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

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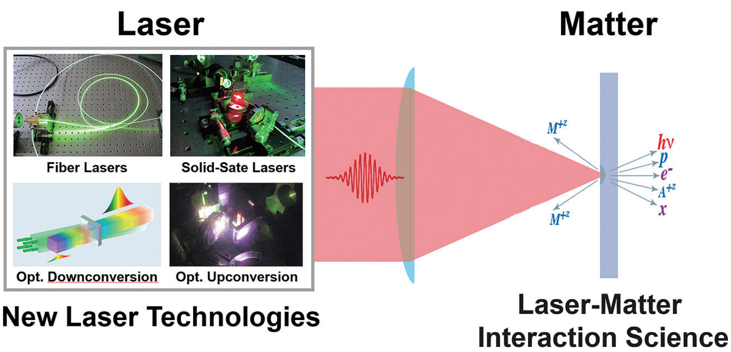
Scope of Research

We are developing cutting-edge high-intensity laser sources and studying experimental research on the laser interaction with matter by using the new laser sources. We are promoting cross-disciplinary research based on high-intensity laser technologies such as development of high-intensity mid-infrared solid-state lasers and fiber lasers, research on particle acceleration and wavelength conversion with plasmas produced by high-intensity ultrafast lasers, development of laser isotope separation method for neutrino research, and search for dark matter using high-intensity lasers.

KEYWORDS

High Power Laser Optics
Ultrafast Laser Physics
Laser-Plasma Interaction Physics
Laser Isotope Separation
Laser Nano-Ablation Physics



Recent Selected Publications

Goya, K.; Sasanuma, H.; Ishida, G.; Uehara, H.; Tokita, S., Fusion Splicing of Plastic Optical Fibers Using a Mid-IR Fiber Laser, *Appl. Phys. Express*, **16,** 052006 (2023).

Homma, K.; Tesileanu, O.; Nakamiya, Y.; Kirita, Y.; Chiochiu, C.; Cuciuc, M.; Giubega, G.; Hasada, T.; Hashida, M.; Ishibashi, F.; Kanai, T.; Kodama, A.; Masuno, S.; Miyamaru, T.; Neagu, L.; Rodrigues, V. R. M.; Rosu, M. M.; Sakabe, S.; Tamlyn, J.; Tazlauanu, S. V.; Tokita, S., Challenge of Search for Cosmological Dark Components with High-Intensity Lasers and beyond, *Eur. Phys. J. A.*, **59,** 109 (2023).

Fujiwara, M.; Inoue, S.; Masuno, S.; Fu, H.; Tokita, S.; Hashida, M.; Mizuochi, N., Creation of NV Centers over a Millimeter-Sized Region by Intense Single-Shot Ultrashort Laser Irradiation, *APL Photonics*, **8,** 036108 (2023).

Ishibashi, F.; Hasada, T.; Homma, K.; Kirita, Y.; Kanai, T.; Masuno, S.; Tokita, S.; Hashida, M., Pilot Search for Axion-Like Particles by a Three-Beam Stimulated Resonant Photon Collider with Short Pulse Lasers, *Universe*, **9,** 123 (2023).

Li, E.; Uehara, H.; Tokita, S.; Yao, W.; Yasuhara, R., A Hybrid Quantum Cascade Laser/Fe:ZnSe Amplifier System for Power Scaling of CW Lasers at 4.0–4.6 μm, *Optics & Laser Technology*, **157,** 108783 (2023).

High-Intensity Mid-Infrared Fe:ZnSe Lasers

The mid-infrared (mid-IR) spectral region has long garnered significant interest for its spectroscopic applications. Thermal lamp-based mid-IR light sources have been traditionally employed for trace gas sensing, which is crucial for environmental monitoring, medical diagnostics, and other uses. However, the recent advancements in mid-IR broadband ultrafast lasers have paved the way for pioneering applications. These applications range from generating attosecond pulses, coherent X-ray radiation, creating high-density plasmas, and even contributing to the investigation of dark matter, in addition to their established use in molecular vibrational spectroscopy.

To achieve the desired high intensity in mid-IR lasers, optical parametric amplification (OPA) based laser systems have been the subject of extensive research in recent years. These systems necessitate the use of an ultra-high intensity near-infrared pump laser source. They also require complex femtosecond-scale timing synchronization mechanisms. Such requirements often lead to laser systems that are inherently unstable and not user-friendly, posing significant challenges for both developers and end-users alike.

