Observation of the signal of the trapped electron cloud at 4K using VECC Cryogenic Penning trap

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Introduction

The Penning trap is a device where the charged particles could be stored in 3D by means of a static quadrupolar electrostatic potential and a homogeneous magnetic field. In this combined field, a charged particle exhibits bounded motions associated with three oscillation frequencies related to the axial, cyclotron and magnetron motions. This oscillation frequency has direct relations with the mass of the stored charged particle. However, a long storage time of the trapped particle is required for the high precision measurements of its various properties like mass, g-factor etc. The collisions between the stored charged particles and the residual gas molecules in the trap reduce the storage time of the trapped particle. Therefore, to reduce these collisions with the background gas molecules, an extremely high vacuum is required in the trap and this could only be achieved through cryo- pumping around 4K.

The cryogenic Penning trap facility at VECC has a sophisticated magnet cryostat where the trap along with its detection electronics were immersed in the liquid helium filled bore of a 5T superconducting magnet. The detailed descriptions of the magnet and mechanical assembly for immersing the trap assembly could be found in ref. [1, 2]. Recently, we observed the signal of a trapped electron cloud for the first time at 4K and it will be described in this work.

Preparation of the Penning trap setup for cryogenic operation

The Penning trap electrodes (except the signal picking electrodes) were kept in the same RF grounding conditions. All the components used in the setup were tested at 4K, because their datasheets do not contain the required information at 4K. The signal picking lower end cap was connected to a low noise amplifier (LNA) via a tank circuit. A carbon nanotube based field emission point (FEP) was integrated with the Penning trap assembly to generate an energetic electron beam of about 600 eV. A lot of care was taken to reduce the cross-talk among the connecting wires by using twisted pairs of wires with the ferrite cores. The optimization was also done in the mechanical arrangement of the feedthrough system. Two cryogenic electrical feedthroughs were used to separate out the high voltage lines from the other voltage cables and RF communication lines within the available 10 cm bore access area in the magnet-cryostat.

The trap assembly was placed inside a vacuum chamber that was initially pumped to 10^{-6} mbar and then placed in the liquid helium bath for cryo-pumping to an ultra-high vacuum. The detailed installation procedure could be found in ref. [3]

Observation of the signal of the trapped electron cloud at 4K

The frequency response of the detection electronics was measured after achieving thermal stability at a temperature of about 4K. The resonance frequency of the tank circuit was 59.3 MHz with quality factor ~ 200. In this test, the superconducting magnet was not turned on and a homogeneous magnetic field of ~0.1T was generated by a pair of annular permanent magnets for trapping the electron cloud. The trapping voltage applied to the ring electrodes (V_r) was varied between 0-10 volt in a repeated cycle with the time duration of ~300 milliseconds. The voltage at the compensation electrodes (Vc) was kept in a potentiometric configuration of $V_C/V_r = 0.8$.

Depending on the applied trapping voltage (V_r), the axial oscillation frequency kept changing [2] and at the resonance condition where the axial frequency was equal to 59.3 MHz, the maximum power transfer between the detection electronics and the trapped electron cloud occurred. This power transfer gave rise to a dip in the amplitude of the LNA output as shown in Fig. 1 & 2.

In Fig. 1 we have shown the response of the signal for different beam currents of the FEP ranging from 11 μA to 41 μA. The primary electron beam collided with the background residual gas molecules and generated low energy secondary electrons which got trapped eventually. As the beam intensity was increased, larger number of secondary electrons were produced. Hence the strength of the axial frequency signal increased with the higher primary electron beam current as shown in Fig. 1.

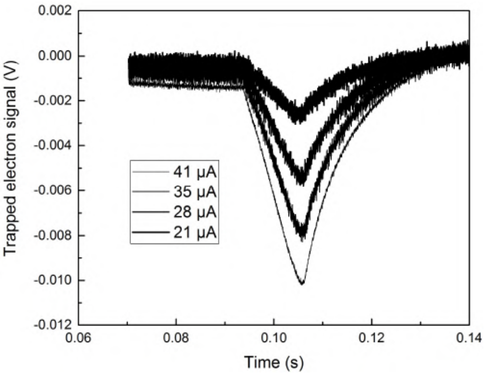

Fig. 1: The signal of the trapped electron cloud at different primary beam currents.

A weak rf signal at the resonance frequency 59.3 MHz of the tank circuit was applied to the upper endcap electrode to excite the electrons at resonance. As the rf excitation was increased, the amplitude of the axial oscillation of the electron cloud increased resulting in the increased signal strengths, as shown in Fig. 2. In Fig. 2 we have shown the response of the trapping signal for different rf excitation power ranging from -5 dB to +10 dB. The rf excitation frequency was varied from 58.9 MHz to 59.7 MHz keeping its amplitude and the primary electron beam current fixed. It was found that the amplitude of the signal of the trapped electron cloud peaked at the resonance frequency (59.3 MHz), as shown in Fig. 3, as expected.

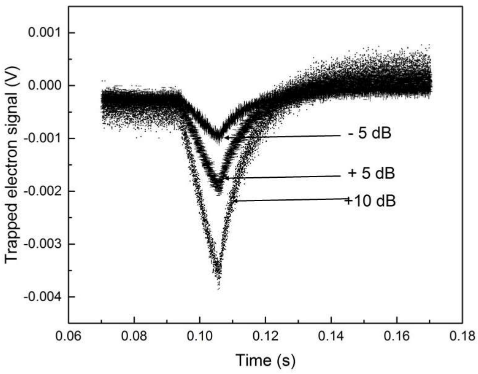

Fig. 2: The signal of the trapped electron cloud at different Rf excitations.

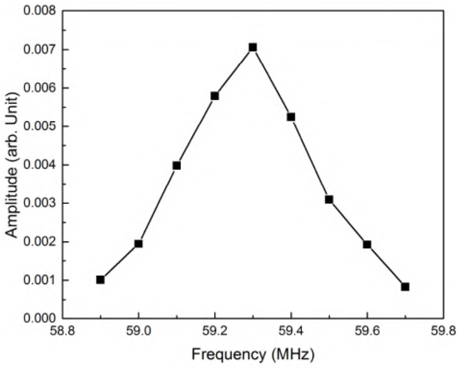

Fig.3: The variation of the amplitude of the trapped electron cloud signal at different excitation frequencies, while the intensity of the primary beam and excitation amplitude were kept fixed.

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References

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