2nd German-Japanese Digitalisation-Dialogue
Additive Manufacturing Forum

The Latest Actions of Technology Research Association for Future Additive Manufacturing (TRAFAM)

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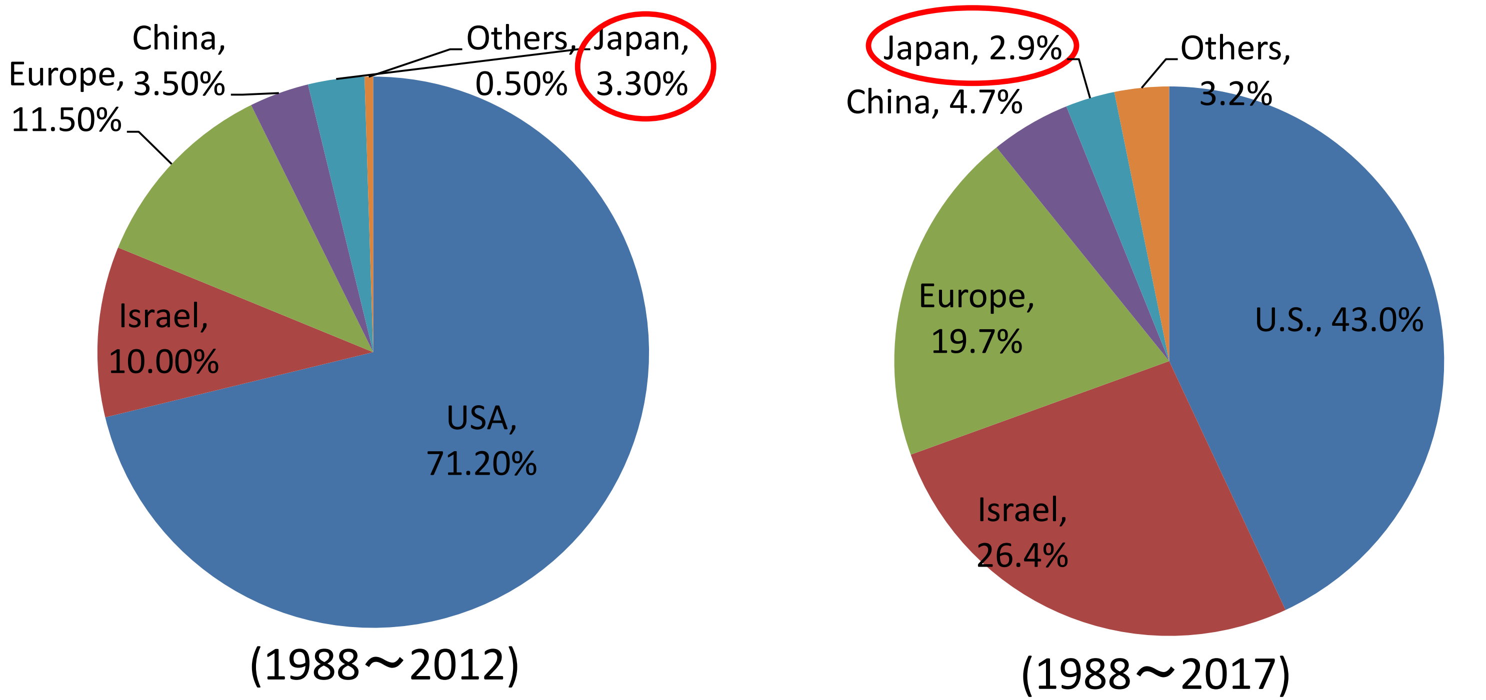
1. Introduction

- Additive Manufacturing (AM) technology has been dramatically attracting attention as a breakthrough technology in advanced manufacturing in Japan.
- It is, however, pointed out that Japan lags behind Europe and the U.S.A. in addressing this technology.



(Source: Wohlers report 2018)

Fig.1 Total shipment volume of AM systems

■AM system manufactures in Japan

- 3D printing technology was invented in Japan in 1980, with the development of a three-dimensional plastic model with a photopolymer by Dr. Kodama.
- And then many companies were founded at early stage. Recently some companies are entering the plastic and metal AM business, especially hybrid-type AM machines, PBF and milling type machine or DED and milling type machine.

【DMG MORI】

DED and milling type machine

(https://www.dmgmori.co.jp/products/machine/id=1542)

PBF and milling type machine

【MATSUURA】 (Courtesy of Matsuura machinery)

1. Introduction

TRAFAM Technology Research Association for Future Additive Manufacturing

- The Ministry of Economy, Trade and Industry (METI) of Japanese Government established a Study Group on New “Monodzukuri (Manufacturing)” in October 2013.
- The Study Group identified the following issues to as a priority;

(1) Developing equipment, materials and software,

(2) Developing the necessary environments,

(3) Fostering human knowledge and skills,

(4) Seeking optimum approaches to creating enterprises.

1. Introduction

- On the basis of the offering of the Study Group, METI invested around $36.5 million (FY2014) to establish a new research association, **"Technology Research Association for Future Additive Manufacturing (TRAFAM)"** in order to implement the national project（FY2014～FY2018）.

- In this presentation, the role and latest actions of TRAFAM for Additive Manufacturing are introduced.

National Project (TRAFAM)

- TRAFAM started in the members of three academic institutions and 29 companies in FY2014.
- The members of TRAFAM are three academic institutions and 34 companies in FY2018.
- TRAFAM implements the following program organized METI:

"Manufacturing revolution program centering on 3D printing technology"(FY2014-FY2018)

(A) Next-generation industrial 3D printers project

(B) Development of 3D printing systems for sand casting cores and molds project

(FY2013-FY2017)

2. TRAFAM project

TRAFAM
Technology Research Association for Future Additive Manufacturing

National Project (TRAFAM)

Mission

Establishment of new manufacturing industry in Japan centering on metal Additive Manufacturing systems that will give rise to the next generation of innovative products.

Goal

- Development of innovative metal Additive Manufacturing systems that will meet the world's highest standards.
- Development of manufacturing technologies for high value-added products of any complicated shape, for aerospace, medical, and transportation industries etc.

Realize this goal through an “All Japan” cooperative structure for technology development (FY2014 to 2018) focusing on machine, materials, and software.

2. TRAFAM project

TRAFAM Technology Research Association for Future Additive Manufacturing

■ Target of TRAFAM project

■ Additive Manufacturing systems

- ● High speed : approximately 10 times the current speed (2013FY)
- ● High precision : approximately 5 times the current precision
- ● Large scale : approximately 3 times the current built area range
- ●Multi-layer structure type: different types of metal materials can be used

●Electron beam (EB) type (multi-layer and large-size high speed EB AM machine)

