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Fundamental Study on Development of Microchip-laser Induced Breakdown Spectroscopy System for Remote Analysis

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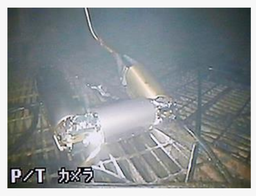
1. Background

1.1 Decommissioning of Fukushima Daiichi Nuclear Power Plant (FDNPP)

- The **decommissioning** of FDNPP is in processing, in which the information of **fuel debris** is important
- The **optical measurement** is the main method of detecting internal of reactors at present
- The **information of fuel debris** are analysis **off-site**
- The ***visualization*** of **fuel debris element** and **shape information** is **needed** for **in-situ investigation**



Internal condition by robot investigation[1]

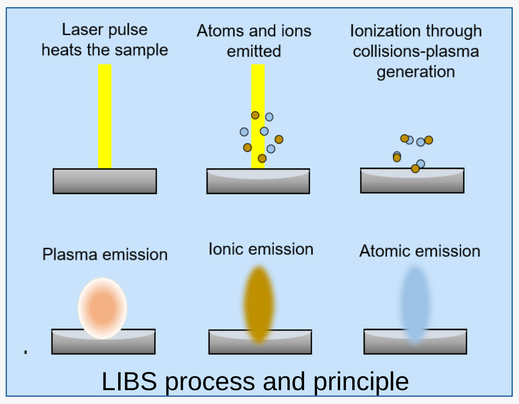
1.2 In-situ measurement for shape reconstruction and element analysis

- **Ultrasound techniques** has a potential for **in-situ** fuel debris **location** and **shape** investigation
- The method for **in-situ** fuel debris **element composition analysis** is still **lacking**

LIBS element analysis is noted

Laser Induced Breakdown Spectroscopy (**LIBS**) is a method for sample **composition** and **content of chemical elements** analyzing

- Laser is reliable in high-radiation and low light level area
- LIBS is **real-time** and **high accuracy**, has a great potential to be applied in decommissioning
- LIBS has wide **element coverage**



LIBS process and principle

How to reomotely control the LIBS measurement?

- In this study, the **fiber optic microchip LIBS system** is proposed based on the protection of the **lifetime of the equipment** and the **sustainability of the research**
- The **ultrasonic measurement** will be integrated with **LIBS** to conduct the **optimal measurement distance measurement, element composition,** and **shape reconstruction**

2. Objective

Development of Microchip-laser Induced Breakdown Spectroscopy System for Remote Analysis

1. **Development** of LIBS system (**fiber optic Microchip LIBS system** is setup);
2. **Parametric** and **excitation mode** study of LIBS system;
3. **Integration experiment** of **LIBS** and **air-coupled ultrasonic measurement** (**Visualization** of the **simulated fuel debris shape and element information**)

3. Construction of LIBS system

3.1 Construction of microchip LIBS system

- The **microchip-LIBS** (MLIBS) system contains:

1. **Beam guiding part (Cage system)**
2. **Laser emitting part (Laser diode pump and microchip laser)**
3. **Observing & analyzing part (Oscillo., etc.)**

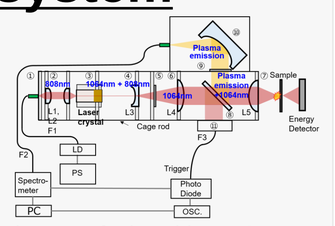
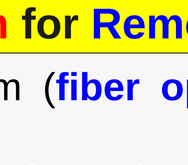


Diagram of microchip LIBS system

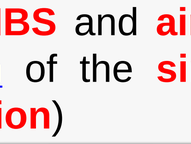
- **Nd:YAG laser crystal** is selected as the microchip laser, (PLSU150, Unitec, Inc.) **laser diode pump source** is selected. A **cage system** contains **lenses**, **filters**, and **mirrors** is built up. **Optical fiber** is applied for remote analysis

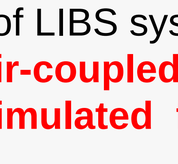
Model of each part in microchip LIBS system

