Acoustic detection of the parametrical resonance effect for a one-component microplasma consisting of the charged microparticles stored in the electrodynamic traps

O. S. STOICAN[*], L. C. DINCA, G. VISAN, S. RADAN
National Institute for Lasers, Plasma and Radiation Physics (INFLPR),
PO Box MG-36, Bucharest-Magurele, ROMANIA

One-component (non-neutral) microplasmas are created in a linear electyrodynamic trap when confining charged microparticles under standard pressure and temperature (STP) conditions. In this paper principle of a method aimed to characterize and to manipulate the stored microparticles is proposed. The method is based on the excitation of the parametrical resonance of the stored microparticles. The excitation field consists of an acoustic wave generated by an external loudspeaker. The effect of the excitation field is observed by analyzing the variation of the intensity of the light scattered by the stored microparticles located on the linear trap axis. Preliminary results are reported.

1. Introduction

The linear electrodynamic trap is a modified version of the classical quadrupole trap first proposed by W. Paul in 1953. The motion properties of a charged particle stored within a quadrupole trap are very well known and are discussed in many papers (e.g. [1]). The electric field generated by the quadrupole trap electrodes creates a potential wall where some kind of charged particles species can be confined. The charged particles are stored in the trap from hours up to months in a quasi interaction-free environment. Various species of charged particles of micrometer dimensions (microparticles) can be stored. In this way a quadupole trap represents an useful tool for various studies, particularly in the field of environment researches (aerosols study) and materials physics (powders study). This work is aimed to study the necessary conditions for the manipulation of the stored particles using an acoustic field.

2. Experimental setup

The structure of the linear electrodynamic trap is similar to that already described in [2] and [3]. Thus, the linear trap consists of four identically brass rods (Fig.1) E_1, E_2, E_3, E_4 of 10 mm in diameter, equidistantly spaced on 10 mm radius, and two "endcap" electrodes E_5, E_6. A hole drilled into one of the endcap electrode (E_5) allows the passing of a laser beam along the longitudinal trap axis. The other endcap electrode (E_6) is a piston cylinder sliding on the brass rods so that the trap length is variable. In order to avoid the perturbations produced by the air streams the whole trap is placed inside a transparent Plexiglas® box.
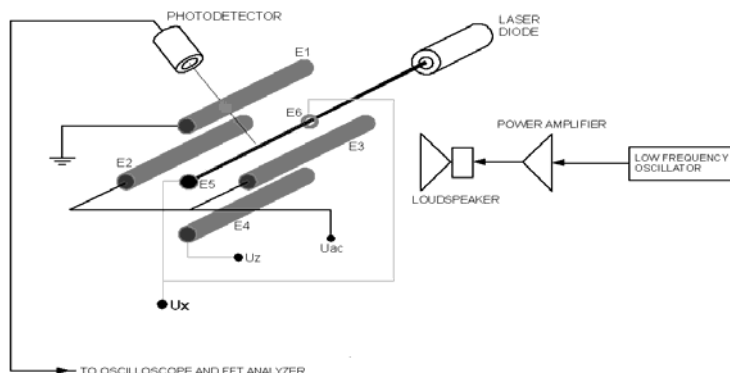

Fig. 1. The block diagram of the experimental setup.

The diagram of the electric supply circuit for the linear electrodynamic trap electrodes is shown in Fig. 2. The rod electrode E_1 is connected to the laboratory ground. A high ac sinusoidal voltage $V \cos \Omega t$ is applied to electrodes E_2 and E_3. A dc voltage U_z applied to electrode E_4 is used to balance the gravity force. By varying the voltage U_z the stored particles cloud can be shifted vertically. The dc voltage U_x applied to the endcaps electrodes E_5, E_6 is used to assure the axial stability of the stored particles. The usual values for the voltages applied to trap electrodes are summarized in Table 1.
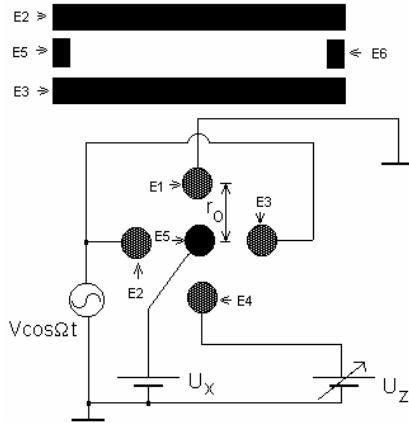

