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

http://laser.kuicr.kyoto-u.ac.jp/e-index.html

Assist Prof
INOUE, Shunsuke
(D Sc)

Program-Specific Assoc Prof *
HASHIDA, Masaki
(D Eng)

*Incubation Support Laboratory

Students

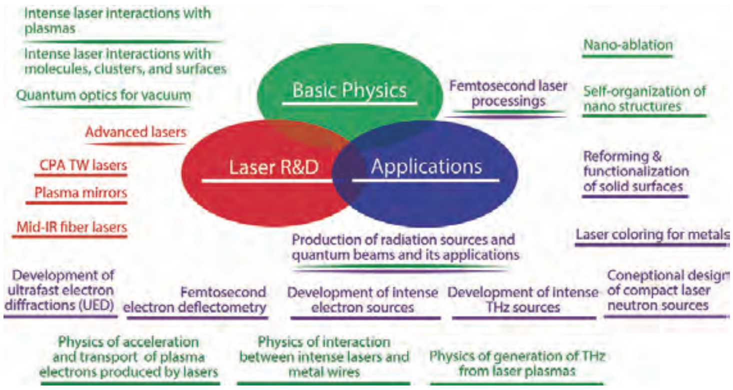
FURUKAWA, Yuki (D3)   KONGO, Ryota (M2)   TANAKA, Yohei (M2)

Scope of Research

The interaction of femtosecond laser pulses with matter involves interesting physics not seen with nanosecond laser pulses. Through investigations 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

Inoue, S.; Sakabe, S.; Nakamiya, Y.; Hashida, M., Jitter-free 40-fs 375-keV Electron Pulses Directly Accelerated by an Intense Laser Beam and Their Application to Direct Observation of Laser Pulse Propagation in a Vacuum, *Sci. Rep.*, **10,** 20387 (2020).

Hashida, M.; Furukawa, Y.; Inoue, S.; Sakabe, S.; Masuno, S.; Kusaba, M.; Sakagami, H.; Tsukamoto, M., Uniform LIPSS on Titanium Irradiated by Two-color Double-pulse Beam of Femtosecond Laser, *J. Laser Appl.*, **32,** 022054 (2020).

Furukawa, Y.; Hashida, M.; Kojima, S.; Inoue, S.; Sakabe, S., Optical Properties of Titanium Induced by Below-ablation-threshold Irradiation, *Appl. Surf. Sci.*, **515,** 146047 (2020).

Mori, K.; Hashida, M.; Nagashima, T.; Li, D.; Teramoto, K.; Nakamiya, Y.; Inoue, S.; Sakabe, S., Increased Energy of THz Waves from a Cluster Plasma by Optimizing Laser Pulse Duration, *AIP Advances*, **9,** [015134-1]-[015134-4] (2019).

Nishiura, Y.; Inoue, S.; Kojima, S.; Teramoto, K.; Furukawa, Y.; Hashida, M.; Sakabe, S., Detection of Alpha Particles from ^{7}Li(p, α)^{4}He and ^{19}F(p, α)^{16}O Reactions Induced by Laser-accelerated Protons Using CR-39 with Potassium Hydroxide–ethanol–water Etching Solution, *Rev. Sci. Instrum.*, **90,** 083307 (2019).

Optical Properties of Titanium Induced by Below-ablation-threshold Irradiation

To understand the changes in the optical properties of a titanium surface induced by irradiation with lowintensity laser light that does not cause surface peeling, we have proposed a pump-and-probe method using femtosecond laser pulses with fluences below and above the ablation threshold (BAT and AAT, respectively). By analyzing the dependence of the ablation rate on the AAT probe-pulse fluence, the dynamical changes in the effective laser penetration depth and effective ablation threshold could be estimated. The dependences of the effective laser penetration depth and effective ablation threshold on the pump-pulse fluence F_{pump} below the ablation threshold F_{th} ($F_{pump} < F_{th}$) were measured with a delay of 100 ps. BAT irradiation with $F_{pump} > 0.18\ F_{th}$ reduced both the effective laser penetration depth and effective ablation threshold compared with irradiation without the pump pulse. The obtained results also indicated a large reduction in the effective laser penetration depth (58% for $F_{pump} = 0.9\ F_{th}$) and a small reduction in the effective ablation threshold (15% for $F_{pump} = 0.9\ F_{th}$).

