Electron Trapping in VECC Penning Trap at 300K and 77K

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Introduction

A Penning trap facility has been indigenously built and tested at VECC, Kolkata both at room temperature and liquid nitrogen temperature. A charged particle could be trapped in 3D by the application of a strong magnetic field and weak quadrupolar electrostatic potential. The trapped charged particle undergoes a complicated motion comprising a simple harmonic axial, cyclotron and magnetron oscillations. In the case of electrons, the cyclotron frequency is generally very high (~GHz) and magnetron frequency is too low (~kHz), whereas axial frequency ~ tens of MHz. At VECC, a cloud of electrons was trapped in a closed-ended, 5-electrode, cylindrical Penning trap by applying an approximately homogeneous ~0.2T magnetic field and quadrupolar electrostatic potential ~10V. The axial oscillations of the trapped electrons were observed when the Penning trap was at room temperature as well as at liquid nitrogen temperature. Several tests were performed to characterize the axial oscillation signal and ensure that it was indeed due to the trapping of the electrons.

Experimental arrangement

A flat ended, 5-electrode cylindrical Penning trap was built at VECC, Kolkata. A schematic drawing of the trap has been shown in Fig. 1 and its dimensions have been tabulated in Table 1. Our simulation with SIMION code shows that the trap should have a large (~2mm) quadrupolar region so that electrons of different energies would oscillate with almost similar axial frequencies and generate a large signal at resonance. A strong magnetic field (~0.2T) was generated using NdFeB permanent annular ring magnets. A photograph and schematic drawing of the Penning trap assembly are shown in Fig. 2. The electrons were generated by applying a negative high voltage (~2 kV) to the Field Emission Point (FEP) tip and keeping the gold foil (C1) with a center hole at ground potential.

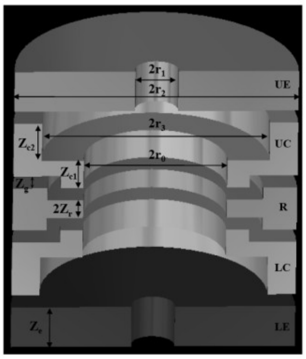

Fig. 1 Closed ended, five electrode Penning Trap. The electrodes are abbreviated as follow, UE: Upper End-cap, UC: Upper compensation R: Ring , LC: Lower Compensation and LE: Lower End-cap.

Table 1 Dimensions(mm)

r_0	3.29	Z_{c1}	1.38
r_1	1.00	Z_{c2}	1.89
r_2	6.50	Z_e	2.00
r_3	5.20	Z_g	0.60
Z_r	0.46		

The emitted electrons with ~2keV energy entered the Penning trap and ionized the residual gas in the trap to produce low energy secondary electrons that could be trapped by the trapping potential. The ring(R), upper compensation(UC) and lower compensation(LC) electrodes were electrically connected and a ramp voltage from 0V to -10V (frequency = 100 Hz) was applied. Lower end-cap electrode was electrically isolated and connected to the input of a parallel LCR circuit whose output was fed to a low noise cryogenic amplifier[2]. The resonance frequency of the LCR tank circuit was 62.3 MHz. The output signal of the low noise amplifier was mixed with a fixed 62.3 MHz frequency and passed through a low pass filter to produce a beat signal that is proportional to the number of the trapped electrons.

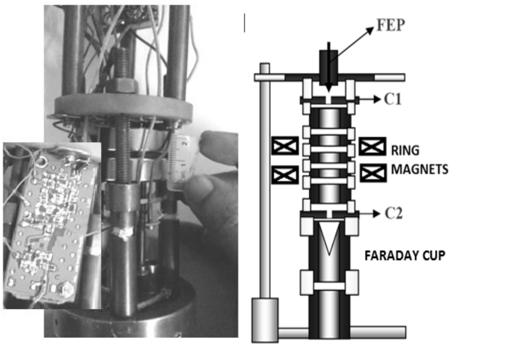

Fig. 2 Photograph and schematic drawing of the Penning trap assembly.

Observation of trapping signal

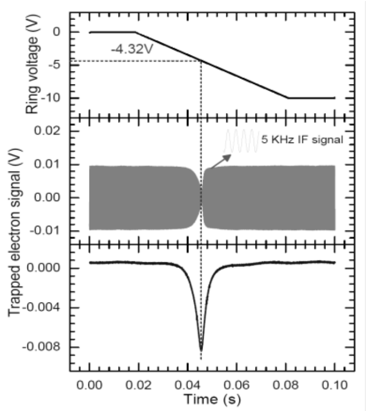

Fig. 3 Representative dip signal of trapped electron cloud.

Let $U_{C\text{-}R}(t)$ be the ramp voltage applied to the ring and compensation electrodes at time t. A fixed voltage U_E= -16V is applied to the end-cap electrodes so that the trapped electrons would see an effective potential difference of $U_{dc}(t)=U_E-U_{C\text{-}R}$. In Fig. 3(top panel), we show a plot of ramp voltage versus time. The middle panel of Fig. 3 shows the voltage dip in the down-converted IF signal of 5 KHz and a typical dip signal for RF drive power of -20 dBm at tank circuit resonance frequency = 62 MHz is shown in Fig. 3(bottom panel). The absorption signal for the down-converted 5 KHz IF signal as well as DC signal has been observed for a trap voltage, U_{dc} ~ -11.68V. The magnitude of the dip in the down-converted DC signal was found to be ~ 8.5 mV. It is seen that the magnitude of the dip signal as well as the ramp voltage at which it was observed varied each time the experiment had been repeated. The signal was observed at different ramp voltages in the range of -3.8V to -4.7V. This could be attributed to space charge effects and other imperfections in the trap.

The Penning trap was operated at 77K by immersing the setup in liquid nitrogen as shown in Fig. 4. The system behaved similarly at both 300K and 77K with reduction in signal height at 77K due to the production of fewer secondary electrons in better vacuum conditions.

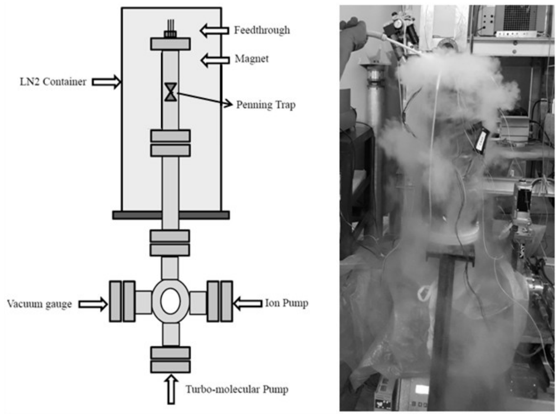

Fig. 4 Schematic drawing of the Penning trap vacuum setup and photograph of testing the setup at liquid nitrogen temperature.

Conclusion

The indigenously built Penning Trap has been successfully tested both at 300K and 77K. The dip signals have all the characteristics of a trapped electron cloud. A. Ray acknowledges financial assistance from SERB grant no: EMR/2016/001914.

References

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[2] A. Reza *et al.*, Rev. Sci. Instrum. **88** (2017) 034705.