# 25G04

# Angular Distribution of Intense Terahertz Emission from Argon Clusters Irradiated by 60 mJ Femtosecond Laser Pulses

60 mJフェムト秒レーザーパルス照射による
アルゴンクラスターから放射する高強度テラヘルツ波強度の角度分布

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The characteristics of THz emission from argon clusters irradiated by intense femtosecond laser pulses have been investigated. Intense Terahertz pulses have been observed from argon clusters with energies of almost three orders of magnitude larger than that from air plasmas. The THz radiation is enhanced by efficient laser absorption in the clusters. The angular distribution and laser-energy scaling with polarization characteristics are studied and the mechanism of THz generation is discussed.

## 1. Introduction

Terahertz (THz) waves are widely used in many applications such as remote sensing, spectroscopic analysis of organic and inorganic compounds, biomedical diagnostics, and threat detection [1]. For further more applications of THz waves, efficient high-energy THz sources are in demand. Intense THz wave pulses with energies in microjoule level have been generated by using huge free-electron laser facilities [2] and recently by employing large nonlinear electro optic crystals [3].

THz radiation from plasmas produced by intense femtosecond laser pulses has been extensively studied, since the first demonstration in 1993 [4]. Strong THz emission has been observed from the plasma of solid targets, because of their high laser absorption. However, this process is companied by debris generation during the laser plasma interaction and also considerable reflection at boundary between plasma and vacuum. Therefore, the plasma of gas targets has attracted attention as convenient and replenishable THz sources. To increase the energy of THz radiation from gas plasmas, a number of artificial schemes such as electric field biasing of the plasma [5] and frequency-mixing methods [6] have been employed. To the best of our knowledge, the highest THz pulse energy at frequencies below 5.5 THz from gas targets has been obtained through a frequency-mixing scheme in air with energy up to 570 nJ [7]. Different gases have been also investigated to find the most efficient gas plasma THz sources. Recently, Rodriguez *et al.* showed that, at laser energies higher than 4 mJ, stronger THz radiation is generated from argon gas than from air, neon, krypton, and xenon [8].

Atomic clusters can absorb laser light as efficient as solid targets to be, convenient and replenishable THz sources. We have studied the compatibility of atomic clusters [9] with gas targets [10] for THz emission under irradiation of intense femtosecond laser pulses. THz emission from argon clusters has been studied as function of cluster size. The enhancement of THz radiation from argon clusters, comparing to that from argon gas, has been explained in terms of laser absorption fraction [9].

To investigate the feasibility of atomic clusters for intense THz source, we have measured the angular distribution of THz waves. Such measurements are important for considering the physical mechanism of THz wave generation and estimating the total energy of THz pulses.

## 2. Experiments

Femtosecond laser pulses from a chirped-pulse amplified Ti:sapphire laser [11] with energy of 10 - 70 mJ, duration of 130 fs, and center wavelength of 800 nm were focused by a spherical lens with a focal length of 200 mm, onto argon clusters in a spot with diameter of 17 μm. A schematic of the experimental setup is shown in Fig. 1. Argon clusters were generated by injecting argon gas [12] with a backing pressure up to 8 MPa into a vacuum chamber with diameter and wall thickness of 100 mm and 5 mm, respectively. The chamber was made of fused silica glass with refractive index of 1.95 and transparency of 90% at 0.5 THz. Such special chamber was designed suitable for a precise measurement of angular distribution of THz waves. The high-energy ions generated by Coulomb explosion of argon clusters have been detected in a separate experiment using time-of-flight measurements. The signal of ion detection was used to confirm cluster production and to synchronize gas injection with the laser pulses.

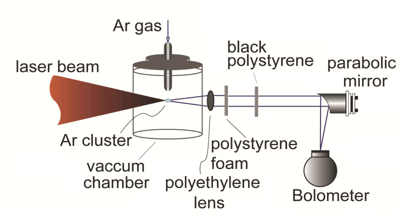

Fig.1. A schematic of the experimental setup

THz radiation from the argon clusters are collected by using a polyethylene lens with a focal length of 150 mm and directly image-relayed on the input window of a helium-cooled InSb bolometer by using a parabolic mirror with a focal length of 119.2 mm. Wire grids with an extinction ratio of ~$10^{-5}$ at 0.5 THz are used as polarizers in front of the bolometer to measure the horizontally and vertically polarized components, and as beam splitters in Martin-Puplett interferometer. Multiple layers of polystyrene foam and a thin black polyethylene filter are installed behind the lens and in front of the bolometer, respectively, to exclude the laser pulses and unwanted lights emitted or scattered from the plasma (Fig. 1).

## 3. Results and Discussion

The spectrum and intensity interferogram of THz waves were measured using a bolometer with spectral sensitivity below 2 THz. The maximum observed frequency was ~1.0 THz with a peak at ~0.5 THz. The spectrum of THz waves did not strongly depend on laser pulse energy, and a nearly identical spectrum was observed both in the forward and backward directions. The detection setup was rotated around the center of the glass chamber and the angular distribution of THz waves was measured. Figure 2 shows a typical angular distribution measured at 7 MPa backing pressure. The highest THz power was detected at ±30° and ±140° with respect to the laser propagation direction.

The direction of maximum THz emission was found to depend on plasma length. For increasing plasma length, the maximum THz peak was found at smaller angle. This result agrees with previous reports [13], which predicts that this angle changes in proportion to $(\lambda/L)^{1/2}$, where $\lambda$ and $L$ are the wavelength and length of plasma, respectively. The angular distribution and polarization properties of THz waves suggest the ponderomotively induced quadrupole radiation with a contribution of four wave mixing process as the mechanism of THz generation in the present experiment.

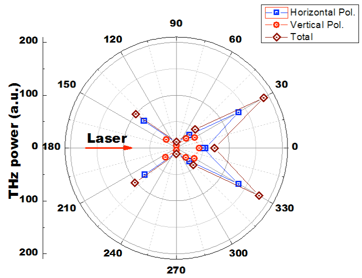

Fig.2. A typical angular distribution measured at 7 MPa backing pressure.

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