Progress in VECC Penning Ion Trap Development

A. K. Sikdar[1], A. Reza[1], R.Menon[1], Y.P. Nabhiraj[1], K. Banerjee[2], B. Dam[2], P. Das[1], A.Ray[1]

[1]*Variable Energy Cyclotron Centre,1/AF Bidhannagar, Kolkata-700064*
[2]*Jadavpur University, West Bengal*
* *email: aksikdar@vecc.gov.in,ray@vecc.gov.in*

Introduction

VECC Cryogenic Penning Ion trap [1] is ready for commissioning. It will be initially tested at room temperature. In this report, the generation of electrons by field emission and detection technique employed to see the signal of a cloud of electron at room temperature have been discussed.

Room Temperature Penning Trap

The charged particles are trapped in a Penning trap under the combined application of a weak quadrupolar electrostatic potential and strong magnetic field [2]. Magnetic field confines the ions in radial direction and quadrupolar electrostatic potential provides axial confinement. In our room temperature Penning trap setup, magnetic field is provided by a NdFeB bar magnet which gives roughly 200 gauss magnetic field at the centre of the trap where the electrons would be trapped. Simulation of electron trajectory with SIMION software [3] has shown that magnetic field as low as 50 gauss is sufficient for trapping thermal energy electron when +10V is applied between ring and end-cap electrodes. Since the trapping time of electron depends on the background pressure, an ultra-high vacuum setup has been built and a pressure of 5×10^{-8} mbar has been achieved in our setup.

Electron Source

The electron source is made up of a sharpened tungsten wire of tip diameter of 1μm [called field emission point (FEP)] fixed to a holding plate and an acceleration electrode separated by macor insulator. When an electric potential of a few keV is applied between the holding plate and the acceleration electrode, electrons are emitted from the field emission point with an emission current $\propto E^2.e^{-1/E}$, E being the electric field at the tip. Typically an electric field of 1keV/mm was applied. The keV energy electrons produced by field emission interact with the residual gas and produce a large number of low energy secondary electrons that could be trapped. The FEP tip was tested at a pressure of 8×10^{-7} mbar. Initial emission of electron from tip requires around 4 kV but once the emission begins, voltages around 2.5 kV is sufficient to provide few μA current at acceleration electrode. A typical I-V characteristic curve of field emission current measured in our setup is shown in Fig. 1.

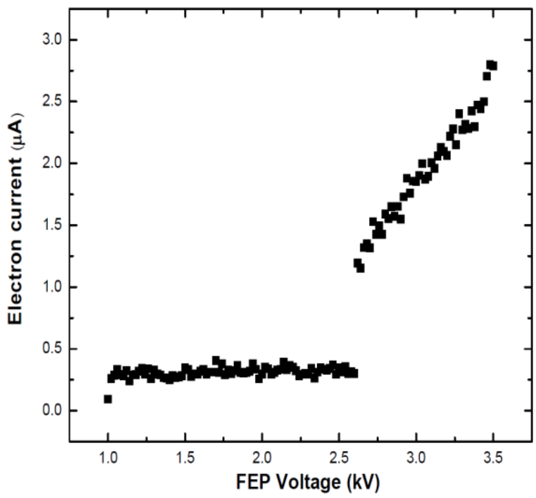

Fig. 1. Measured current-voltage characteristic of field emission point.

Trapping technique

We have employed non-destructive swept-tuned resonant technique for detection of trapped electrons. The image current induced by oscillating trapped electrons on the end-cap electrodes is picked up by a high quality factor resonant LC circuit (tank circuit). For this purpose, a high Q helical resonator [4] is developed. At resonance, the image current develops a large voltage signal across the tank circuit. This voltage signal is amplified by high input impedance, low noise amplifier to produce a measurable signal for further processing as shown in Fig. 2.

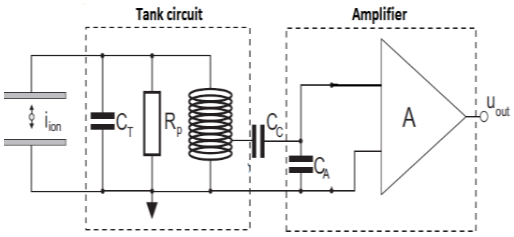

Fig. 2. Typical equivalent circuit of tank circuit coupled to trap electrodes and amplifier [5] where C_T is the capacitance of trap electrodes, C_A is the input capacitance of amplifier and C_C is the coupling capacitor.

The high Q tank circuit is realized in the form of a helical resonator developed at VECC. The Q factor of helical resonator with a capacitive load of 15 pF was measured to be 650 at a resonant frequency of 61 MHz. With the resonator coupled to the amplifier and end-cap electrodes of Penning trap, a Q factor ~ 250 is obtained at a resonant frequency of 61.45 MHz.

For the detection of trapped electron, tank circuit is weakly excited at its resonant frequency of 61.45 MHz. When the trapping voltage V between ring and end-cap is ramped, the axial electron oscillation frequency f_Z changes as given by equation (1)

$$f_Z = \frac{1}{2\pi}\sqrt{\frac{qV}{md^2}C_2} \qquad (1)$$

where C_2 and d depend on trap geometry. At a certain voltage (about 10 V) when the axial frequency f_Z becomes equal to f_o, the trapped electrons absorb energy and consequently a resonant damping in the response of the tank circuit would be observed. The signal from tank circuit is mixed with resonance frequency (f_o) signal and passed through a low pass filter. This produces a signal whose amplitude is proportional to the number of trapped electrons. A typical signal [6] along with the voltage ramp applied between ring and end-cap is shown in Fig. 3. The trap voltage in our experiment would be varied from -5V to +15 volts at a ramp frequency of about few Hz. The negative voltage applied to the electrodes will ensure complete expulsion of trapped electrons after each detection cycle and one would obtain identical initial conditions at each detection cycle.

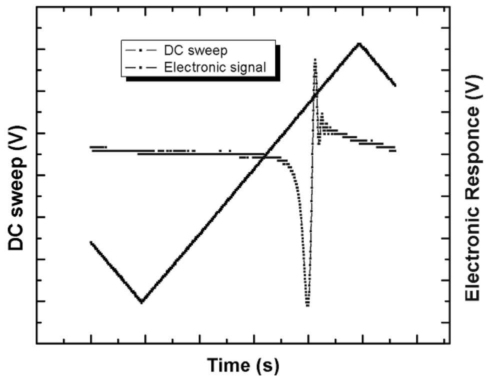

Fig. 3. Typical signal obtained along with voltage ramp.

Trials will be attempted to see the signal of trapped electrons in near future.

References

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