Number (L: lens, Number: holder, filter, etc.)	Model (Thorlabs)
①	CP02/M, SM1SMA
L1; ②	C230TMD-B; CP1M09/M
L2; ②	C330TMD-B; CP1M09/M
③	SM1Z, SM1AD5
L3; ④	LC2969-C; CPN06
⑤	NF808-34, DCP1A
L4; ⑥	LA1560-C; CP14/M
L5; ⑦	LA1540-YAG; CP14/M
⑧	DMLP950, CP360R/M
9	SM1PD2A
⑩	RC08SMA-F01, SM1A6, CP30

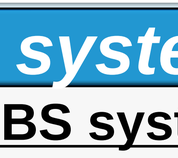

808nm laser diode

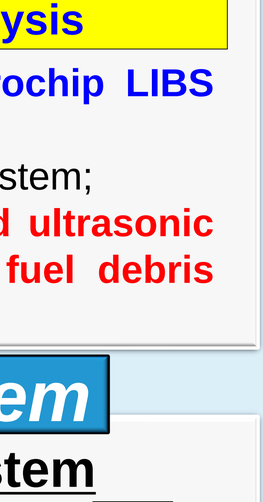
Nd:YAG/Cr:YAG composite ceramic


Energy detector


Spectrometer in LIBS system


Oscilloscope


Optical fibers



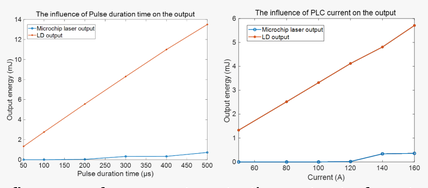
Cage system

4. Parametric Study

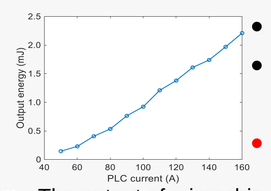
4.1 Output study of LD and microchip laser

- The influence of **PLS current** and **pulse duration time** to the system are **investigated**
- The **output** of microchip laser and LD are **recorded respectively**

Main parameters that influence output



Influence of parameters to the output of system (left: pulse duration time, right: PLC current)

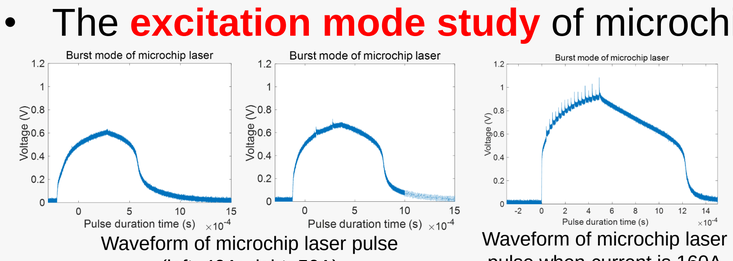


The output of microchip laser

- LD maximum output: **49.9mJ;**
- Microchip laser maximum output: **2.21mJ;**
- **Output difference** is great between **LD** and **microchip laser**

4.2 Burst mode study of microchip laser

- The **excitation mode study** of microchip laser were **conducted**



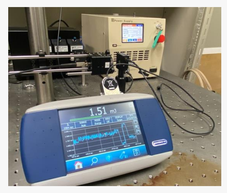
Waveform of microchip laser pulse (left: 40A; right: 50A)

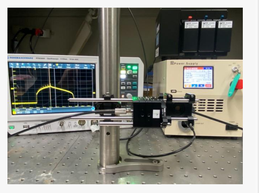
Waveform of microchip laser pulse when current is 160A

Important parameters of microchip LIBS:
- **Maximum output: 2.21mJ;**
- **Maximum output burst number: 17;**
- **Minimum output: 0.078mJ;**
- **The microchip LIBS system is work under multi-burst mode;**

Burst number of microchip laser is increasing with increase of parameter

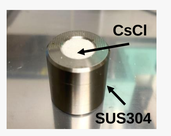
- The peak power of both LD and microchip laser could be obtained through burst data
- LD maximum peak power: **99W;**
- Microchip laser peak power: 2.21×10^4**W**

