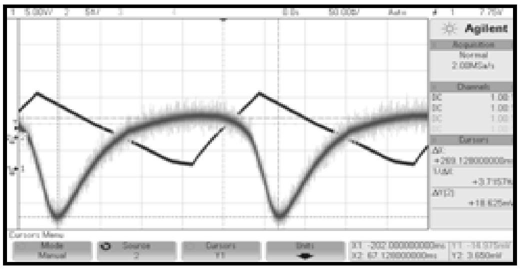


Fig. 3a : Signal from trapped electrons.

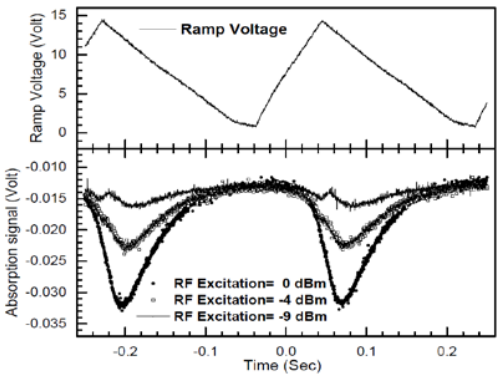


Fig. 3b : Variation in absorbed signal

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