Fig. 2. Electrical circuit of the linear electrodynamic trap electrodes.

Table 1. The usual values for the voltages applied to the linear electrodynamic trap electrodes

Voltage	Electrodes	Frequency	Comments
$U_{ac}=V cos \Omega t$;V=0-4kV	E_2,E_3	30-100Hz	
U_z =0-1000V	E_4	dc	Polarity can be reversed
U_x=0-1000V	E_5,E_6	dc	

3. Principle of the method

The confinement of a certain charged particle depends on its charge to mass ratio, *q/m,* and the parameters of the trap, respectively. Accordingly to the existing theory the trajectory of a confined charged particle is very complicated, but in usual conditions it can be expressed as: $x_i = R_i \cos \omega_i t (1+ \frac{q_i}{2} \cos \Omega t)$. As a consequence, the motion of a charged particle confined in a Paul trap can be decomposed in a harmonic oscillation at frequencies ω_i /2π with amplitude R_i, called "secular motion", and a "micromotion" at the frequency of ac supply voltage $\Omega/2\pi$ [4] . Theoretically, if a supplementary excitation field having angular frequency equal to 2ω_i is applied then the amplitude of the stored particles motion increases exponentially (parametrical resonance effect). The other weak resonances may also occur at frequencies expressed by the relation $p\Omega /2 \pi \pm q\omega_i /2\pi$. If the amplitude of the excitation signal is strong enough and its frequency has an

appropriate value, as explained above, the certain microparticles species could be rejected out from the trap.

The supplementary excitation of the stored microparticles motion is produced by the acoustic waves due to a loudspeaker. The microparticles have been stored in air at normal pressure. The acoustic waves determine an oscillatory movement of the air molecules. The stored particles are dragged by the moving air molecules which act as a supplementary force field. The loudspeaker is excited by a low frequency oscillator. The effect of the excitation field is observed by analyzing the variation of the intensity of the light scattered by the stored microparticles placed on the linear trap axis. In this purpose the output beam of a low power laser diode is focused on the longitudinal axis of the linear trap where the density of the stored particles has a maximum value. An integrated photodetector directed normal to the linear trap longitudinal axis collects a fraction of the radiation scattered by the stored microparticles and converts it into an electrical signal. This detection principle is suggested by the method described in [5] applied to a linear electrodynamic trap. The output electrical signal provided by the integrated photodetector is amplified then is displayed using a digital oscilloscope. The amplitude of this signal depends on the number of the stored microparticles located near the symmetry-axis of the trap and illuminated by the laser beam. A spectrum analyzer is used to perform Fourier transform of the signal allowing a frequency domain analysis of the scattered radiation intensity. By analyzing the time variation of the photodetector output signal amplitude as a function of the acoustic wave frequency the parametrical resonances might be detected. Knowing the frequency of the secular motion the stored particle charge to mass ratio, *q/m,* can be estimated as $q/m \sim \omega_i \Omega z_0^2/V$. Thus, this technique represents an effective alternative to the electrodynamical balance method.