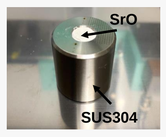

Output recording by energy detector


Waveform is recording by oscilloscope

5. Integrated Experiment by LIBS and Ultrasonic measurement

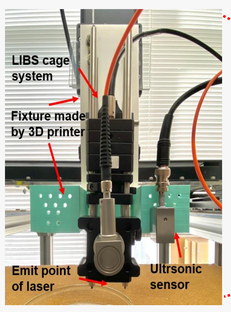
5.1 Experiment setup



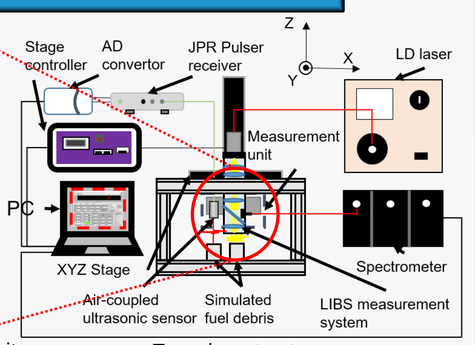


Simulated contaminated stainless pipe structure


HAR0.4K 14×20N flat air-coupled ultrasonic sensor



Integrated measurement unit



Experiment setup

5.2 Integration measurement for optimum measurement distance and element composition

Ultrasonic distance measurement specification

Sound velocity (m/s)	340
Sampling rate (S/s)	25M
Number of elements	1
Basic frequency (Hz)	1M
Pulse repetition frequency (Hz)	500
Number of repetitions	2

LIBS element analysis measurement specification

Integration time (ms)	5000
Scans to Average	1
Boxcar width	0
Trigger mode	Continuous
Electric dark	On

Experiment steps:

① **LIBS** and **ultrasonic measurement** conducted on **Z-axis**;

② **Element analysis** and **distance measurement** are conducted **simultaneously**;

③ **Measurement range** is (9-15mm, 1mm interval), and (9.6-11mm, 0.2mm interval)

Sr element and distance measurement result

Cs element and distance measurement result

- Constructed **LIBS system** can conduct **element analysis effectively**;
- The **optimum measurement distance** of LIBS system is (10.2-10.4mm)

5.2 Integration measurement for shape reconstruction and element analysis

Experiment steps:

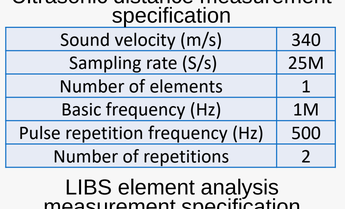
① **Ultrasonic** shape reconstruction measurement scan **X-Y plane** while keeping **Z=10.2mm**;

② **LIBS** conducted **simultaneously**

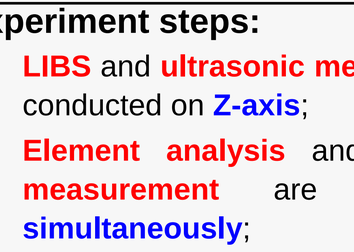
3D stage movement specification

X axis start (mm)	0
X axis end (mm)	110
X pitch (mm)	1
Y axis start (mm)	0
Y axis end (mm)	70
Y pitch (mm)	1
Distance from ultrasonic sensor to the ground (mm)	57.3
Distance from ultrasonic sensor to the sample surface (mm)	30.4
Scanning area (mm²)	7700
Scanning points	7700
Measurement time / point by ultrasonic measurement (ms)	2

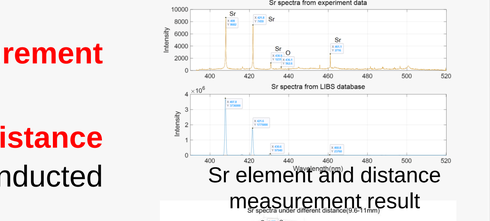
Ultrasonic shape measurement result



LIBS element measurement result



Integrated measurement result



✓**Ultrasonic shape reconstruction** is **successful;**

✓By combining with **LIBS**, the **shape accuracy** is **enhanced** and **2D element distribution** is ***visualized***

6. Conclusion

- ✓ **Fiber optic Microchip-LIBS system** was constructed
- ✓ **Parametric study** of **LIBS system** were conducted
- ✓ **Visualization** of the **integrated experiment** result by **LIBS** and **ultrasonic** is **achieved**

Reference

[1] Tokyo Electric Power Company Holdings, Inc, "The Status of Fuel Debris Retrieval" (2020). http://www.tepco.co.jp/nu/fukushima-np/handouts/2017/images1/handouts_170327_14-j.pdf (Reference date: August 24. 2021)
[2] Applied Spectra, "What is LIBS", https://appliedspectra.com/technology/libs.html (Reference date:Septemer 2, 2021)