Indian J.Sci.Res. 13 (1): 20-23, 2017

ISSN: 0976-2876 (Print)
ISSN: 2250-0138 (Online)

THE EFFECT OF ASYMMETRIES ON DEPENDENCE OF CONFINEMENT TIME OF ELECTRONS ON MAGNETIC FIELD IN A GEOMETRICALLY PERTURBED QUADRUPOLE PENNING TRAP

B.M. DYAVAPPA[a1], DURGESH DATAR[b] AND SHARATH ANANTHAMURTHY[c]

[abc]Bangalore University, Bengaluru, Karnataka, India

ABSTRACT

Electrons are confined in quadrupole penning trap under various magnetic fields. The space charge effects and imperfections in the trap geometry cause perturbations, therefore electrons are lost from the trap. The nature of the perturbations should be understood, for developing methods for minimizing instabilities to confine electrons. We are presenting results that characterize the anharmonicity due to asymmetries arising from geometrical perturbation through identifying dependence of confinement time of electrons on magnetic field. The confinement time (τ)of a trapped electron is directly proportional to the square of the external magnetic field ($\tau \propto B^2$) in the absence of perturbations. However asymmetries in the hyperboloid geometry and anharmonicities due to the space charge effects limit the confinement timeand alter the nature of its dependence on magnetic field. We have measured the confinement time of an electron cloud under weak magnetic fields from 250G to 7500G. The confinement time in our experiment found to scale with external magnetic field as $\tau \propto B^{1.41}$.When the trap is further perturbed by distortion through pushing the filament slightly into the trap region, the asymmetry introduced results in further degradation of the confinement time and it was found that the confinement time $\tau \propto B^{0.27\pm0.03}$.This confirms a strong dependence of the confinement time on asymmetries in the trap and reduces confinement time under identical conditions.

PACS:37.10.Ty: Ion trapping, 41.85.Lc: Quadrupole, 52.20.Fr: Electron collisions

KEYWORDS: Assymmetry, Confinement Time, Anharmonicicity, Quadrupole Penning Trap

In Penning trap electrons are confined through the superposed electric and magnetic fields. The electric field confines electrons in the axial direction through an electric potential minimum. The electrons inside the trap are confined in the radial direction by the Lorentz force of magnetic field. An essential requirement of the ion traps is to trap electrons for a long period of time. However, the anharmonicities caused by the imperfections in the trap cause the confinement time of trapped electrons to be finite. There is no force due to the electric field alone, in the radial direction that drives the electrons towards the centre of the trap. The harmonic potential minimum confines the electrons in the axial direction. The trapped electrons may escape from the trap due to various reasons. Thus, a large number of electrons are lost in the radial direction due to plasma expansion(R C Davidson and Chao E H, 1996; E H Chao et al., 2000).Theoretically two-component electron plasma can be confined for very long period of time. The confinement time of an electron found to scale as $\tau \propto B^2$(J Notte and J Fajans, 1994; J H Malmberg and Driscoll C F,1980; C F Driscoll and J H Malmberg, 1983).When the trap is at low pressures and high magnetic fields then the confinement time of electrons depends on magnetic field as$\tau \propto B^{1.5}$(J Notte and J Fajans, 1994).On the other hand if the trap is at slightly high pressures and low magnetic fields the confinement time is slightly more than $\tau \propto B^2$ dependence. The asymmetries in the hyperboloid geometry and anharmonicities limit the confinement time and the confinement time in these conditions found to scale as$\tau \propto B^{1.41}$(Dyavappa B M et al. 2017).When the trap is further perturbed by distortion through pushing the filament slightly into the trap region, the asymmetry introduced results in further degradation of the storage time and it was found that the confinement time $\tau \propto B^{0.27\pm0.03}$ .This confirms a strong dependence of the confinement time on asymmetries in the trap and reduces confinement time under similar condition.

THEORY

The quadrupole Penning trap consists of two identical end-cap electrodes and a ring electrode as shown in Fig.1.The three dimensional quadrupole electric potential is given by (R D Knight, 1983)

$$\Phi(x, y, z) = \frac{U_0}{r_0^2 + 2z_0^2}(2z^2 - x^2 - y^2) \quad (1)$$

Where, U_0 is the applied electric potential, $d = \sqrt{r_0^2 + 2z_0^2}$, is the dimension of the trap.