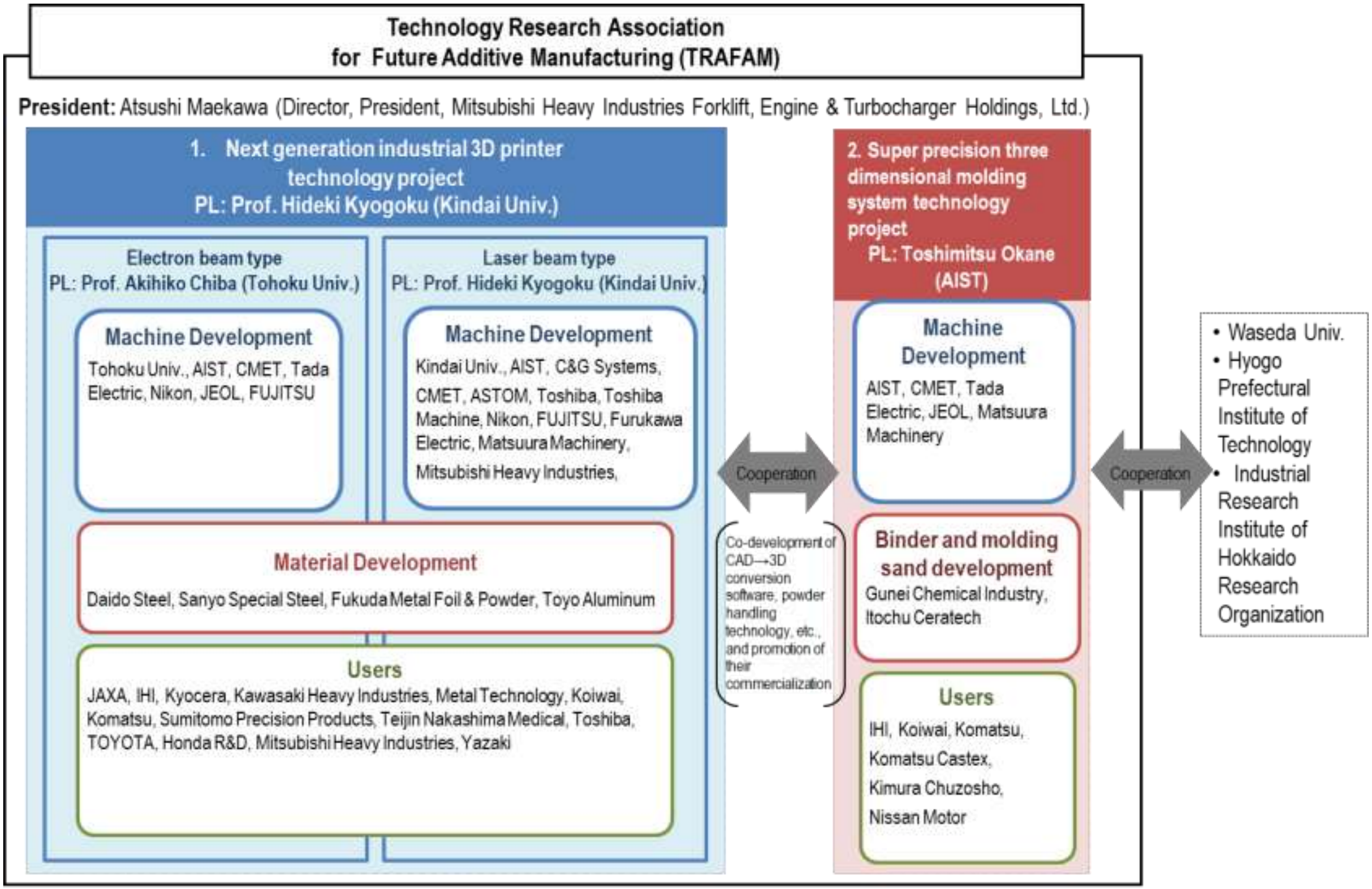
●Laser beam (LB) type (multi-layer and large-size high speed LB AM machine)

■ The ultimate goals of the TRAFAM project (to be reached in FY2018)

	Light Source	Product Size (mm)	Building Speed (cc/h)	Dimensional Precision (μm)
Type I	EB	Large (1000 x 1000 x 600)	500	50
Type II	EB	Small (300 x 300 x 600)	500	20
Type III	LB	Large (1000 x 1000 x 600)	500	20
Type IV (Deposition method)	LB	Small (300 x 300 x 300)	500	20

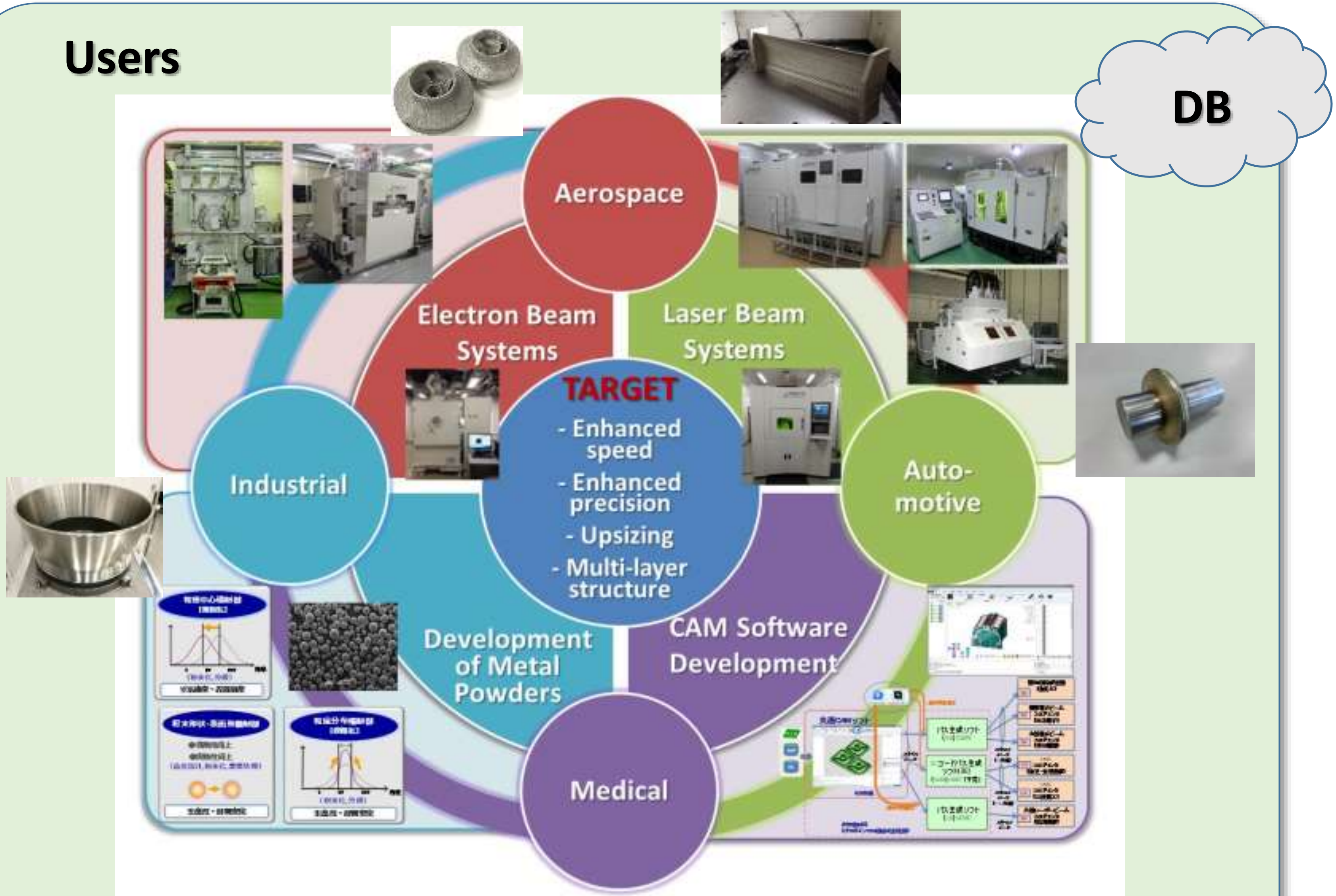
TRAFAM
Technology Research Association for Future Additive Manufacturing

