Project report 2020

# LASMAT

**Nd3+/Yb3+rare earth ions-doped transparent laser ceramics by Spark Plasma Sintering method. Comparison with single crystals**

## MAIN PARTICIPANTS

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| **Georges BOULON**[a] | **Akira YOSHIKAWA**[b] | | |
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## OVERVIEW *(keep within this page)*

**Starting year:** 2014 **Current researchers** (permanent/non-permanent): 2 person-month/year

| **Positioning** *(Multiple selection allowed – total 100%)* | **Transportation** | **Energy** | **Eng. for Health** |
|---|---|---|---|
| **Materials and structure design** | | 100% | |
| **Surfaces and interfaces** | | | |
| **Simulation and modeling** | | | |

**Other:**

Include partner from ☒ Outside ELyT ☐ Industry

Main funding source(s)
☒ Public project(s) ☐ Industrial ☒ Own resources

IFS CRP/LyC project? ☐ Yes ☒ No

For main projects: Agency / year / name of project *(up to 3, past projects in gray)*

Estimated annual budget:

*LASMAT project is now completed. However we continue to work on these refractory materials grown by the new technique of bulk crystal growth from the melt in the cold crucible at IMR (Sendai) and for ceramics fabricated by SPS and HIP techniques at MATEIS, INSA-Lyon.*

**Highlights & Outstanding achievements** *(3-5 bullet points)*

- We have grown single crystals of $Nd^{3+}/Yb^{3+}$-doped $Lu_2O_3$ by µ-PD technique
- We have fabricated transparent ceramics of $Nd^{3+}/Yb^{3+}$-doped $Lu_2O_3$ by SPS technique.
- The spectroscopic properties of the two $C_2$ and $C_{3i}$ sites occupied by $Nd^{3+}$ or $Yb^{3+}$ of the sesquioxide lattice have been characterized.
- Laser outputs have been measured for all samples.

# PROJECT DESCRIPTION

**Background** (10 lines max; Calibri 11)

$Nd^{3+}/Yb^{3+}$-doped $Lu_2O_3$ refractory single crystals show the highest thermal conductivity (12.5 W/m/K) and are very promising as high power laser application. We are here at the frontier of materials science with a melting point of 2510°C so that successful growths of high crystal quality is a challenge. Indeed, instead to grow single crystals, it should be much easier to fabricate $Lu_2O_3$ into a ceramic structure -solid-state reaction process- because the sintering temperature is about 700 °C lower than its melting point and no expensive crucible is required. $Nd^{3+}/Yb^{3+}$-doped $Lu_2O_3$ single crystals have been grown by the Micro-Puling Down (µ-PD) in Yoshikawa's group at IMR and transparent ceramics by the non-conventional and fast Spark Plasma Sintering (SPS) method in Goto's group at IMR.

**Key scientific question** (2 lines max; Calibri 11)

Growth of $Nd^{3+}/Yb^{3+}$-doped $Lu_2O_3$ single crystals by µ-PD and now from the melt in the cold crucible at IMR, Sendai.

Fabrication of $Nd^{3+}/Yb^{3+}$-doped $Lu_2O_3$ transparent ceramics by SPS and now by HIP at MATEIS, INSA-Lyon.

**Research method** (8 lines max; Calibri 11)

We have mainly grown single crystals and transparent ceramics from IMR, analysed the spectroscopic properties at iLM-UCBLyon1 and laser outputs at Firenze (Italy). Especially the spectroscopy of the two $C_2$ and $C_{3i}$ sites of the cubic $Lu_2O_3$ sesquioxides have been characterized. **The project is completed**. However, after retirement of Prof. Goto at Tohoku two years ago, we improve the homogeneity of nanometric sizes of raw materials with Dr Malgorzata Guzik at the University of Wroclaw (Poland) in order to fabricate now transparent ceramics by SPS and HIP methods at MATEIS (INSA-Lyon). We experiment the fabrication of transparent ceramics by comparing with cubic $Y_6MoO_{12}$ molybdate under study with another grant. Also, Yoshikawa'group at IMR works on the improvement of the crystal quality of single crystals by creating the new technique of bulk crystal growth from the melt in the cold crucible.

