Applied Laser Technology Institute
Japan Atomic Energy Agency

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Summary

We are pursuing to develop useful laser based techniques in the field of nuclear engineering. At the same time we are also pursuing to develop the safe and robust techniques as advance industrial technology. We are happy to advertise our own efforts to the variety of industrial and academic societies all over the world to extend the applicability of laser and light technology originated from the nuclear applications. On the other hand, we are also very happy to make fruitful collaborations with people in Fukui prefecture such as Wakasa wan Energy Research Center, the University of Fukui and local industries.

H. Daido, Director

Organization of Applied Laser Technology Institute

Applied Laser Technology Institute
Director: Hiroyuki Daido

Laser Technology Promotion Office
General Manager: Noboru Tsuchida

Advertisement and consultation of development of laser technology for Industrial applications.

Applied Laser Technology Development Office
General Manager: Toshiharu Muramatsu
Principal Researcher (Group Leader): Akihiko Nishimura

Research and development of laser techniques for nuclear engineering and nuclear facilities as well as industrial applications originated from nuclear engineering.

Subjects of the Applied Laser Technology Institute

• Responding to business needs
  ○ Implementation of laboratory tours from the industry
  ○ Technology transfer to the industry

• Organization of symposiums, research meetings
  ○ Seminars
  ○ Various meetings of academic societies and so on

• The laser engineering for nuclear engineering and relevant techniques

• Outreach activities
  ○ Summer Science Camp (for High school students)
  ○ Summer internship (for Graduate students and university students)
  ○ Organization of laboratory tours
- Development of fiber laser cutting and crushing techniques applied to removal of fuel debris for decommissioning of the Fukushima Daiichi NPPs.

- Monitoring techniques with laser and light technology for decommissioning of nuclear plants.

- Standardization of laser welding / cutting technologies supported by high quality experiments and computer science simulations.

- Maintenance and repair techniques of heat exchanger tubes in the nuclear facilities

- Research and development of structural health monitoring with an optical fiber technique for a coolant pipeline of nuclear power plants

- Medical applications of laser technology originated by nuclear engineering.

- Fundamental study on transparent sodium in the vacuum ultraviolet spectral range.

- Research on improving surface properties by laser irradiation

- Composition analysis for Laser Induced Breakdown Spectroscopy

Laser crushing experiment  Laser cutting experiment  Laser cutting-crushing experiment

Laser micromachining experiments using a microscope objective  Heat exchanger tube repair experiment  Laser irradiation experiments of simulated blood vessel using a composite optical fiber
Development of laser cutting and crushing control system and classification of irradiation conditions fit to an object. Experiments are being conducted by 6kW+4kW fiber lasers.

**Reactor construction of nuclear power plant**

According to the decommissioning of the Three Mile Island Nuclear Power Station Unit 2, fuel debris were characterized by indefinite shapes, porous bodies, multi-compositions, higher-hardness.

**Underwater laser cutting and crushing system**

1. A surface of a test piece is characterized as a complicated geometry.
2. An indefinite shape is measured by a 3D underwater laser scanner.
3. Form an optical path of a laser by an assist gas.
4. A continuous irradiation and pulsed irradiation makes it possible to cut the stainless steel and to crush the ceramic pellet underwater.

Laser power: 6 kW
Pulse irradiation time: 100 ms
Assist gas: compressed air
Assist gas flow rate: 350 ℓ/min.
Sweep velocity: 30 mm/min.
Stand-off: 5 mm
Water depth: 130 mm
Laser cutting

Mechanism of laser cutting
Melting a target by laser irradiation.
Remove a molten metal by an assist gas.
Cutting

Underwater cutting example of stainless steel

Bird view of Transfer reactor “Fugen” under a decommissioning process.

Helium cleaning room, poison resolution room
Helium circulation system (3rd Floor)
Room for Cleaning heavy water
Supplementary building for Reactor

Reactor building
Core of Reactor such as calandria tanks
Heat exchange pump for heavy water
Dross (Solidified molten metal)
Cross-section

Test underwater laser of the cutting for decommissioning of a nuclear reactor.

