*33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.**30I**, P-2.079 (2006)*

FIR scattering on plasma crystals

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Abstract

We have designed, built, and characterised parts of an experiment for collective Far-Infrared (FIR) scattering on plasma crystals. This method is similar to the Debye-Scherrer and Laue procedures and should allow examination of dynamic collective properties of plasma crystals.

Introduction

Plasma crystals – discovered in 1994 [1, 2] – are a most interesting object to study various aspects of condensed matter both experimentally and theoretically [3]. Among these are structure, dynamics, phase transitions, defects, and thermal properties. All the experiments are done by observing individual particles or planes of the particle cloud via (scanning) laser sheet illumination or by direct imaging. This allows a direct access to the crystal phenomena involved on the kinetic level which is a big advantage of the investigation of plasma crystals compared to the study of solid state crystals. But this approach has disadvantages as soon as statistical quantities are tried to be measured like the crystal temperature [4], the time evolution of the density of defects and crystalline domains, or the ratio of the number density of different structure domains during a structure phase transition. When analysing the structure and dynamics of relatively large 3d or "2.5d" plasma crystals, visual observation methods meet their limits because the simultaneous determination of all 3d particle positions is challenging but essential. The opaqueness of a particle ensemble is a big problem. Furthermore, when using two or more cameras it is necessary to identify one and the same particle in the different video frames recorded under different angles of view. This becomes a major problem when a huge number of particles has to be analysed. The digital holographic particle image velocimetry which is under development could be a solution to the problem for the future [5].

To overcome the drawbacks of exclusive optical observations, we propose the adaptation of the Debye-Scherrer and Laue procedures – well known from solid state physics – to the investigation of plasma crystals and their simultaneous use together with the standard optical observation. With this approach one could directly assess the former procedures and gain a new access

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to plasma crystals which could lead to the observation of hitherto non accessible phenomena. To obtain collective scattering the incoming wavelength has to be in the range of but smaller than the lattice constant which is of the order of several Debye lengths and lies between 100 and 500 μm in our 3d crystals. For this reason we use the Far-Infrared (FIR) wavelength region for the collective scattering investigations. It is expected that well defined interference reflexes occur. Their analysis will not only yield information on the structure but also on the quality of the crystal and its collective dynamic effects, e.g. during melting or when electric and magnetic fields are applied. The latter will become accessible via the shape and intensity of the reflexes. The scattering signal provides global information on the crystal, averaged over the observation volume of about 1 cm^3.

As a long term vision it is possible to test the use of plasma crystals as FIR filters as suggested by Rosenberg and Sheehan [6].

Experimental Setup and Results

A sophisticated and extensively investigated radiation source with sufficiently high power in the FIR wavelength region is the waveguide resonator pumped by a tuneable CO_2 laser [7]. We have therefore designed, built and carefully characterised a FIR laser system [8] consisting of an Edinburgh Instruments Ltd. PL5 CO_2 laser (80 lines, 50 W at strongest line) and a homemade FIR waveguide resonator (Figure 1). The resonator can be filled by differ-

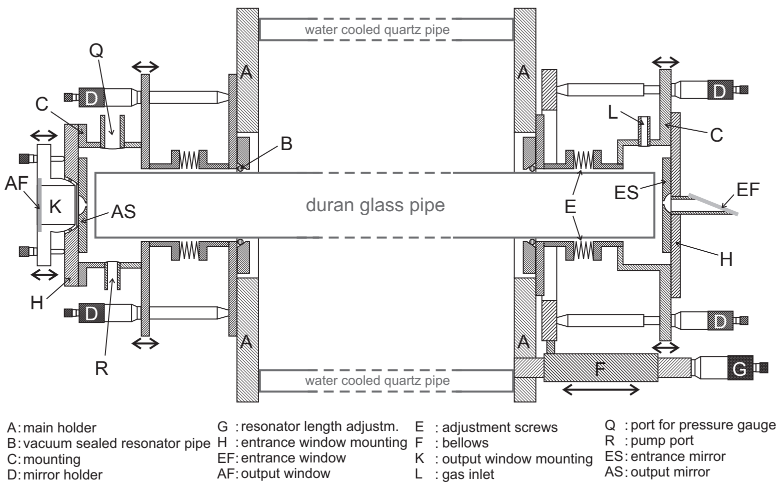


Figure 1: Sketch of the FIR resonator.

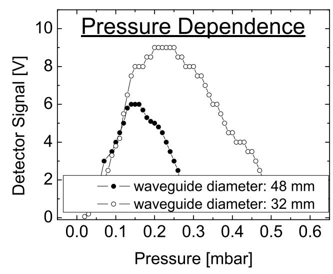


Figure 2: Influence of the laser medium gas pressure on the FIR signal ($\lambda = 170.58\,\mu$m) for two waveguide diameters.

ent FIR active media like the vapours of methane (CH_3OH) and formic acid (HCOOH). We have determined beam quality and power for various design parameters such as waveguide diameter, mirror roughnesses, and mirror hole diameters (Figures 2–4). Figure 5 shows the

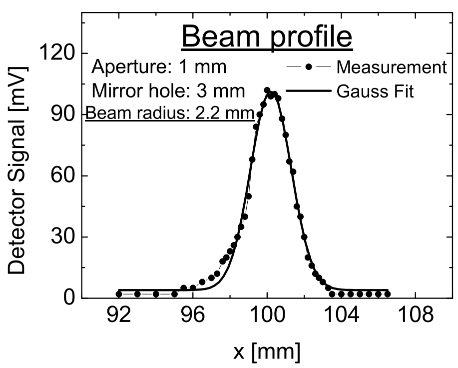


Figure 3: Beam profile of the CH_3OH 170.58 μm line at 55 mm distance. Beam radius: 2.2 mm.

