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A FREON-FILLED BUBBLE CHAMBER FOR GAMMA-RAY DETECTION IN INTENSE LASER-PLASMA INTERACTION*

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Abstract

Electron resonance acceleration in laser plasma interactions can work as a brilliant gamma-ray synchrotron only on a micron scale, the photon energy may ranges from ~1MeV to ~10^2MeV [1]. Because more than 10^10 gamma-ray are emitted in femtosecond-scale duration, which are hardly distinguished from each other at the same time. A small freon-filled bubble chamber is being built to measure the energy spectrum of these brilliant high-energy photons, which has a good energy and spatial resolution with a large depth of field, allowing a large number of tracks. The principle and conceptual design are introduced in this paper.

INTRODUCTION

Hard X rays of ~MeV generated in the laser-plasma interaction were reported in recent years [2]. The characters of ultra short pulse make the laser-plasma induced photon radiation suit for high temporary resolution applications [3]. There are two main difficulties in detecting the photon radiation for the unique characters. Those are various kinds of high energy, quite brightness and extremely short in time scale. The time resolution of scintillator based or semiconductor based gamma spectrometer usually larger than nanosecond. However the photon radiation produced in the laser-plasma interaction is as short as the laser duration, which is a few tens of femtoseconds. It is very difficult in measuring the high energy photons by a single standard gamma-ray spectrometers.

Interaction between photon of several MeV and detector in this region is mainly through Compton scattering and electron pair effect Large enough sensitive space (a few cm^3 in per unit) is needed for scintillator or semiconductor detectors to increase the possibility to record the full energy of each incident photon. It would cost quite much to build a hundreds of thousand elements array with large sensitive volume detectors. The spectrum of photon radiation from laser-plasma reaction has never been preciously measured in the MeV range before.

The high energy photons can be measured by using bubble chambers. A bubble chamber is a transparent liquid based trace detector. It gets high detection efficiency and high spatial resolution. The traces are recorded by the means of optical images. Multiple traces can be recorded simultaneously. This character make the bubble chamber be able to detect the gamma burst with ultra short duration.

The structure of the system is shown in Fig. 1.

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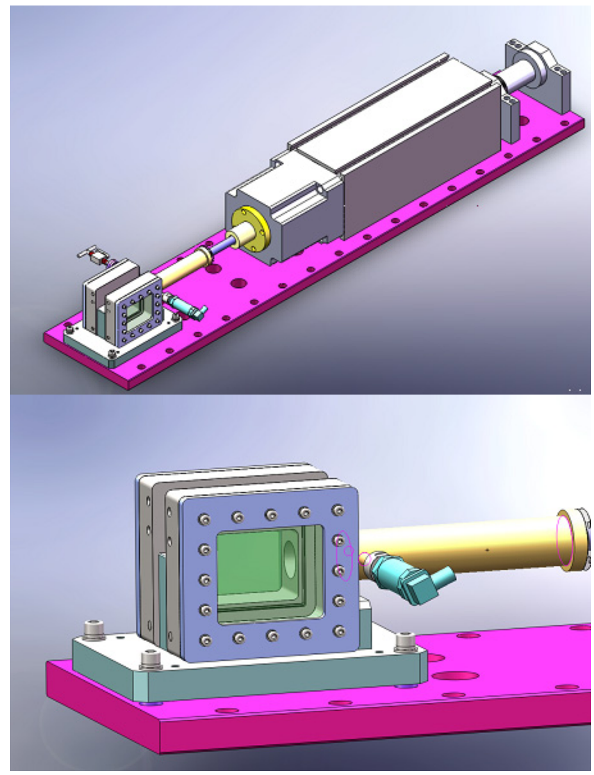

Figure 1: CAD model of bubble chamber system (up) and the main chamber (down).

THE DESIGN AND WORK PRINCIPLE OF A BUBBLE CHAMBER

The bubble chamber system is mainly made up by cavity, optical glass, pressure sensor, temperature sensor, control circuit and laser lighting device. The internal part is an empty cubic cavity. The outer material fixed on the base plate is 316L preventing from external damage. The signals measured by temperature and pressure sensors are transported to the loop control system for achieving real-time monitoring and controlling the inner parameters. Both sides of the chamber is composed of optical glass pressed by stainless steel, which is lighted by green laser observation window. Linear motor is to achieve the increase and decrease of the pressure. Basic expected process is as follows：There is a microsecond scale delay before the motor is triggered when the laser pulse is emitted. At the same time, the digital cameras are also triggered. We aim at recording the growth rate of bubbles.