[1]Corresponding author

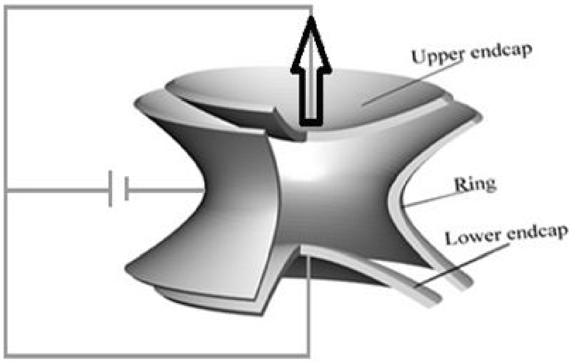

Figure 1: Quadrupole Penning trap

The equation of hyperbola of ring electrode is given by (F G Major et al. 2005;P K Ghosh, 1995)

$$\frac{r^2}{r_0^2} - \frac{z^2}{z_0^2} = +1 \quad (2)$$

And the equationof hyperbola of two end- cap electrodes are given by(F G Major et al. 2005;P K Ghosh, 1995)

$$\frac{r^2}{r_0^2} - \frac{z^2}{z_0^2} = -1 \quad (3)$$

Where$r_{0=}\sqrt{2}\,z_0$, $r_0$is the inner radius of the ring electrode and z_0 is half the distance between the two end-caps.Our quadrupole Penning trap designed with the radius of the ring electrode $r_{0=}\sqrt{2}\,z_0 = 7mm$ and z_0 is 5mm. The pole pieces of the magnet are separated by 11.5cm.The hyperboloid surfaces of electrodes aremachined to a surface fineness of about 15μm. Electrons enter through a hole of *3mm* diameter drilled in one end-cap electrode of the trap. The outer structure of the trap appears to berectangular and is placed in a cylindrical glass chamber which is connected through flanges and bellows to a six-way cross vacuum chamber.A thoriated-tungsten filament bent into V-shape, fixed through screws and nuts, which ejects electrons into the trap when filament current is switched ON (K T Sathyajit, 2010).A slightly extralength filament is fixed inside the trap as shown in Fig.2,in these conditions the hyperboloid geometry is slightly gets modified causing extra loss rate of electrons.

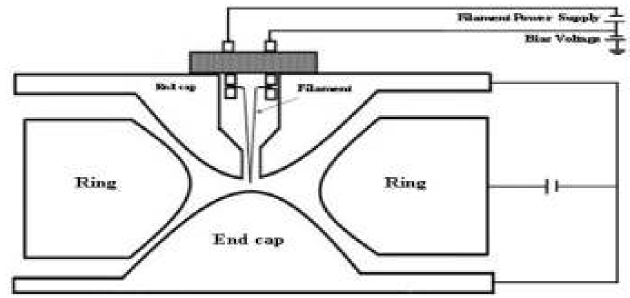

Figure 2: Quadrupole trap with extra lengthy filamentbeing inserted into the trap region

EXPERIMENTAL PROCEDURE

The confinement time of the electrons trapped in an ion trap is '*the time during which the total initial number of electrons decreases to* $1/e$ *of the original number of electrons'*(Soumen Bhattacharya et al. 2006; K T Satyajit et al. 2010).

i.e., $$N(t) = N_0(t_1) + N_0(t_2)e^{-\frac{t}{t_2}} \quad (4)$$

Where N_0 is the original number, $N(t)$ is the number after time *t* and $\tau = t_1 + t_2$ is the confinement time of electrons trapped in ion trap as shown in Fig. 3. Theelectrons are generated by the passage of 6V dc current through the thoriated-tungsten filament and are loaded into trap, and then the filament current is switched OFF (C W Oatley, 1975). At resonance the number of trapped electrons is measured through ramping, mean while the trapping voltage is applied. The confinement time of trapped electrons is measured by acquiring resonance absorption signal, the data obtained is fitted to exponential decay function which gives a loss curve of the trapped electrons as a function of time. The resonance absorption signal of the trapped electrons was acquired at fixed intervals of time. The number of trapped electrons is measured continuously up to 1second in time steps of 10ms. The process is repeated after the filament current is switched OFF. The resonance induced ejection of the trapped electrons from the trap in each ramp cycle cause inaccurate measurement of confinement time. The filament current fluctuates and hence single loading of electrons is more helpful than continuous loading to measure accurate confinement time (K T Satyajit et al. 2010).