The Cooperate Structure of TRAFAM



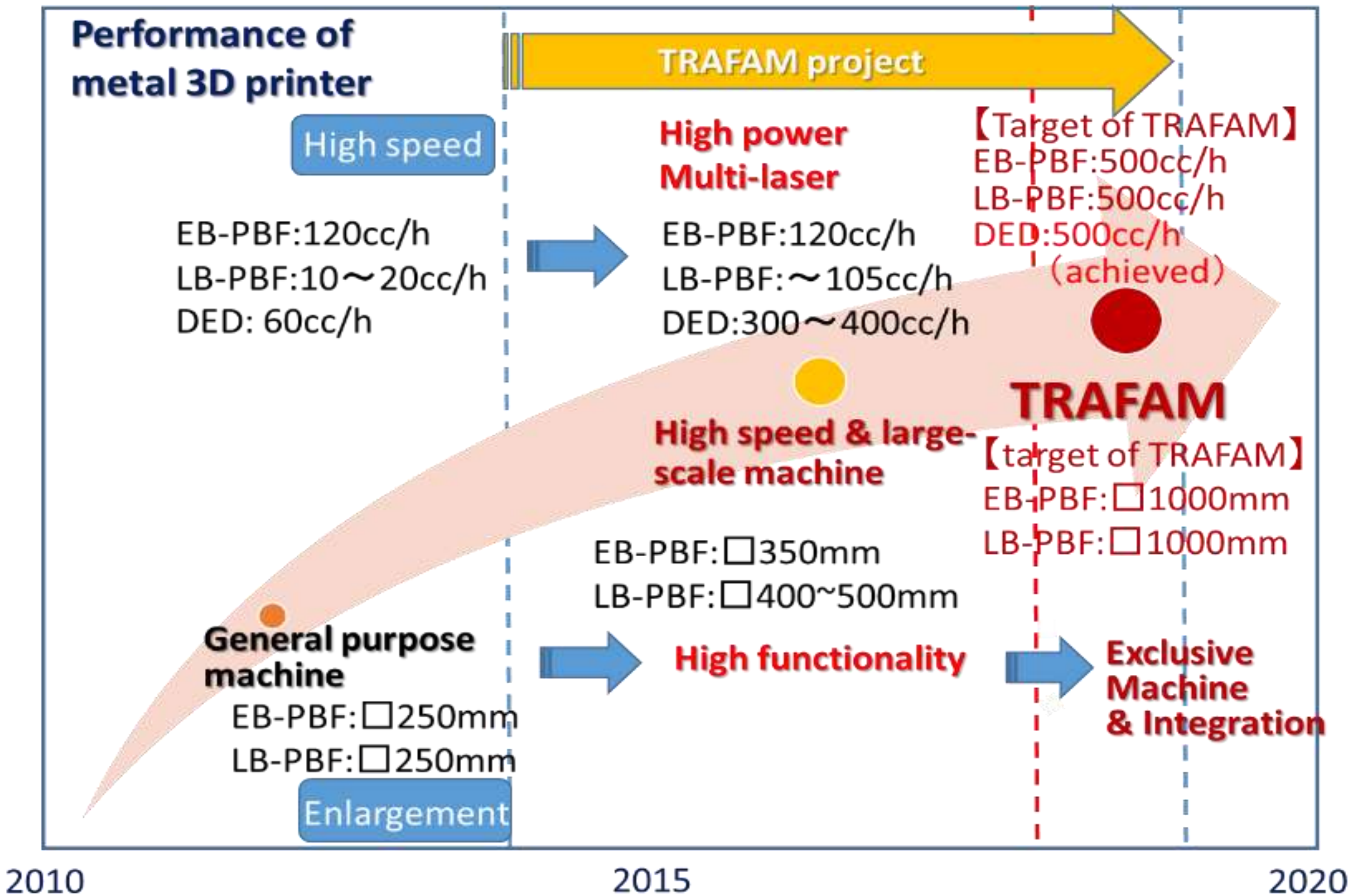
(As of April 1, 2017)

2. TRAFAM project



Schematic chart of TRAFAM project

Changes in metal AM machines



3. Development of PBF & DED machines

■ Test benches & prototype AM machines

Electron Beam system

Powder Bed Fusion type (Test bench)

Powder Bed Fusion type (Multi-layer, Small-scale prototype machine)

Powder Bed Fusion type (Large-scale prototype machine:500x500)

Laser Beam system

Powder Bed Fusion type (Test bench)

Powder Bed Fusion type (Large-scale prototype machine:600x600)

LMD type (Multi-layer prototype machine)

LMD & Milling type (Multi-layer prototype machine)

EB-PBF machine by JEOL

●Design of Electron Gun and Electron Optic System for 6kW at 60kV$_{acc}$

- Prevent electric discharge
- Stable emission of electrons from
- LaB_6 cathode
- narrow beam at the powder bad
- large deflection angle with short work distance

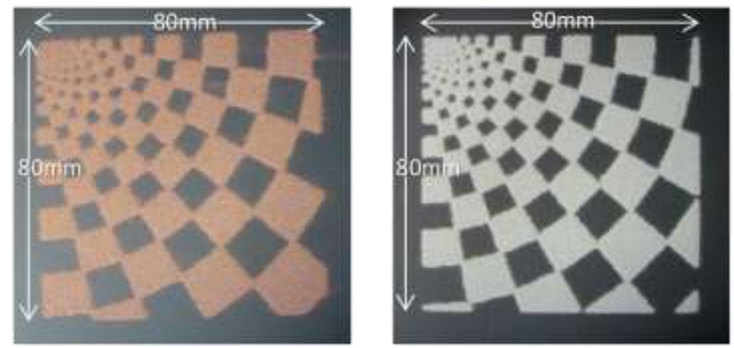
The first EB machine was set up in 2015/04 by JOEL.

3. Development of PBF & DED machines

■ EB-PBF machine by JEOL

● The second EB-PBF machine

● Development of multi-material powders dispersing process technology



Copper and M2 powder
Accuracy of positioning: 200 µm
Results of multi-material powder dispersion

The second EB machine was set up in 2018/03 by JOEL.