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A bubble chamber detects particles only in its superheated state. The thermodynamic phase diagram is shown in Fig. 2, describing the behavior of Freon as the active medium [4]. The liquid state exists above the vapor pressure line, the gaseous state exists below the foam limit line, and a metastable coexistence state is found in the middle. During the bubble chamber operation, the temperature is held constant while the pressure is rapidly decreased from a point on the upper curve (start/stable) to a value close to the lower curve (working unstable), where it is ready to record any interactions with the incident particles. The lines of constant bubble density come closer to the foam limit at higher temperatures.

For a different active medium, the values described in Fig. 2 may vary widely, but all the liquid bubble chambers operate with the same principle [5].

An incident particle will interact with the sensitive medium inside a bubble chamber as following:

1. High energy photons are indirectly detected in the bubble chamber. The MeV photons react with electrons mainly through Compton scattering. .

2. The ejected electrons interact with molecules of the active medium, freeing nuclei or electrons from the medium atoms or moving the bound electrons to excited states.

3. The energetic electrons lose their energy inside the medium over a distance proportional to their initial velocity. When these processes occur at stable states in temperature and pressures, a bubble is generated.

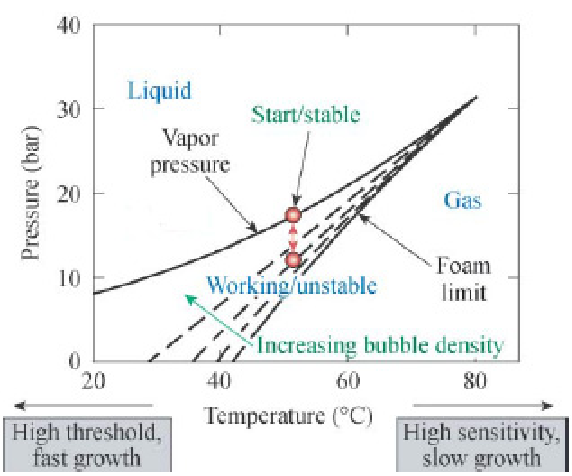

Figure 2: Bubble production as a function of pressure and temperature in Freon bubble chamber. The working region is the area between the vapor pressure line and foam limit line.

METHOD TO OBTAIN THE ENERGY SPECTRUM

Interaction between photon and detector in this region is mainly Compton scattering effect when the energy ranges from 1MeV to 10 MeV.

Scattered Compton electrons are produced after going through the ray window. The energy, emission angle and range of the electrons are determined by the following formulas.

$$\mathrm{Ee} = \frac{\mathrm{E}^2\gamma(1-\cos\varphi)}{m_e c^2 + E\gamma(1-\cos\varphi)}$$

Where Ee is Compton electron energy, Eγ is photon energy, φ is electron direction, me is mass of election and c is light speed.

gamma cross section

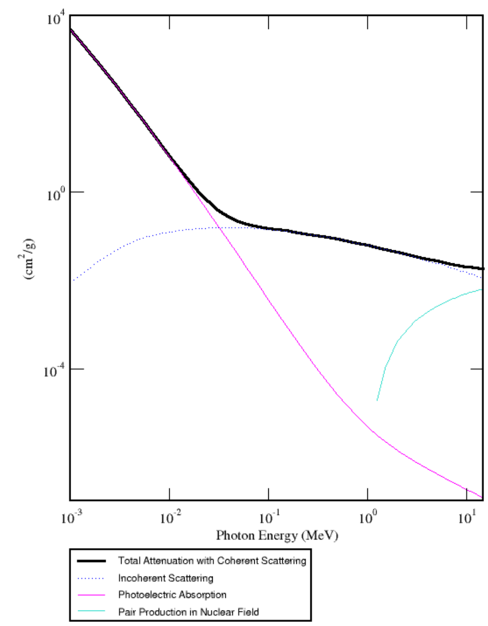

Figure 3: The compton scattering cross section of high energy photon interacting with R134a.