In our project, we have focused on iron-doped zinc selenide (Fe:ZnSe, as depicted in Fig. 1) as a promising laser gain medium. Fe:ZnSe exhibits a broad emission spectrum centered around the 4-micron wavelength and is capable of supporting ultrafast laser operations with a temporal duration of 100 femtoseconds. Additionally, it possesses an absorption band at the 3-micron wavelength, aligning perfectly with our home-made, world-class high-power continuous wave laser systems, such as erbium-doped ZBLAN fiber lasers and Er:YAP solid-state lasers (in collaboration with Prof. Yasuhara's group at NIFS). The Fe^{2+} ions' 3d electronic energy levels in ZnSe facilitate an upper state lifetime of approximately 100 microseconds, which obviates the need for an ultra-high intensity near-infrared pump laser source and sophisticated timing synchronization systems.

Figure 2 shows our mid-infrared laser system, which integrates a home-built seeding apparatus — comprising a Yb:CaF_2 regenerative amplifier and a three-stage KTA OPA — with an Fe:ZnSe amplifier. The entire system, which is compactly assembled on just two optical tables, would offer a robust and user-friendly platform for cutting-edge mid-IR laser research and applications.

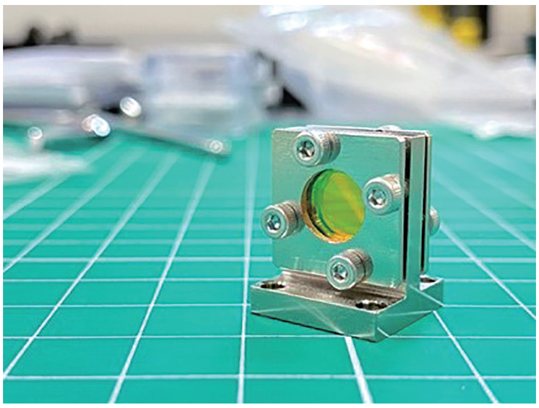


Figure 1. The picture of Fe:ZnSe laser crystal.

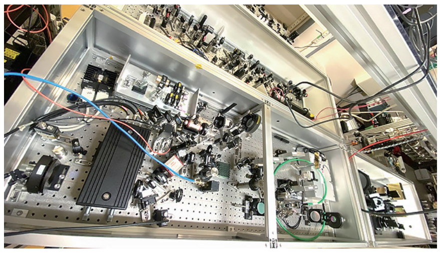


Figure 2. The picture of our mid-infrared laser system.

Blue-Violet High-Power Diode Laser System for ^{48}Ca Isotope Separation

In an effort to confirm the Majorana nature of neutrinos, experiments worldwide are conducting double beta decay studies without neutrino emission (0νββ decay). Given that 0νββ decay is exceptionally rare (with an experimental lower limit half-life of approximately 10^{26} years), it's crucial to have a substantial quantity of target nuclei in an ultra-low background setting. Among the various nuclei capable of undergoing double beta decay, ^{48}Ca stands out due to its highest Q-value (4.27 MeV), surpassing natural radioactive activities, thereby promising minimal background interference. The CANDLES experiment achieved a background level of roughly 10^{-3} events/keV/yr/(kg of ^{nat}Ca), using about 305 kg of $^{nat}CaF_2$ scintillator (containing ~7.3 mol of ^{48}Ca) as the primary detector [Phys. Rev. D, 103, 092008 (2021)]. To enhance the experiment's sensitivity, isotope enrichment is imperative due to ^{48}Ca's low natural abundance (0.187%), along with ongoing efforts to further reduce background noise. Traditional enrichment methods like centrifugation and gas diffusion are unfeasible for ^{48}Ca, as it lacks a gaseous compound at room temperature, prompting the development of alternative chemical and physical techniques.

Our team is exploring a laser isotope separation (LIS) method for ^{48}Ca enrichment. The transition of calcium from its ground state occurs at a wavelength of approximately 422.7 nm, which can be excited using commercially available blue-violet laser diodes (LDs). The linewidth of these external cavity LDs is sufficiently narrow relative to the isotope shift in this transition, which is about several hundred MHz. However, generating around 1000 kg of ^{48}Ca for the experiment demands a high-power laser system exceeding kilowatts.

The gallium nitride (GaN) LD is emerging as the most promising laser source for this application due to its efficiency, compactness, longevity, reliability, and cost-effectiveness. Yet, developing a cost-effective technology that combines high power with single frequency in LDs is a challenge. For example, achieving a total optical power of 1 kW could require between 100 and 10,000 LD emitters. It's crucial that the wavelength of all emitters is precisely stabilized to match the absorption line of the ^{48}Ca isotope, with absolute accuracy within a few MHz to counteract the ~60 MHz Doppler broadening of the Ca atomic beam. We are currently devising a method to stabilize the wavelengths of multiple GaN-LDs simultaneously. This technique will enable the scaling of laser power by increasing the number of LDs while preserving the laser wavelength and spectral linewidth, paving the way for practical LIS applications and future isotope enrichment.