Axial oscillations of electron cloud in Penning Trap

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Introduction

An electron cloud was trapped in a Penning trap under the application of a strong magnetic field of 0.2T produced by annular permanent magnets and a weak quadrupolar electrostatic potential ~10V. The trapped electron cloud underwent a complicated motion in 3D comprising axial, cyclotron and magnetron oscillations [1,2,3]. The axial oscillation was about 62 MHz and the corresponding induced voltage on the end-cap electrode was picked by a resonant LCR circuit, amplified by an amplifier and mixed with a suitable frequency to observe as a beat signal. The details of the experimental arrangement have been described in ref. [4].

We have studied the characteristics of the trapped electron cloud and seen how it behaved when the system was excited by a radiofrequency (RF) drive. The nonlinear characteristics of the trapped electron cloud were studied by observing sub-harmonic and higher harmonic axial oscillations of the system under the application of a RF drive.

Variation of trapping signal with end-cap voltage

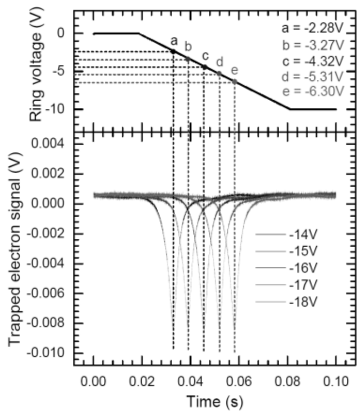

Fig. 1 Variation of dip signal with various end-cap voltages.

The ring and compensation electrodes were electrically connected and a ramp voltage $U_{C-R}(t)$ was applied to them. A fixed voltage U_E was applied to the end-cap electrodes so that the trapped electrons would see an effective potential difference of $U_{dc}(t)=U_E-U_{C-R}(t)$. A RF signal having frequency = 62.3 MHz was applied to the lower end-cap electrode to excite the electrons. The axial oscillation of the electrons was seen as a dip signal in the beat spectrum when the axial frequency of electrons matched with the natural frequency of LCR circuit creating resonance condition for a specific value of U_{dc}. When the potential on the end-cap electrode was changed to a different value, the position of the dip signal shifted accordingly as shown in Fig. 1 [5]. It has been observed that the position of the dip signal shifted by almost 1V for a unit change in the voltage on end-cap electrodes.

Variation of trapping signal with RF excitation power

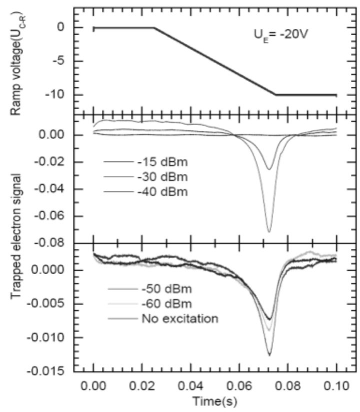

Fig. 2 Variations of dip signal for various strengths of RF excitation.

In Fig. 2(top panel), ramp voltage versus time plot has been shown. In Fig. 2(middle and bottom panels), the variations of the magnitude of dip signal for different RF power in the range from -15 dBm to -60 dBm and also for no RF drive have been shown. The magnitude of dip signal increased with the increase in RF power drive from -60 dBm to -30 dBm. However, when very large RF power (-15 dBm) was applied, the electrons escaped from the trapping well leading to the disappearance of the dip signal. One of the interesting observations is the occurrence of dip signal with no RF drive. This is the attributed to the excellent performance of our low noise amplifier which could pick up tiny signals of the trapped cloud of electrons oscillating coherently inside the trap without any RF excitation.

Fractional Frequencies

When a harmonic system is excited at a frequency which is twice as high as the eigen-frequency of the system, i.e. 2ω, then the system itself starts oscillating at a frequency ω. This is known as parametric excitation. Additionally one observes resonances at the fractional frequencies 2ω/n, where n is an integer. These subharmonics are one of the fundamental characteristics of the nonlinear systems [6,7].

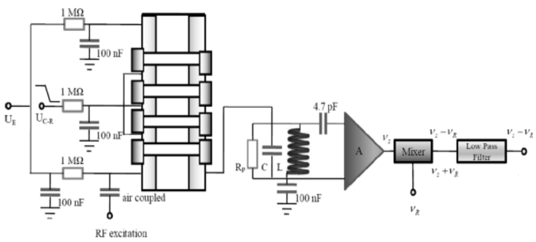

Fig. 3 Electronic circuit diagram

We excited the axial motion of the trapped electrons by R.F. field at resonance frequency of the tank circuit (ω_z= 62.3 MHz, power= -20 dBm) applied to the lower end-cap electrode. The axial motion of the electrons produced induced ac voltage on the end-cap electrode that was amplified, mixed with a suitable frequency from a local oscillator (LO) and seen as a beat signal [8].

In the beat spectrum, we observed dip signals at LO frequencies $2\omega_z/n$, where n is an integer ranging from 1 to 31. The observation of minimum signal height was limited by the noise floor of the amplifier. The dip signals observed at frequencies $2\omega_z/n$ behaved in similar fashion with variation of end-cap voltages and excitation power. The variation of magnitude of dip signal for different values of n at various frequencies $2\omega_z/n$ is plotted in Fig. 4. One of the interesting observation is the enhancement of signal strength at the order n=2(2m+1), where n and m are an integers.

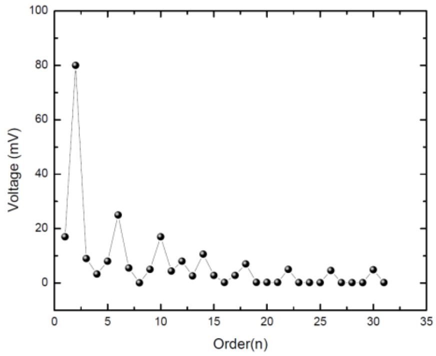

Fig. 4 Signal height at frequencies $2\omega_z/n$ for order n =1 to 31.

Conclusion

We have studied the behavior of trapped electron cloud with variations of end-cap voltage and the strength of R.F. drive. The presence of subharmonics was seen in the axial oscillation indicating the nonlinear characteristics of the system. We are in the process of quantitatively understanding the results. A. Ray acknowledges financial assistance from SERB grant no: EMR/2016/001914.

References

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