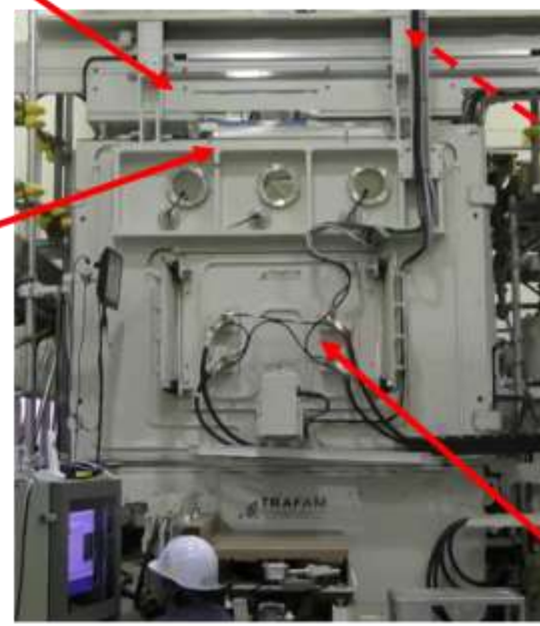
- Power: max 10 kW
- Prevention of electric discharge, “smoke phenomenon”
- Material: TiAl

3. Development of PBF & DED machines

■ EB-PBF machine by TADA ELECTRIC

● Development of Large-Scale EB Powder Bed 3D Printer (build size: 500x500 mm)

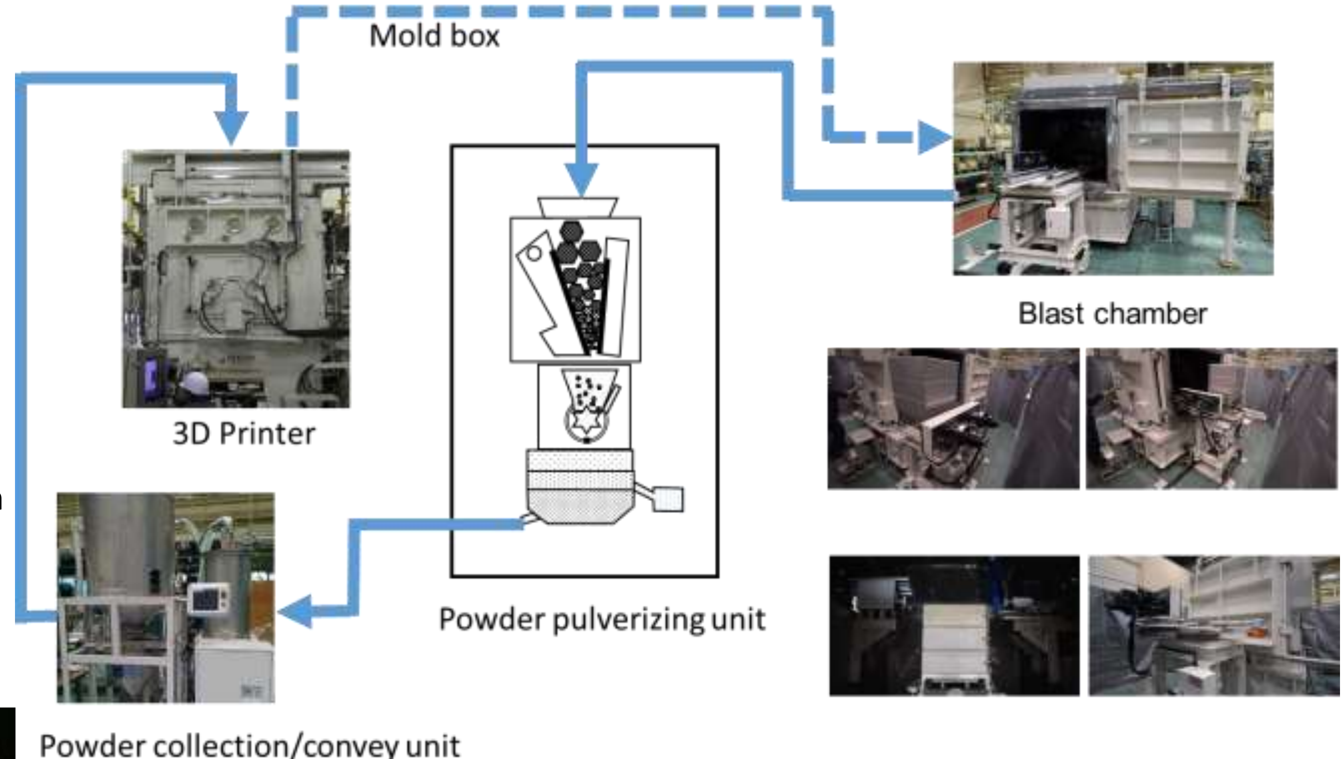
・Maximum Mold Size: W500xL500xH600mm
・Rated output: 6 kW
Original Long lifetime Cathode (Over1,000 h)



EB-PBF machine by TADA ELECTRIC

● Powder Recycle System for Large-Scale Printer

Powder supply system



Molding

3. Development of PBF & DED machines

■ LB-PBF machine by MATSUURA MACHINARY

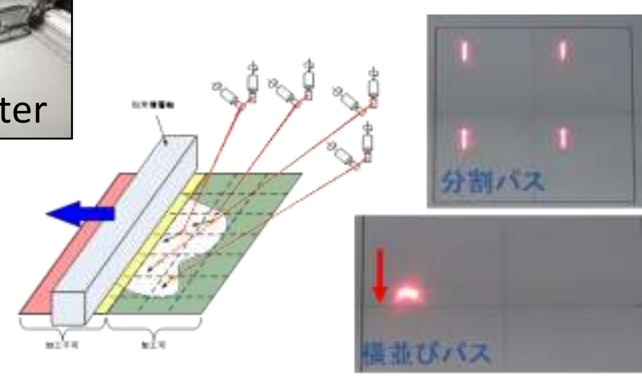
(Large-scale prototype machine:600x600)(Large-scale commercial machine:600x600)

1. High power laser

- 1 KW single mode fiber laser
- 2 kW single mode fiber laser

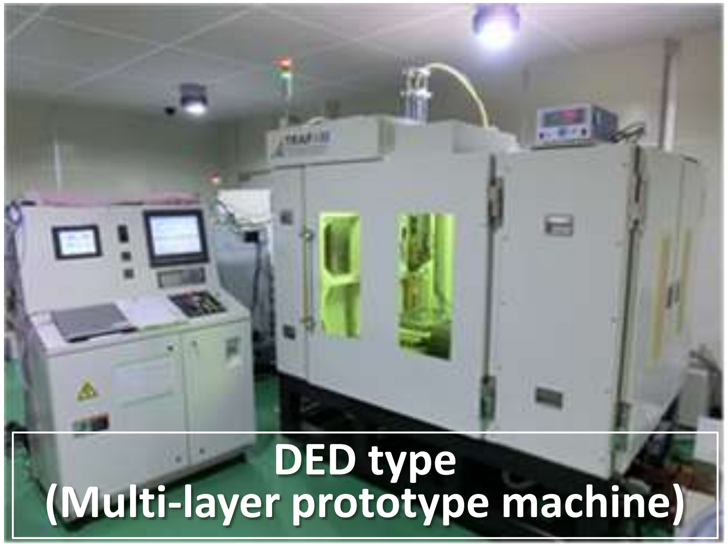
2. Multi-laser control system

- 4 laser units



3. High-speed recoater

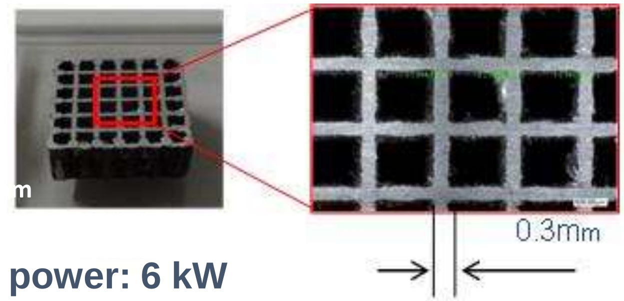
■ LB-DED machine by TOSHIBA & TOSHIBA MACHINE