Uniform LIPSS on Titanium Irradiated by Two Color Double-pulse Beam of Femtosecond Laser

We have investigated the uniformity of laser-induced periodic surface structures (LIPSSs) generated on titanium surfaces irradiated with a two-color double-pulse cross-polarized beam with a time delay of $\Delta t = 0–200$ ps. The double-pulse beam consisted of 800 nm pulses with a duration of 150 fs and 400 nm pulses with a duration of >150 fs. The fundamental-pulse fluence F_{800} and the second-harmonic pulse fluence F_{400} were set to be near the corresponding ablation thresholds of F_{800th} = 0.108 J/cm^2 and F_{400th} = 0.090 J/cm^2, respectively. We found that uniform LIPSSs could be produced on titanium surfaces using laser fluences of $1.5F_{400th} + 0.9F_{800th}$ and a delay of $\Delta t = 0–2$ ps. The periodicity and direction of the LIPSSs were characterized by the wavelength and electric field of the fundamental (800 nm) pulse. The results suggest that the longer-wavelength pulse influences surface plasma wave generation and improves uniformity by the second harmonic pulse even though laser plasma is produced on the surface.

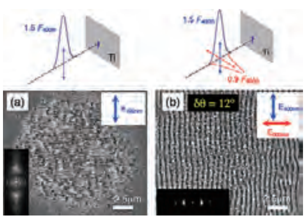


Figure 1. SEM images of titanium surfaces irradiated with (a) only the fundamental wavelength pulse with N = 60 pulses and (b) the two-color double-pulse beam with delay of $\Delta t = 0$ and N = 60 pairs of pulses. The LIPSS uniformity ($\delta\theta$) shows LIPSS characterized by the 800 nm pulse.

Generation of Jitter-free 40-fs 375 keV Electron Pulses Directly Accelerated by Intense Laser

In recent years, ultrafast science using ultrashort pulsed electrons with the high temporal and high spatial resolution has made rapid progress. Electrons with the energy of several hundred keV or less, short pulse width, and high brightness have succeeded in providing information that cannot be provided by other quantum probes in applications like ultrafast electron diffraction and electromagnetic field observation. For further development of these applications, namely for observation of more high-speed phenomena or irreversible phenomena with highly temporal-spatial resolutions, it is essential to shorten the pulses of electrons and further increase the amount of charge. In the development of ultra-short pulse electrons, which began with the generation of short-pulse electrons using a DC electron gun, it is a significant challenge to prevent the space charge effect which increasing the pulse width by self-generated electric fields. In order to overcome this problem essentially, the technique of electron pulse compression with RF cavity as a temporal-lens has been introduced, and this technology has been a great success, providing sub pC, several hundred fs electron pulses. When conducting pump-probe experiments with high time resolution using pulse compressed electrons, the critical parameter is not only the pulse width of the electron pulse. The timing jitter of the pump pulse and electron pulse as the probe pulse is also significant. No matter how short the probe pulse can be generated, if the time origin is not clear, high time resolution cannot be obtained when observing ultrafast phenomena. However, these methods use high-frequency electric fields in pulse compression, and jitter cannot be completely eliminated. This problem remains a very critical problem when using relatively slow electrons. In this work, we report the generation of ultrashort pulse electrons with extremely low timing jitter with a static field type compressor. By using electrons that are directly accelerated by shooting a solid thin film with an intense femtosecond laser, and using a pulse compression method with a phase rotator using permanent magnets, ultrashort electron pulses with extremely low timing jitter and short pulse width have been achieved. The number of electrons measured was 20 fC, the pulse width was 38 fs in RMS, and the long-term timing jitter was 14 fs in RMS. By adopting the electron pulse compression method using only the static field, the timing jitter is essentially zero. Therefore, we have succeeded in creating electron pulses that are extremely robust against external fluctuations. In addition, by generating electron pulses from the laser-plasma, there is no need to consider degradation and damage of photocathode limiting the amount of the number of electrons.