Monitoring techniques with laser and light technology for decommissioning of nuclear plants.

The work is performed under the collaboration with the Wakasa Wan Energy Research Center, Fugen Decommissioning Research Center, etc. The objective of this collaboration is development of a nuclear reactor dismantling technique using a 6kW+4kW high-power fiber lasers.

Laser illuminates from the audience.

Kerf width: 1.5~2mm

Total Height: 66m

15 cm
10 cm
5 cm
Standardization of laser welding / cutting technologies supported by high quality experiments and numerical simulation.

**Laser welding** Toward the understanding of the welding phenomena and controlling the residual stresses, we have been developed a real-time X-ray imaging technique using an intense monochromatic X-ray beam and simulation code.

**Multi-physics phenomena in a laser welding process**

- Real-time observation of interior of a molten pool during laser welding using an intense monochromatic X-ray beam at SPring-8.

- Based on thermofluid dynamics
  - Thermofluid dynamics, Fluid-solid interaction,
  - Surface transfer (gas-liquid-solid), Phase change

**Laser cutting** Optimization of laser cutting conditions for decommissioning of aging nuclear power plants with help of the numerical simulation code.

**Multi-physics phenomena in a laser cutting process**

- Real-time observation of laser cutting process using video camera

- The laser cutting simulation using SPLICE code
Maintenance and repair techniques of heat exchanger tubes in the nuclear facilities

We have developed maintenance and repair techniques of heat exchanger tubes in nuclear facilities and industrial plants by composite-type optical fiberscope system. This was composed of a central fiber for beam delivery surrounded by fibers for visible image delivery including illumination.

**Laser cladding device to repair wall thinning in 1-inch tube**

We could irradiate the work with the best accuracy of laser beam and with a filler wire in laser cladding. This device was designed to work in a 1-inch tube.

A welding expert successfully made a line clad on a flat plate by manual handling of a laser torch and a wire.

**Example of a clad on a flat plate.**

A molten droplet of a wire tip was formed and grew up. It is important that the wire is contact with a base metal to make a clad.
We should pay careful attention to the strength degradation at every aging welded joints when massive earthquakes may attack nuclear power plants. Advanced monitoring system is now getting more important against coming catastrophic earthquakes along the Nankai Trough.

**Heat resistant strain sensor fabricated by ultra-short laser processing**

We are now fabricating heat resistant strain sensors using an ultra-short pulsed laser in our laboratory. The installation of the strain sensors on the sodium coolant pipeline of Fast Breeder Reactor is under development.

Ultra-short laser pulses can generate a grating structure along a fiber core (Fiber Bragg Grating :FBG). The FBG can hold the designed reflection peak even over 600 ℃. Such a superior heat resistance can make it possible that laser cladding strongly embedded it on a SUS plate.

Reflection of the grating structure shows peak shift due to strain and heat.
We have developed a laser treatment system that keeps minimum damage to patients and treat precisely by irradiating a laser while watching the affected part. Started to commercialize at OK Fiber Technology Co., Ltd. that is the venture company certified by JAEA.

**Minimally invasive laser treatment device**

- Optical fibers for image transmission (~±4 mm, ~10,000 pixels)
- Laser source
- Illumination light
- Laser
- Image
- Monitor
- Composite-type optical fiber scope
- Composite-type optical fiber
- Coupling device
- Dichroic mirror
- CCD camera
- Source for illumination