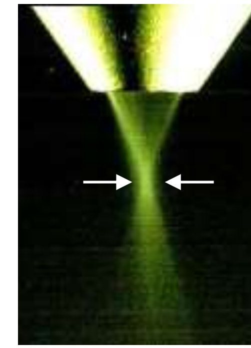


DED type
(Multi-layer prototype machine)

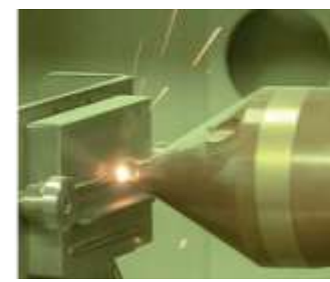
● **Development of high performance nozzle**

- **Laser: 6 kW**

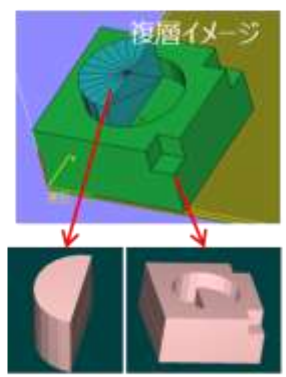




- Laser power: 6 kW
- Multi-layer type
- Build speed: 510 cc/h

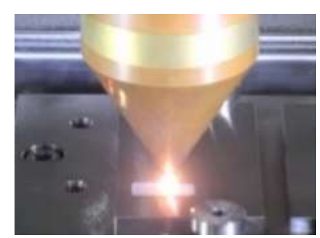


● **Development of CAM software for 5-axis control & multi-material DED**



A B

5-axis control & Multi-material DED



In low oxygen atmosphere

In air

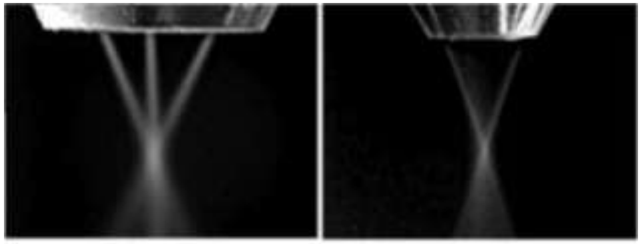
LB-DED machine by MITSUBISHI HEAVY INDUSTRIES MACHINE TOOL

DED & Milling type (Multi-layer prototype machine)