4. Results and discussion

In Fig. 3 is shown the spectrum of the photodetector output signal without the acoustic excitation. The operating point of the electrodynamic linear trap was characterized by the following parameters: U_{ac}=3kV$_{rms}$, $\Omega/2\pi$=85.3Hz, U_z=501V, U_x=634V, trap length = 50mm. The stored microparticles consist of the Al_2O_3 powder with 63-200 μm in diameter.
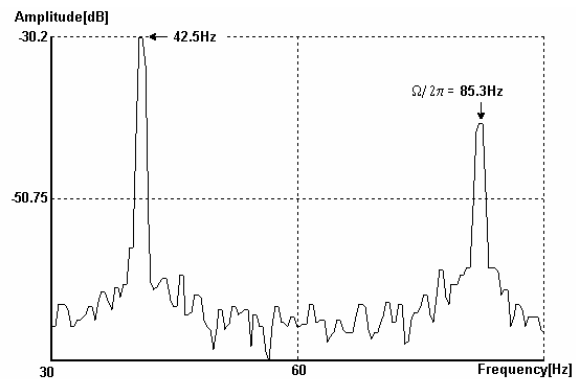

Fig. 3. The spectrum of the photodetector output signal without the acoustic excitation.

The spectrum of the photodetector output signal contains two main components, namely, 85.3Hz, corresponding to the frequency of ac supply voltage $\Omega/2\pi$, and 42.5Hz, respectively. The amplitude of the

$\Omega/2\pi$ component represents a measure of the charged particle density stored in the region of the trap longitudinal axis. Using a lock-in amplifier, this amplitude has been measured independently. In this purpose the electrical signal from the integrated photodetector is applied to the lock-in amplifier input, while a square-wave signal in phase with ac supply voltage is used as a reference signal. The time variation of the lock-in amplifier output voltage is recorded by a digital oscilloscope. Preliminary studies on the particle motion amplitude as a function of the acoustic wave frequency have been performed. The acoustic wave frequency has been varied in the range from 20Hz to 200Hz. The frequency of ac supply voltage $\Omega/2\pi$ was maintained at 85.3Hz. The experimental results shown an important variation of the $\Omega/2\pi$ component amplitude for the acoustic wave frequency near the 42.5Hz or 85.3Hz. The phenomenon appears to be similar to beats oscillations due to the interference of two harmonic signals. In Fig. 4 is shown the time variation of the $\Omega/2\pi$ component amplitude produced by the action of an acoustic wave at the frequency 87.4Hz. The variation of the $\Omega/2\pi$ component amplitude increases with the intensity of applied acoustic wave.
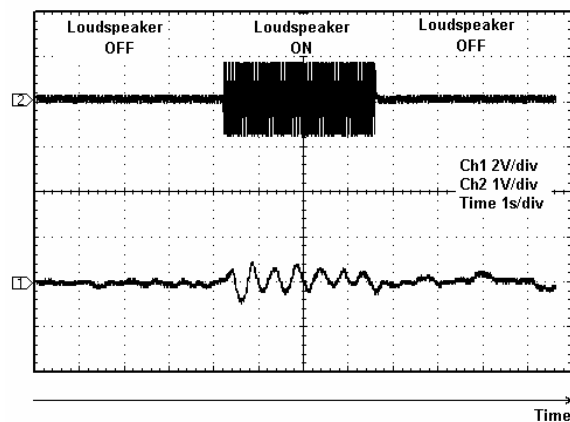

Fig.4. Oscilloscope image representing the time variation of the $\Omega/2\pi$ component amplitude as a result of the action of an acoustic wave at 87.4Hz. Lower trace (1)- the time variation of the $\Omega/2\pi$ component amplitude. Upper trace (2)- the excitation signal applied to the loudspeaker.

5. Conclusions

The described experiment shown that the charged particle density stored in the region of the trap longitudinal axis can be modified using an acoustic wave at an appropriate frequency. An experimental difficulty arises from the low efficiency of the common loudspeakers at low frequency. The complete interpretation of the experimental results requires the existence of a theoretical approach able to describe properly the motion of a charged particle in a quadrupole electric potential taking into account the friction charged particle-air.

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*Corresponding author: stoican@infim.ro