Advanced Research Center for Beam Science
– Laser Matter Interaction Science –

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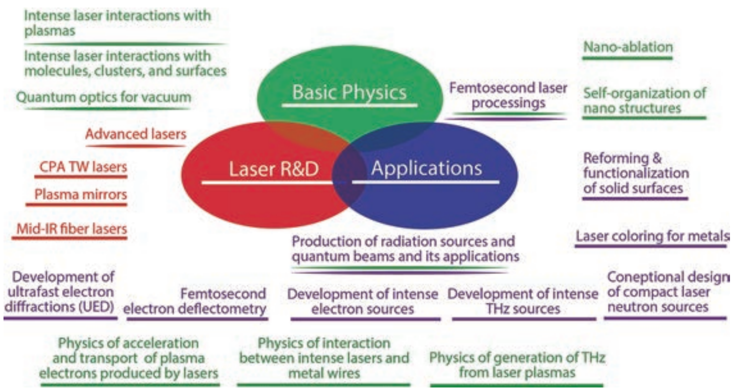
Scope of Research

The interaction of femtosecond laser pulses with matter involves interesting physics not seen with nanosecond laser pulses. Through investigation of the interaction physics, the potential of intense femtosecond lasers for new applications is being developed (e.g., laser-produced radiation and laser processing). Ultra-intense lasers can produce intense radiations (e.g., electrons, ions, and THz), which are promising as next-generation radiation sources. Ultra-short lasers can process any matter without thermal dissociation. Femtosecond laser processing is also the next-generation of laser processing. Our laboratory is equipped with an ultra-intense femtosecond laser named T6, to study the physics of intense laser–matter interactions and its applications.

KEYWORDS

Intense Laser Science
Laser Plasma Radiations (electrons, ions, and THz)
Ultrafast Electron Diffraction (UED)
Laser Nano-ablation Physics
Femtosecond Laser Processing



Selected Publications

Mori, K.; Hashida, M.; Nagashima, T.; Li, D.; Teramoto, K.; Nakamiya, Y.; Inoue, S.; Sakabe, S., Directional Linearly Polarized Terahertz Emission from Argon Clusters Irradiated by Noncollinear Double-pulse Beams, *Appl. Phys. Lett.*, **111,** 241107 (2017).

Furukawa, Y.; Sakata, R.; Konishi, K.; Ono, K.; Matsuoka, S.; Watanabe, K.; Inoue, S.; Hashida, M.; Sakabe, S., Demonstration of Periodic Nanostructure Formation with Less Ablation by Double-pulse Laser Irradiation on Titanium, *Appl. Phys. Lett.*, **108,** 264101 (2016).

Hashida, M.; Nishii, T.; Miyasaka, Y.; Sakagami, H.; Shimizu, M.; Inoue, S.; Sakabe, S., Threshold Fluence for Femtosecond Laser Nanoablation for Metals, *Electron Commun. Jpn.*, **99,** 88-95 (2016).

Inoue, S.; Maeda, K.; Tokita, S.; Mori, K.; Teramoto, K.; Hashida, M.; Sakabe, S., Single Plasma Mirror Providing 104 Contrast Enhacement and 70% Reflectivity for Intense Femtosecond Lasers, *Appl. Opt.*, **55,** 5647-5651 (2016).

Induction of Sub-terahertz Surface Wave on a Metal-wire by Intense Laser Interaction with a Foil

In recent years, the generation of terahertz-frequency electromagnetic waves (hereinafter simply THz waves) has been made possible by advances in femtosecond laser technology. A high peak-power THz wave is required for many applications. Because plasma does not suffer damage when used as a source element, even for intense laser pulses, laser plasma has been the subject of considerable study for the generation of intense THz waves.