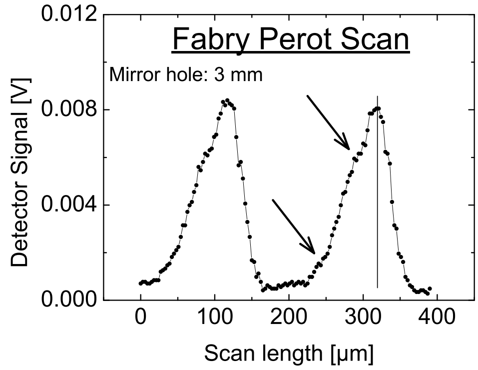


Figure 4: Fabry-Perot-Scan of the 396.63 μm line of HCOOH shows three modes.

planned experimental setup. The plasma chamber is made out of the polymer TPX which is transparent for the FIR and visible radiation. We have designed a mirror system to guide the FIR laser beam into the plasma chamber under a variable angle of incidence. This setup is necessary because to our knowledge it is not possible to rotate a 3d plasma crystal in a well defined way without changing particle distances and crystal structure. Therefore we have to simulate the rotating crystal recording by changing the angle of incidence of the incoming beam. Two mirrors mounted on the laser table deflect the FIR beam to the top of the plasma reactor, where four additional mirrors are situated. Three of them are fixed to a metal frame on carriages on a 360° guide rail which allows an angle of incidence variation of about 90°. A Golay cell detector, which is much more sensitive than a pyroelectric device, is placed on a separate carriage. Both the mirror system and the detector can be moved by a motorised drive which allows the separate movement as well as the synchronous one. Thus it is possible to change the Bragg reflection angle (separate motion) as well as the investigated crystal plane orientation (synchronous motion).

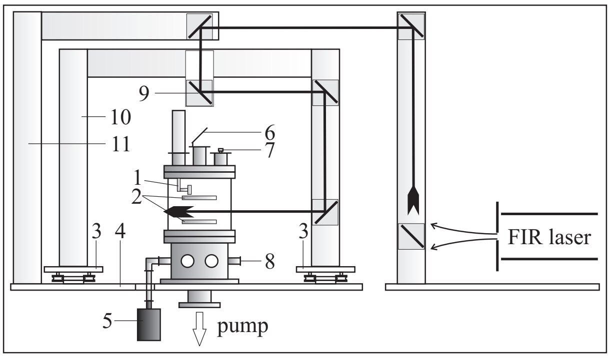
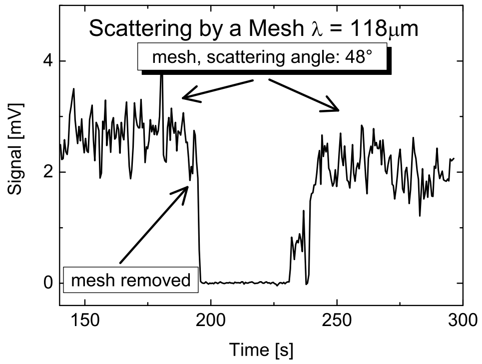
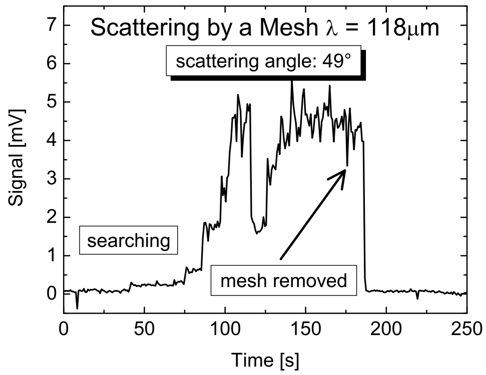


Figure 5: Sketch of the experimental setup. Labels: 1: dust dispenser, 2: electrodes, 3: guide rail, 4: table, 5: pressure gauge, 6: mirror, 7: rf connection, 8: different ports, 9: mirrors, 10: rotating mirror support, 11: fixed mirror support.



(a) Mesh is removed and replaced again.



(b) Mesh is removed after finding the peak.

Figure 6: Scattering of the 118.834 μm line of CH_3OH incident on a metall wire mesh with lattice constant of 163 μm and wire thickness of 63 μm.

As a first test of FIR scattering by a well defined periodic structure, we have measured the scattering signal of the 118.834 μm line of CH_3OH incident on a wired metal mesh with a lattice constant of 163 μm and a wire thickness of 63 μm placed directly in the beam path near the FIR laser. We have obtained a scattering angle of about 48° to 49° (Figure 6) which would correspond to a lattice constant between 157 μm and 160 μm. As a cross-check, we have performed the same experiment using a 633 nm He-Ne laser and obtained a scattering angle (first order) of 0.22° which gives a lattice constant of about 165 μm. This demonstrates the principle of our planned investigation. This work is supported by SFB 591.

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