- Laser power: 6 kW
- Multi-layer type
- Build speed: 510 cc/h

● Development of High performance nozzle

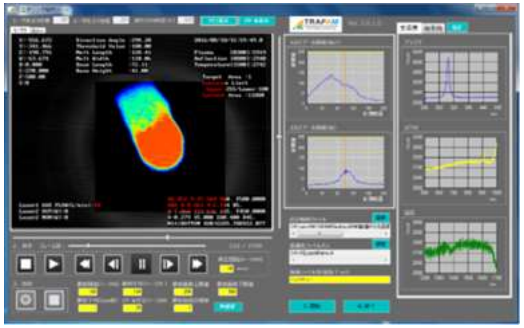
- Laser: 6 kW



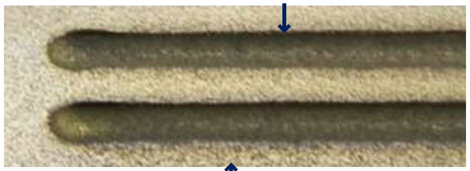
3 beam type   Co-axial type

● Development of monitoring feedback system

Test bench for monitoring

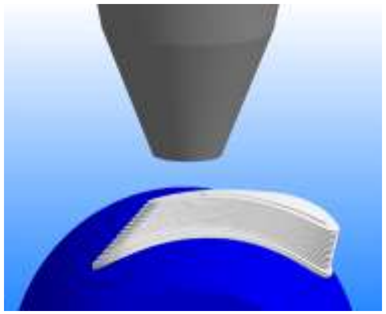


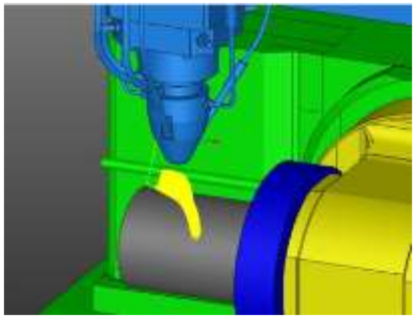
Before feedback control



After feedback control

● Development of CAM software for 5-axis control & multi-material DED

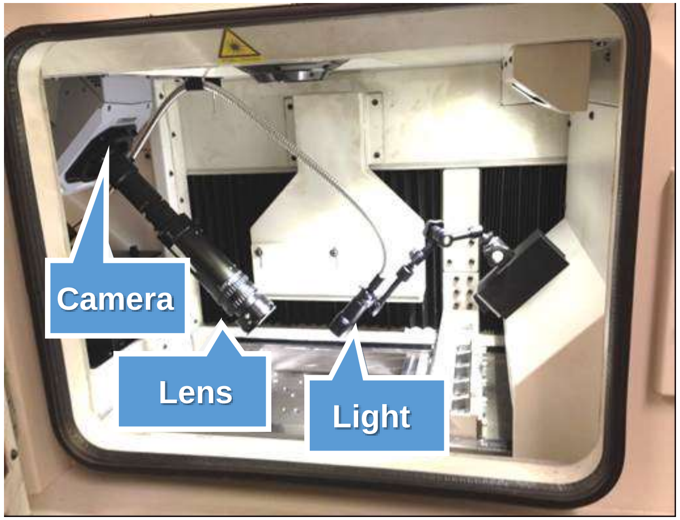




■ LPBF-type Test Bench

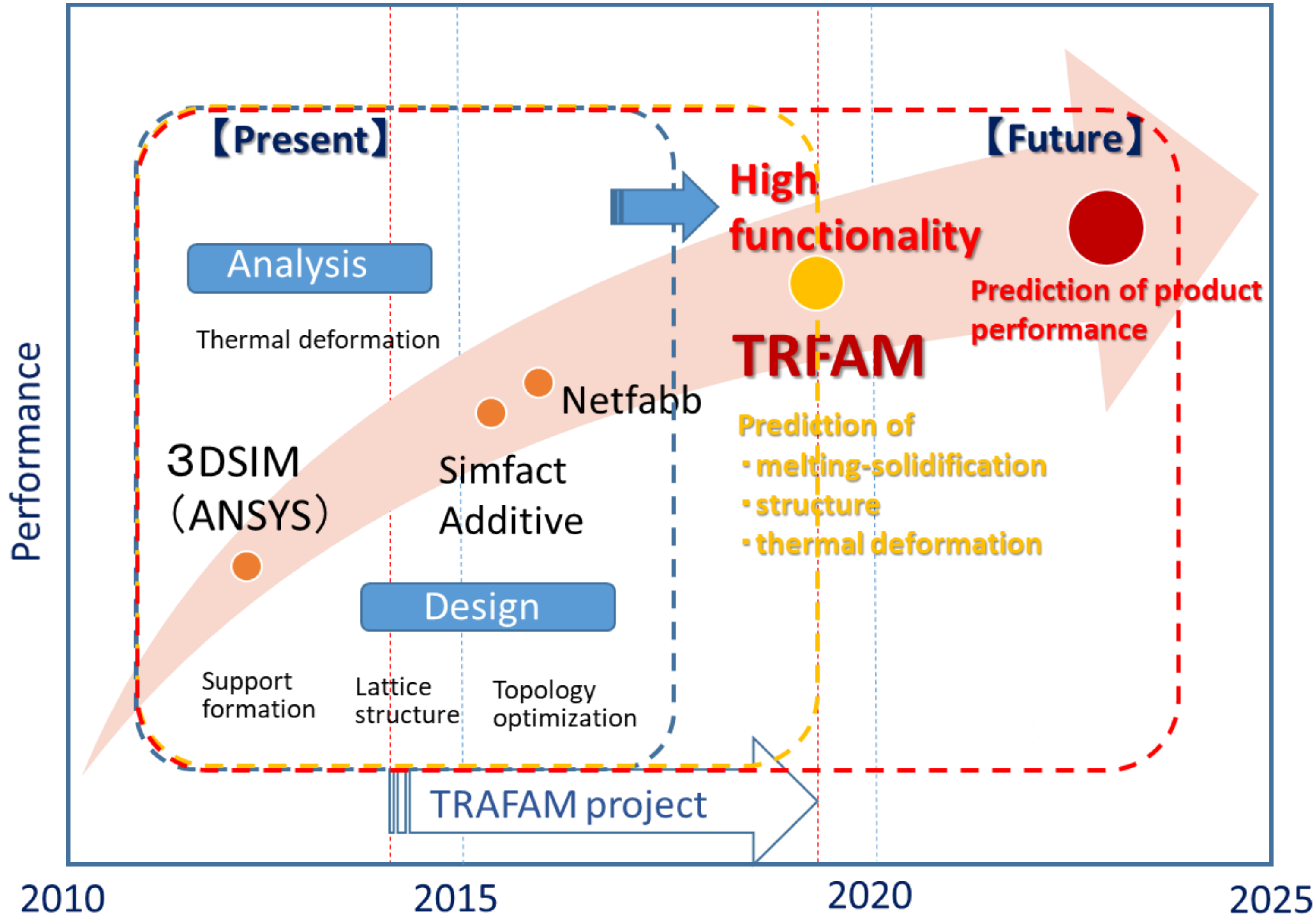
【Specification】
- Powder bed fusion type machine
- Build size : □250 × H185
- Laser : 1 kW single mode fiber-laser

●**Analysis of melting-solidification phenomenon using high-speed camera & thermo-viewer to make the optimum process map and to simulate precisely**
- **Stainless steel (17-4PH)**
- **Nickel alloy (IN 718)**
- **Aluminum alloy (Al10Si0.4Mg)**
- **Titanium alloy (Ti6Al4V)**