**Applications of Minimally invasive laser treatment device**

<table>
<thead>
<tr>
<th>Laser hyperthermia for cancer of the uterine body</th>
<th>Photodynamic therapy (PDT) for peripheral lung cancer</th>
<th>Non-occlusive bypass surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Uterine cancer</strong> (The onset in the uterine body)</td>
<td><strong>Peripheral lung cancer</strong> (The onset in the peripheral part)</td>
<td><strong>Aneurysm</strong></td>
</tr>
<tr>
<td>Development of laser treatment system for early cancer of the uterine body that can be uterus-sparing.</td>
<td>Development of laser treatment system for peripheral lung cancer that can observe and treat.</td>
<td><strong>Donor vessel</strong></td>
</tr>
<tr>
<td><strong>Hemostasis of bloody issue</strong></td>
<td><strong>Diagnostic equipment for Bile duct and Pancreatic duct</strong></td>
<td><strong>Recipient vessel</strong></td>
</tr>
<tr>
<td>Development of non-contact hemostatic tool using a laser.</td>
<td>Development of diagnostic equipment without having to incise the duodenum papilla.</td>
<td><strong>Incision and suturing of the vessel wall</strong></td>
</tr>
<tr>
<td><strong>Small-bowel endoscope for the ileus patient</strong></td>
<td><strong>Small bowel disease</strong></td>
<td><strong>Building a tool that allows to bypass surgery without cutting off the blood flow.</strong></td>
</tr>
</tbody>
</table>

Medical applications of laser technology originated by nuclear engineering.
Optical property of alkali metals including sodium was intensively investigated in the 20th century. Wood and Sutherland et al. Obtained the plasma wavelength of 218 nm. In the wavelength range of 218 nm, the sodium can be partially transparent down to the threshold of the core electron excitation wavelength of 40.5 nm.

On the basis of the previous works, we should extend the characterization into much thicker sodium region to clarify the value of the coefficient. We have made the direct measurement of actual transmittance of a sodium samples in a spectral range longer than 115 nm, resulting in several tens of % transmittance of a 3 mm-thick solid sodium sample including windows at the wavelength of ~120 nm.

The extinction coefficient ~5 orders of magnitude lower than the previous result. We also find very weak temperature dependency of the transmittance up to 150 degrees centigrade where the solid sample is melted at 97 degrees.

In order to confirm measured transmittance, we also make a simple imaging experiment with a 8-mm-thick sodium sample. The photo of the sample and the mesh with the optical system is shown. We successfully obtain a clear image The result opens a way to construct an optical imaging device for objects inside or through a solid or a liquid sodium medium. The result also encourages us to find out the physical origin of the high transparency.
We are trying to improve surface properties of materials by laser irradiation. Nanosecond or femtosecond laser pulses are available for industrial demands. A compact vacuum chamber, X-Y linear translation stage, focusing optics are prepared. Highly trained technical staff will support you to proceed your study. Surface modification for advanced materials is under development by laser irradiation.

Material irradiation technique by laser pulses

Examples of materials irradiation test environment

A sample was held on a material position control stage in an irradiation chamber. Laser light timing is controlled by a mechanical shutter. It is possible to perform the sample in various irradiation environments such as an inert gas atmosphere or under reduced pressure depending on the characteristics of the material.

State of the material irradiation test

Example was continuously irradiated over a wide range of materials

Users can try surface modifications for a test sample with femtosecond laser pulses.
When laser pulses are focused on a target, one can see a tiny flash by laser induced plasma on the target. This can be used for a real time composition analysis of the target material. A nanosecond laser pulse can generate plasma effectively. By combining a laser system, a multichannel spectrometer and fiber optics, you can get the information of breakdown plasma emission spectra.

This technique is named laser-induced breakdown spectroscopy. (“Laser-Induced Breakdown Spectroscopy”=LIBS). The following is an example to apply LIBS to the mold made by laser cladding. It can also be applied to verify the distribution of specific elements on the sample. You can see that the chromium containment is higher at the cladding mold (yellow) than that of piping material (red).
Joint research with The Wakasa Wan Energy Research Center, Fugen, Lasax.

**6kW+4kW Fiber laser**

**Applications**
Development of laser processing technology aimed at using in general industrial facilities and nuclear facilities.

**Specifications**
- 4kW Fiber Laser, Chiller
  - Emission Wavelength: 1070 ~ 1080nm
  - Nominal Output Power: 4 kW
- 6kW Fiber Laser, Chiller
  - Emission Wavelength: 1070 ~ 1080nm
  - Nominal Output Power: 6 kW

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**Equipment for High-Power Laser Welding**

**Applications**
- Development of technology for laser welding of same kind or different kinds of materials intended for thick plates.