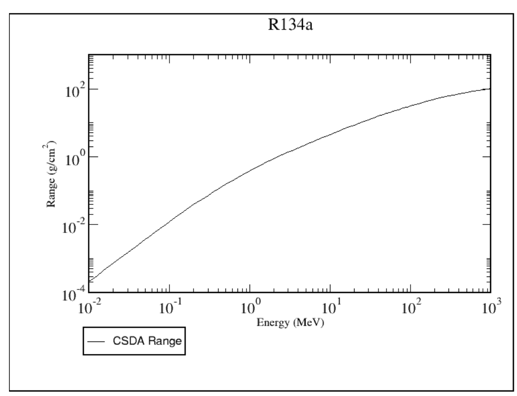

Figure 4: The range of scattered electrons in R134a.

The gamma cross section as shown in Fig.3 is calculated by software according to formulas [6]. The range of the scattered electrons in R134a as shown in Fig. 4 depends on the active medium when the energy is more than 2MeV [6]. And the bubbles recorded in carbonated beverage of the experiments are shown in Fig. 5.

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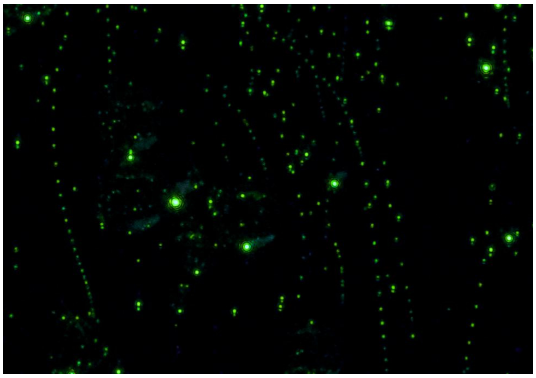

Figure 5: The real bubbles formed in carbonated beverage contained in transparent material recorded by digital camera.

We have done some simulation recording to the ideas. In the pre-experiments, we made use of the bubbles generated by carbonated beverage to replace the real ones in the chamber. In the real situation, the traces are recorded by 3or 4 digital cameras from different direction and then reconstructed into 3D curves. The work of three-dimensional image reconstruction is so onerous that it takes so much time to debugging. The code is being developing gradually.

We will get the important physical parameters such as track length, track radius of curvature, the angle between the spatial directions from the reconstructed 3D curves. Accumulating the total number of incident photons with various energy from the track information. Then we get the energy spectrum.

RECENT PROGRESS AT PKU

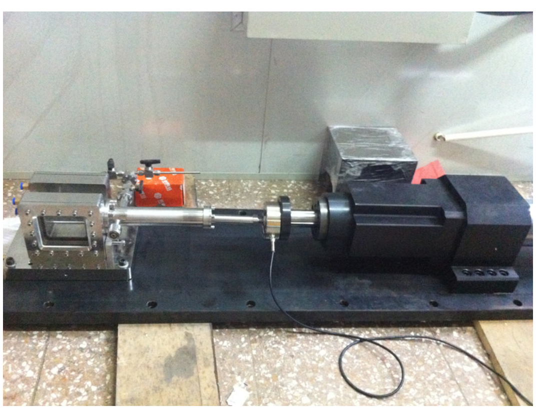

Figure 6: One part of the real bubble chamber system at PKU.

We have completed the entire physical system a few weeks ago. The front part of spectrometer is shown in Fig. 6.

We don’t take advantage of magnetic field in the spectrometer, which is a typical difference from previous ones. As a result, the operation, recording, and data processing are innovative.

The spectrometer using in the experiment can detect the photon energy from ~1 MeV to ~10 MeV.

Its energy resolution is about 20%. The sensitive cross section is 50 mm (vertical) by 15 mm (horizontal) and the sensitivity is about 20% for 3 MeV photons. The space for placing this spectrometer is 60 cm (along the beam) by 170 cm.

The active medium R134a hasn't been used before. Some important parameters such as temperature and pressure have to be determined in repeated experimentation and comparison.

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