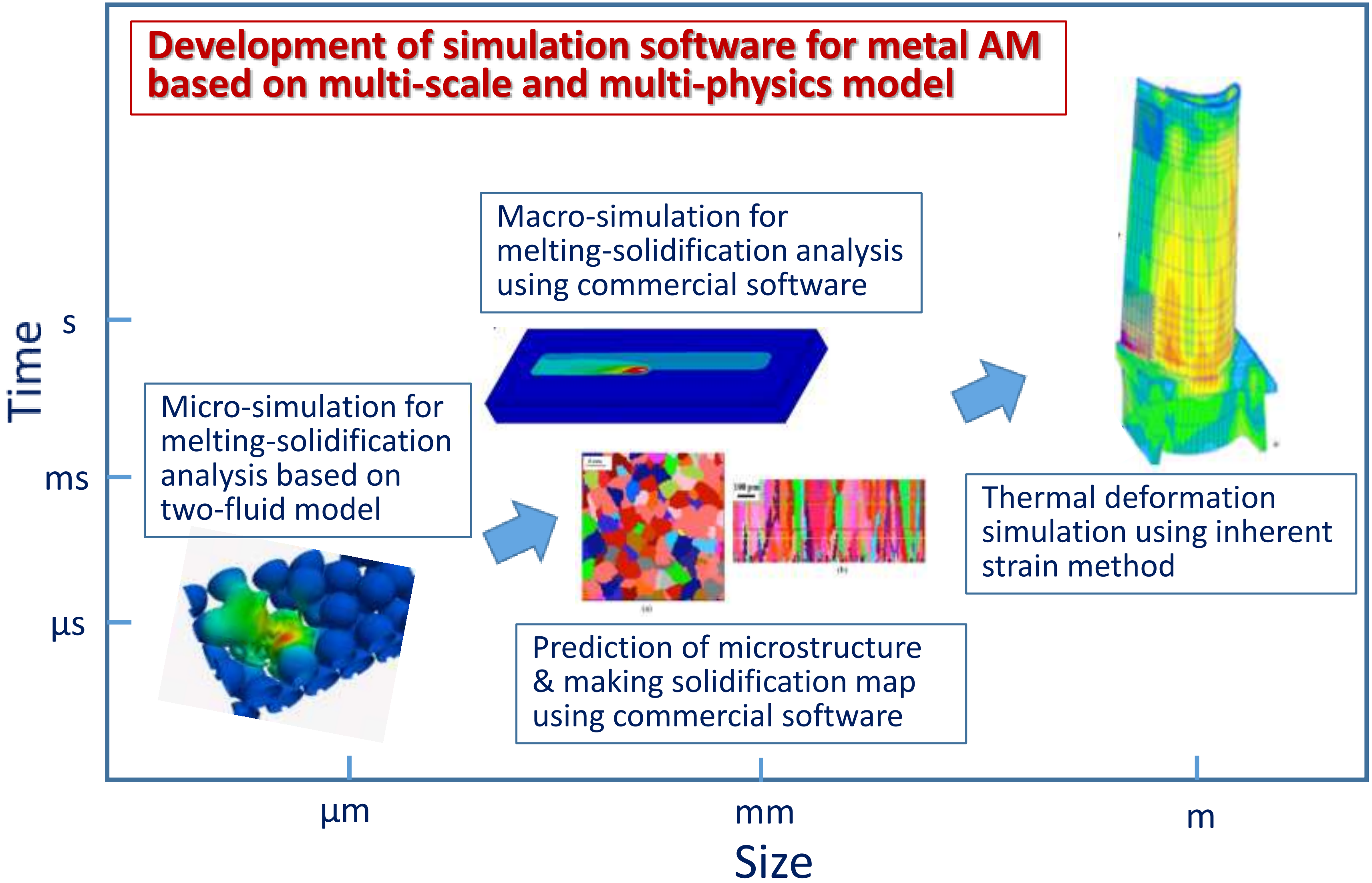


Laser beam PBF type Test bench

Changes in simulation software for AM



■ Development of simulation software for metal AM

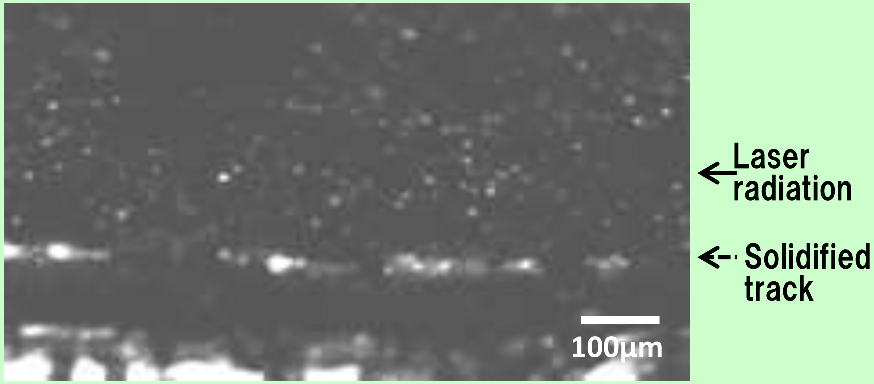


■ Development of simulation software for metal AM

Micro-simulation for melting-solidification analysis based on two-fluid model

Image of melting-solidification phenomenon observed by high speed camera

・IN718 ・Laser power: 292W ・Scan speed : 610mm/s

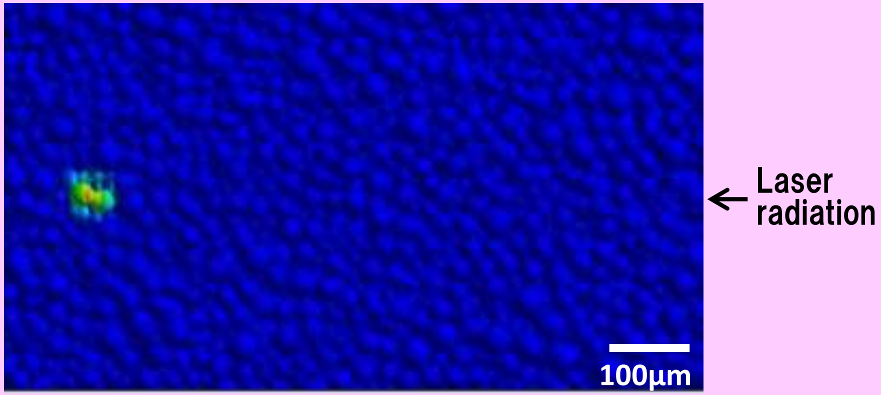


The multi-physics model in the EB-PBF system was constructed to simulate melting and solidification phenomenon at a microscopic level by using a super computer.

Simulation result from top view

TRAFAM（two-fluid model developed by MHI）

・IN718 ・Laser power:118W ・Scan speed: 1600mm/s



• The generation of plume flow and spatter which cannot be expressed by one-fluid model were successfully able to be simulated using two-fluid model.

LLNL（one-fluid model）

4. Development of simulation software

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Macro-simulation for melting-solidification analysis using commercial software

■ Prediction of fabrication conditions of pure copper using macro-simulation

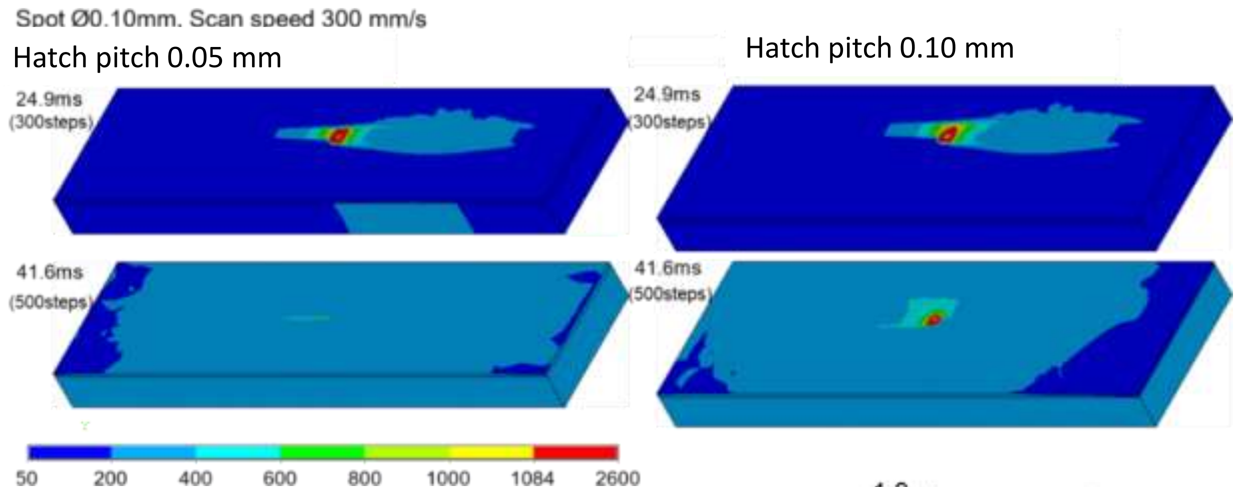
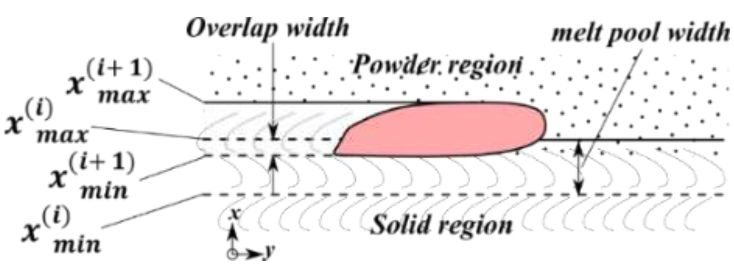


Fig.1 Results of simulated temperature distribution



$$r_{overlap} = \frac{(Overlap\ width)}{(Melt\ pool\ width)} = \frac{x^{(i)}_{max} - x^{(i+1)}_{min}}{x^{(i)}_{max} - x^{(i)}_{min}}$$

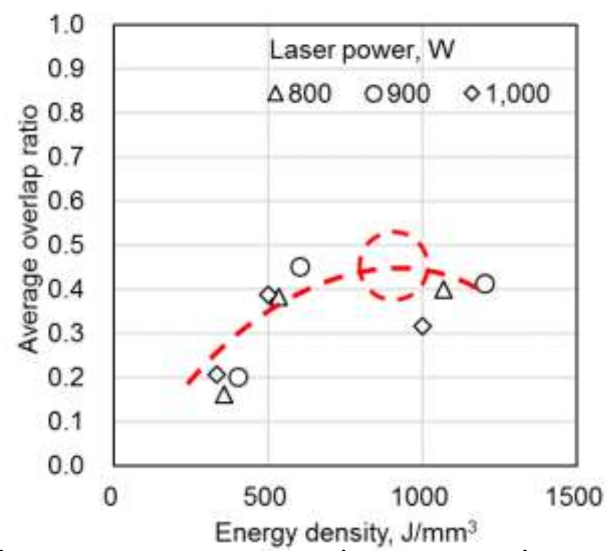
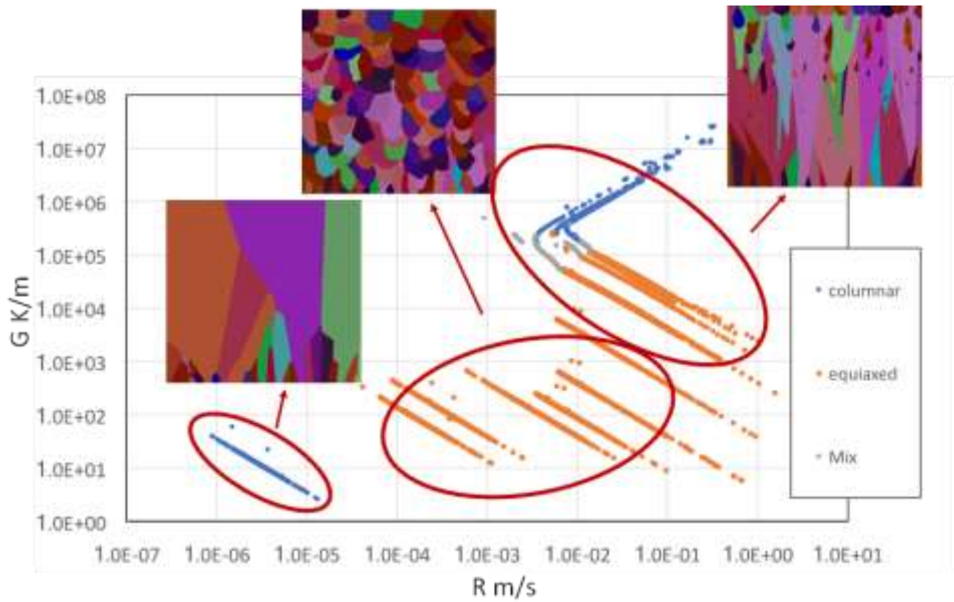