**Specifications**
- x-y-z Stage, Welding jig

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**Equipment for High-Power Laser Cutting in Air / Under Water**

**Applications**
- Development of laser cutting in air / under water.

**Specifications**
- X-Y-Z Triaxial Robot System
  - Speed Range: 5 mm/min ~ 5000 mm/min
- Laser Scanner
  - Wavelength: 520 nm, Power: 30 mW,
  - Waterproof Performance: Maximum Water Depth 100 m
- Water Tank
  - Maximum Water Depth: 3 m

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**Particle Image Velocimetry (PIV) system**

**Applications**
- Development on the quantitative evaluation method of an assist gas flow related to laser cutting.

**Specifications**
- Double-pulsed Nd: YAG laser
  - Wavelength: 532nm, Power: 50mJ/pulse,
  - Repetition rate: 20Hz
  - Pulse width: 6 ~ 8ns
- High-speed camera
**Inner wall laser welding repair device for a heat exchanger tube**

**Applications**
Technical development of weld repair of metal piping and other.

**Specifications**
- Fiber laser
  1) YLR-300-AC: Wavelength: 1,070nm, CW, Power: 300W
  2) YLR-150/1500/QCW: Wavelength: 1,070nm, Pulse/CW, Pulse width: 0.2-50ms, Power: 150W/250W(CW)
- Coupling device: Light guide up to 1kW, The observation by the CCD camera
- Composite optical fiber: (Core fiber) Φ0.2mm (Image transmission fiber) About 20,000
- Laser torch: Φ15mm, Length: 120mm, Jet of gas can be
- Wire feeder: Φ0.4mm use wire, Feed rate: 0.5-20mm/s

**Femtosecond laser system**

**Applications**
Fiber Bragg Grating(FBG) processing into the optical fiber. Development of ultra-short pulsed laser processing.

**Specifications**
- Laser unit
  Center wavelength: 790nm
  Pulse width: ~150fs
  Pulse energy: ~10mJ
  Repetition rate: ~1kHz
- Processing stage and microscope

**Q-switched Nd:YAG laser**

**Applications**
Development of pulsed laser processing.

**Specifications**
- Laser unit
  Wavelength: 1064nm or 532nm (SHG)
  Pulse width: 5-7ns
  Pulse energy: ~270mJ@1,064nm, ~130mJ@532nm
  Repetition rate: 10Hz
- Processing stage
Soft X-ray and ultraviolet spectroscopy, microscopy test equipment

**Applications**
Fundamental and applied studies on ultraviolet light and soft x-ray such as measurement of sodium transmission, microscopy, and surface cleaning.

**Specifications**
- Soft X-ray microscope
  - Wavelength: 20nm, 4nm
  - Optics: Schwarzschild
  - Resolution in the XY direction: 100nm
  - Observed area: 1mm x 1mm
  - Resolution in the Z direction: 30nm
  - Imaging range: 40 x 40μm - 200 x 200μm
- Soft X-ray, ultraviolet spectrometer
  - Main vacuum vessel: Inner diameter 560mm
  - Vacuum ultraviolet spectrometer:
    - Wavelength: 100nm - 300nm
  - Soft X-ray spectrometer:
    - Wavelength: 0.5nm - 5nm, 5nm - 30nm

Minimally invasive laser treatment equipment 1

**Applications**
Development of techniques of irradiating a laser to the affected area while watching an image using the composite optical fiber.

**Specifications**
- Fiber laser
  - YLR-50-SMLP: Wavelength 1,070nm, CW, Power 50W
- Blood flow meter
- Coupling device
- Control of certain irradiation output
- Monitor
- Composite optical fiber

Minimally invasive laser treatment equipment 2

**Applications**
Development of techniques to observe the affected area by placing minimally invasively optical fiber inside pancreas.

**Specifications**
- Uninterruptible power system
- Image observation device
- Monitor
- Optical fiber: outer diameter 0.8mm
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【Photo】The Tsuruga Peninsula from a airplane on the Japan sea.