**Research students involved** *(gray color for previous years)*

*Master students (years):*

*M. Sobota and P. Sobota (iLM-UCBLyon1 and MATEIS INSA-Lyon (2018-19)*

*Post-Doc: Guillaume Allombert-Goget (iLM, UCBL) (2015-2018)*

**Visits and stays** *(gray color for previous years)*

*FR to JP (date, duration):*

G. Boulon (Pr UCBL) Feb 2016, Feb 2017, Feb 2018, March 2019, Oct 2019, (3 weeks)

# COMMUNICATIONS AND VALORIZATION

**Journal publications** *(gray color for previous years)*

| | Authors | Title | Journal | Vol. | pp. / ID | Year | DOI |
|---|---|---|---|---|---|---|---|
| 1 | P. Sobota, M. Guzik, V. Garnier, G. Fantozzi, M. Sobota, E. Tomaszewicz, Y. Guyot, G. Boulon | The challenge of fabrication of optical transparent ceramics from cubic nano-crystals $Y_6MoO_{12}$ molybdate | Ceramics International | 46 Issue 4 | 4619-4633 | 2020 | https://doi.org/10.1016/j.ceramint.2019.10.192, |
| 2 | M. Sobota, P. Sobota, M. Bieza, M. Guzik, E. Tomaszewicz, Y. Guyot and G. Boulon | Influence of synthesis route and grain size on structural and spectroscopic properties of cubic $Nd^{3+}$-doped $Y_6MoO_{12}$ nano and micro-powders as optical materials | Optical Materials | 90, | 300-314 | 2019 | https://doi.org/10.1016/j.optmat.2019.02.021 |
| 3 | Y. Guyot, M. Guzik, G. Alombert-Goget, J. Pejchal, A. Yoshikawa, A. Ito, T. Goto | Spectroscopy of $C_{3i}$ and $C_2$ sites of $Yb^{3+}$-doped $Lu_2O_3$ sesquioxide either as ceramics or crystal | J. of Luminescence | 170 | 513-519 | 2016 | https://doi.org/10.1016/j.jlumin.2015.04.017 |
| 4 | M. Guzik, G. Alombert-Goget, Y. Guyot, J. Pejchal, A. Yoshikawa, A. Ito, T. Goto | Spectroscopy of $C_{3i}$ and $C_2$ sites of $Nd^{3+}$-doped $Lu_2O_3$ sesquioxide either as ceramics or crystal | J. of Luminescence | 169 | 606-611 | 2016 | https://doi.org/10.1016/j.jlumin.2014.12.063 |
| 5 | G. Alombert-Goget, Y. Guyot, M. Guzik, G. Boulon, A. Ito, T. Goto, A. Yoshikawa, M. Kikuchi | $Nd^{3+}$-doped Lu2O3 transparent sesquioxide ceramics elaborated by the Spark Plasma Sintering (SPS) method. Part 1: structural, thermal conductivity and spectroscopic characterization | Optical Materials | 41 | 3-11 | 2015 | https://doi.org/10.1016/j.optmat.2014.10.014 |
| 6 | G. Toci,, M. Vannini, M. Ciofini, A. Lapucci, A. Pirri,A. Ito, T. Goto, A. Yoshikawa, A. Ikesue, G. Alombert-Goget, Y. Guyot, G. Boulon | $Nd^{3+}$-doped Lu2O3 transparent sesquioxide ceramics elaborated by the Spark Plasma Sintering (SPS) method. Part 2: First laser output results and comparison with Nd3+-doped Lu2O3 and Nd3+-Y2O3 ceramics elaborated by a conventional method. | Optical Materials, | 41 | 12–16 | 2015 | https://doi.org/10.1016/j.optmat.2014.09.033 |

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| 7 | Malgorzata Guzik, Milosz Siczek, Tadeusz Lis, Jan Pejchal, Akira Yoshikawa, Akihiko Ito, Takashi Goto, Georges Boulon | Structuralinvestigations of un-doped $Lu_2O_3$ as Single Crystal and Polycrystalline Transparent Ceramic | Crystal Growth and Design, | 14 | 3327 −333 4 | 2014 | https://doi.org/10.1021/cg500225v |
| 8 | Shunsuke Kurosawa, *Liqiong An,* Akihiro Yamaji, Akira Suzuki, Yuui Yokota, *Kenji Shirasaki, Yamamura Tomoo, Akihiko Ito,* Takashi Goto, Georges Boulon and Akira Yoshikawa | Scintillation Properties of $Nd^{3+}$-Doped $Lu_2O_3$ Ceramics in the Visible and InfraRed Region | IEEE Transactions On Nuclear Science | 61 | 316-319 | 2014 | DOI: 10.1109/TNS.2013.2290554 |

**Conferences** *(gray color for previous years)*

| | **Authors** | **Title** | **Conference** | **Date** | **City** | **Country** | **DOI** *(if applicable)* |
|---|---|---|---|---|---|---|---|
| 1 | G. Boulon, G. Alombert-Goget, Y. Guyot, M. Guzik, J. Pejchal, A. Yoshikawa, A. Ito, T. Goto, A. Ikesue, G. Toci | A challenge for laser materials $Nd^{3+}$-doped $Lu_2O_3$ ceramics/crystals . | CIMTEC, 14th International Ceramics Congress, Invited | 4-8 June 2018 | Perugia | Italy | |
| 2 | G. Boulon | Achievements, progress and issues in laser ions-doped optical transparent ceramics. | International School of Atomic and Molecular Spectroscopy Invited | 20 July-4 Aug 2017 | Erice (Sicily) | Italy | |
| 3 | G. Boulon, A. Yoshikawa, M. Guzik, G. Toci | A challenge: $Nd^{3+}$-doped $Lu_2O_3$ ceramics. Fabrication by the SPS and HIP techniques, spectroscopic characterization and laser output. | 12th Laser Ceramics Symposium. International Symposium on Transparent Ceramics for Photonic Applications Le FORUM – Invited | 28 Nov. – 2 Dec. 2016 | Saint-Louis | France | |