Fig.2 Change in average overlap ratio with energy density

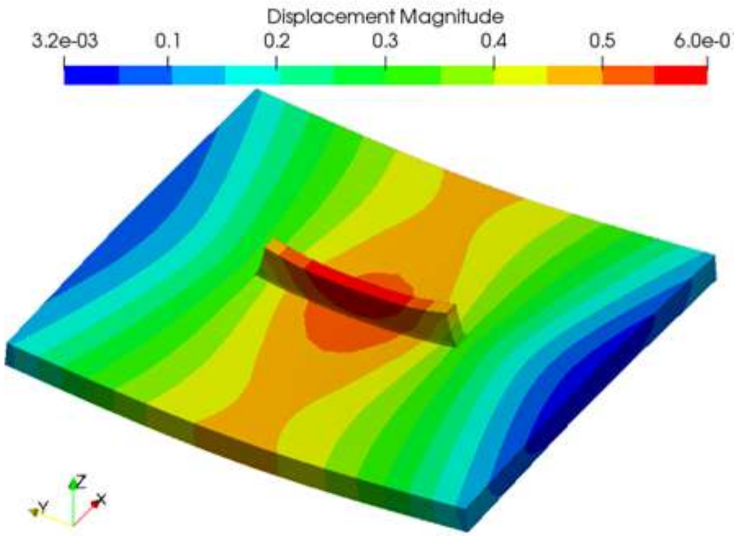
Development of simulation software for metal AM

Prediction of microstructure & making solidification map using commercial software



Solidification map of A7075 by cellular automaton simulation

Thermal deformation simulation using inherent strain method



Result of deformation during laser direct energy deposition

In addition to the analysis of melting-solidification phenomenon of a melt pool by a computational fluid dynamics (CFD), the solidification maps, displaying solidification microstructure as a function of solidification rate and thermal gradient at the solidification front, were determined by using a cellular automaton simulation.

The results analyzed by the inherent strain method coincided considerably with those of the thermal elastic-plastic FEM analysis by optimization of the inherent strain of material.

- **ISO/TC261 committee member**
  - The committee was held in Tokyo in 2016
  - Proposal of some standards
- **The committee of the Japan Industrial Standards for AM technology**
  - Preparation of the JIS for AM
- **AM Seminar**
  - Three times per year
  - Preparation of two textbooks (about 180 pages)

    * I appreciate EPMA in giving us some data.

Textbooks for AM seminar

6. Summary

Technology Research Association for Future Additive Manufacturing (TRAFAM) was carried out the following two projects in order to develop the innovative Additive Manufacturing systems that would meet the world's highest standards and the manufacturing technologies for high-value-added products. The results obtained by FY2017 were as follows:

(A) Next-generation industrial 3D printers project

(1) Morphology and temperature of a melt pool were observed and analyzed by using the electron-beam powder-bed fusion (EB-PBF) system for the basic research, developed in this project, equipped with a high-speed camera. Based on this basic survey, an advanced monitoring system for the EB-PBF has been also designed and prototyped.

(2) The electrical and thermal properties of alloy powders used in the EB-PBF were measured, and the effect of a surface oxide layer was analyzed in order to consider the methodology to suppress the smoke phenomena in EB-PBF.

(3) In addition to the analysis of melting and solidification pehnomenon of a melt pool by a computational fluid dynamics (CFD), solidification maps, displaying solidification microstructure as a function of solidification rate and thermal gradient at the solidification front, were determined by using a cellular automaton simulation, not experiments.

6. Summary

(4) Considering the melting and solidification phenomena by laser radiation, the macroscopic simulation was carried out by using the newly developed heat input model considering the different laser absorption factor values by the powder layer, solidified part, and liquid phase in the unsteady heat conduction analysis. And, by using the overlap ratio, it was suggested that the optimum value of energy density could be predicted.

(5) The multi-physics model in the EB-PBF system was constructed to simulate the melting and solidification phenomena at a microscopic level by using a super computer.

(6) The thermal elastic-plastic simulation program was developed by using the inherent strain method in order to predict the deformation of the parts fabricated by directed energy deposition (DED). The results analyzed by the inherent strain method coincided considerably with those of the thermal elastic-plastic FEM analysis by optimization of the inherent strain of materials.

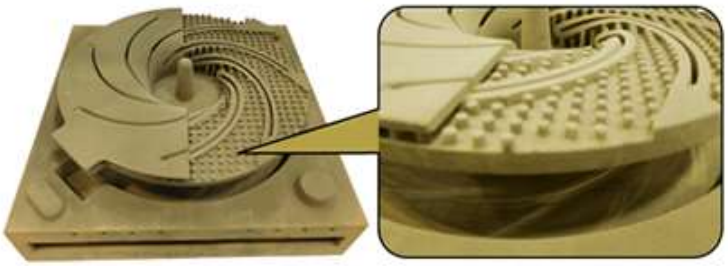
(7) The tensile tests and fatigue tests were carried out using the specimens fabricated by PBF and DED types of 3D printers. The tensile strength of the as-built and HIPed specimens was similar to that of the wrought materials. The fatigue strength of the as-built specimens was lower than that of the wrought materials, while the fatigue strength of the HIPed specimens was similar to that of the wrought materials.

The obtained data have been stored in the database designed and developed in this project.

(B) Development of 3D printing systems for sandcasting cores and molds

We developed AM machines and materials for sand mold, which enable us to produce the required complex molds and unified cores for metal casting.
By FY2016, we developed the first and large AM machine with the organic binder and coated sand, then achieved the desired value of build speed (100,000 cc/h) and work size (more than 1,000 x 1,000 x 600 mm).
In FY2017, we developed the non-organic binder sand mold AM system for environmental improvement of foundry. We got a good result in casting test. We also developed the sand mold AM machine which can use two type of sand partially. We verified the effect to reduce casting defects by the difference of heat capacity in sand mold parts.

CEMET : Sand Casting Machine “SCM-1800”
(1,800 x 1,000 x 750 mm)



An example of sand mold

Acknowledgements

This report is based on results obtained from a project commissioned by the Ministry of Economy, Trade and Industry (METI) and the New Energy and Industrial Technology Development Organization (NEDO).

Thank you for your kind attention!

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