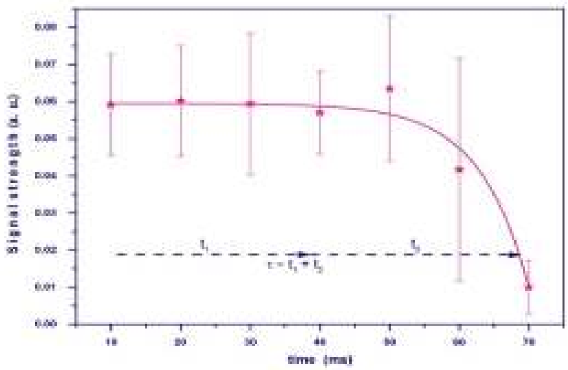

Figure 3: Confinement time of the electrons trapped in an ion trap

RESULTS AND DISCUSSION

Confinement time dependence on magnetic field in a geometrically perturbed trap: The product of the peak of signal amplitude and full width at half maximum of resonance absorption signal of electrons is plotted against the scanning time interval. Alternately, the height of resonance absorption signal of electrons is plotted against the scanning time interval (Soumen Bhattacharya et al. 2006). The confinement time of trapped electrons is measured by acquiring resonance absorption signal, the data acquired is fitted to exponential decay function which gives a loss curve of the trapped electrons as a function of time. The following graphs are plotted for signal decay of electrons at magnetic field range of 250G-7500G, at a pressure of 2×10^{-8} $torr$.Figures 4(i), (ii) and (iii) show the fall-off of signal strength of electrons with time, for electron loading times of 2s, 10s and 30s respectively and which reveal the confinement times of 69.97ms, 68.82ms and 67.89ms respectively. When the trap is further perturbed by distortion through pushing the thoriated-tungstenfilament slightly into the trap region, the asymmetry introduced results in further degradation of the confinement time. When experiment was performed from 250G to 750Gthen the confinement time gradually increases from 60ms to 75ms.The $B - \tau$ graph in this region is linear on logarithmic scales, and the slope is found to be 0.27. The effect of loading time of electrons was ruled out as the confinement time remains almost a constant as in figures 4(i), (ii) and (iii). The $B - \tau$ graph in Fig.5 shows that$\tau \propto \mathrm{B}^{0.27\pm0.03}$.

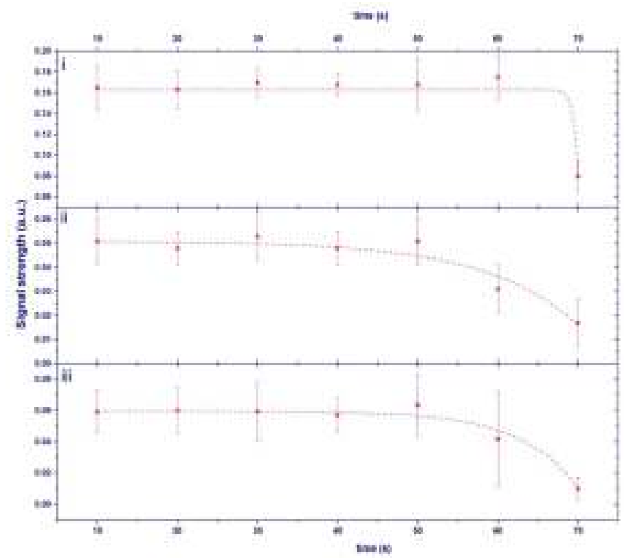

Figure 4: Electrons' signal strength fall-off with time (i) Loading time 2s, $\tau = 69.97$ms (ii) Loading time 10s, $\tau = 68.82$ms and (iii) Loading time 30s, $\tau = 67.89$ms

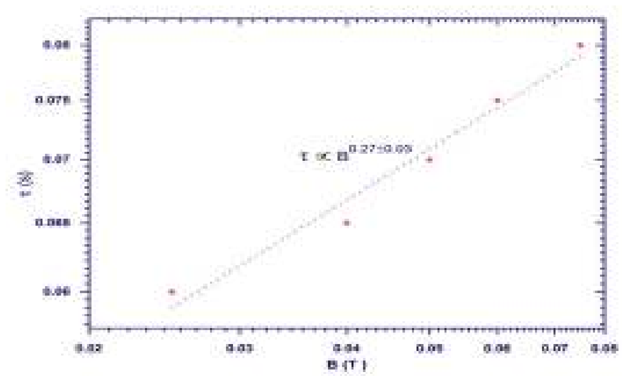

Figure 5: Dependence of confinement time with magnetic field in the range from 250G to 750G