We have demonstrated that a pulsed electromagnetic wave (surface wave) of sub-terahertz frequency and an 11-MV m^{-1} field strength is induced on a metal wire by the interaction of an intense femtosecond laser interaction with an adjacent metal foil at a laser intensity of 8.5×10^{18} W/cm^2. A tungsten wire is placed normal to an aluminum foil with a gap so that the wire is not irradiated and damaged by the laser pulse, making it possible to generate surface waves on the wire repeatedly (Figure 1 (a)). Figure 1(b) shows typical waveforms of the sub-THz surface wave induced by the irradiation of the intense laser pulse on the foil target for various foil-wire gaps (d = 0.5, 1, 2, 4 mm) with a resolution of 500 fs. The electric field has a rapid (sub-picosecond) rise time for each distance. A half-cycle surface wave is observed over ~10 ps and low frequency fluctuations follow the peak for tens of picoseconds. We also performed a three-dimensional electromagnetic field numerical simulation for understanding the process of surface wave induction. Figure 1 (c) shows the dependence of the peak electric field at the wire surface on the foil-wire gap *d*. Open and closed circles represent the peak electric field of the surface wave which obtained by the experiment and the calculation for various foil-wire gaps d respectively. The experimental data are well reproduced by the simulation. Numerical simulation suggests that electromagnetic wave associated with electron emission from the foil induces the surface wave.

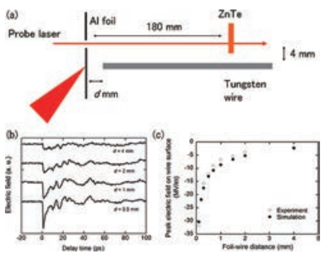


Figure 1. (a) Experimental setup for the generation and measurement of the surface wave. (b) Typical waveform of the surface wave at various distances (d = 0.5, 1, 2, 4 mm) between the foil and the wire. (c) Peak electric field of the surface wave on the wire for various distances between the foil and the wire.

Linearly Polarized Terahertz Wave Generation from Argon Cluster Plasma Produced by Double-Pulse Laser

The distinguishing properties have been observed in the THz wave emission from argon clusters irradiated by double intense femtosecond laser pulses with appropriate intervals in time and space: high directivity, power enhancement, and linear polarization, which is variable by changing the pointing of the second pulse relative to that of the first pulse. All are useful for applications because of high use efficiency, higher power, and variability of polarization, respectively. To understand the mechanism of THz emission from clusters under the irradiation of double pulses, we have proposed that the ions emitted from clusters Coulomb-exploded by the first pulse work as a bias. After the ions are emitted by Coulomb explosion, they form a positively charged ion cloud that works as a DC field (Figure 2).

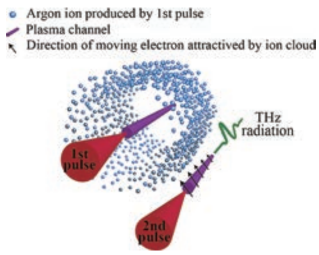


Figure 2. Diagram of THz generation from cluster plasma under irradiation by a double-pulse beam.

Reduction of Ablation Rate on Silicon Surface Irradiated by Double-Pulse Beam

To achieve laser nano-fabrication much smaller size than that of diffraction limit, the knowledge of the laser-matter interaction is important, especially for reducing the ablation rate of materials. To discuss the ablation rate dependence on materials, the ablation threshold for objective material has been measured precisely for single laser beam irradiation. We found that the nonlinear absorption on metal surface irradiated by femtoseocnd laser pulses is important role. Recently, ablation rate reduction has been clearly observed by using double pulsed beam with single color. The mechansim of reduction is under debated and we need further investigation. The characteristics of laser processing (ablation threshold, ablation rate, and interspace of grationg structures depended on laser fluence) were also measured for discussing the optimum laser condition for double laser beam irradiation. In this study we have demonstarted the reduction of ablation rate on a silicon surface irradiated by a double-pulse beam cross-polarized in time delays of $\Delta t = -1000$–1000 ps. We find that ablation rate of silicon is clearly decreased at delay times of 600 ps.