CONCLUSION

It is very essential to trap electrons in the ion traps for a long period of time. However, the confinement time of trapped electrons is found to be finite due to the anharmonicities in the trap. The investigations to reduce anharmonicities in the trap are therefore quite essential. The confinement time for single electron in a symmetric trap is $\tau \propto B^2$(J Notte and J Fajans, 1994; J H Malmberg and Driscoll C F,1980; C F Driscoll and J H Malmberg, 1983).When non-neutral electron plasma is confined in a Penning trap, space charge effects lead to small shifts in eigen frequencies - the modified cyclotron frequency (f_c'), magnetron frequency (f_m) and axial oscillation frequency

(f_z)of electrons. As few millions of electrons are trapped the space charge effects are clearly observed (Yu J Desaintfuscien M and Plumelle F, 1989).The asymmetries in the hyperboloid geometry and anharmonicities limit the confinement time and in these conditions found to scale as $\tau \propto B^{1.41}$(Dyavappa B M et al. 2017).When the trap is further perturbed by changing the electron filament's position bypushing slightly into the trap, the asymmetry was introduced and it was found that the confinement time found to scale as $\tau \propto B^{0.27\pm0.03}$ .This confirms a strong dependence of the confinement time on asymmetries in the trap and reduces confinement time.

ACKNOWLEDGEMENT

Prof. Pushpa Rao, Spectroscopic Division, BARC Mumbai India.

REFERENCES

Chao E. H., Davidson R.C., Paul S. F. and Morrison K.A., 2000. Effects of background gas pressure on the dynamics of a non-neutral electron plasma confined in a Malmberg-Penning trap. Physics of Plasmas, **7**(3):831.

Driscoll C. F. and Malmberg J. H., 1983. Length-dependent containment of pure electron plasma column, Phys. Rev. Lett., **50**:167.

Oatley C.W., 1975. The tungsten filament gun in the scanning electron microscope. J. Phys. E: Sci. Instrum.

Davidson R.C. and Chao E.H., 1996. Nonlinear expansion and heating of non-neutral electron plasma due to elastic collisions with background neutral gas, Physics of Plasmas.

Dyavappa B.M., Durgesh Datar, Prakash, Satyajith K.T, Sharath Ananthamurthy, 2017. Depenedence of confinement of electron plasma on magnetic field in a Quadrupole Penning trap (communicated in EJPIT).

Major F.G., Gheorghe V.N. and Werth G., 2005. Charged Particle Traps, Physics and techniques of charged particle confinement-17, 18, 19, 20, 21, 44, 49, 67, 78, 79.

Malmberg J.H. and Driscoll C.F., 1980. Long-Time containment of a pure electron plasma. Physical Review Letters, **44**:654-657.

Notte J. and Fajans J., 1994. The effect of asymmetries on non-neutral plasma confinement time. Department of Physics, University of California, Berkeley, California.

Sathyajit K.T., PhD thesis, 2010. Spectroscopy of electrons and ions in electromagnetic traps.

Satyajit K.T., Gupta A., Joshi G., Mohan S., Rao P. and Ananthamurthy S., 2009. Loading Detection and Number Estimation of an Electron Plasma in a Penning Trap. Plas.Sci.Tech., **11**(5).

Satyajit K.T., Datar D. and Ananthamurthy S., 2010. Electron Storage Instabilities and Resonances in a Quadrupole Penning Trap. Asian Journal of Physics, **19**(3):1-8.

Ghosh P.K., 1995. Ion Traps,Clarendon Press, Oxford.

Knight R.D., 1983. The general form of the quadruple ion trap potential. Int.J.Mass.Spec.Ion.Proc., **51**:127. 8, 25, 26.

Bhattacharya S., Guptha A., Nakhate S.G. and Rao P.M., 2006. Measurement of storage time estimation of ion number and study of absorption line profile in a Paul trap. PRAMANA journal of Physics. **67**.

Yu J., Desaintfuscien M. and Plumelle F., 1989. Ion density limitation in a penning trap due to the combined effect of asymmetry and space charge. Applied Physics B Photophysics and Laser Chemistry.