Laser Micro Fabrication Laboratory

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1. Brief Overview

In April 2000, Laser Micro Fabrication Laboratory was established as part of the Research Center for Superplasticity in Ibaraki University. This center mainly focuses on three research fields: applied superplasticity (Division A), nano smart materials fabrication (Division B), and laser micro fabrication (Division C).

Our laboratory is in charge of Division C and put high priorities on research of synergistic effects of materials and processing, including fabrication of three- dimensional (3D) as well as surface (2D) micro structures having various functional properties. Novel technologies, such as laser processing, spark plasma sintering, rapid prototyping and RF plasma-assisted CVD, are utilized to advanced metals, ceramics and polymers.

Professor Maekawa heads up Laser Micro Fabrication Laboratory. A Russian researcher and a dozen of students join this team: one PhD, six masters, and six undergraduates as of December 2005 (Fig. 1). Some research themes are carried out in collaboration with National Institute of Advanced Industrial Science and Technology (AIST) and National Institute for Materials Science (NIMS) in Tsukuba, Japan Atomic Energy Agency (JAEA), and local companies, including Kinzoku Giken, Star Engineering and Harima Chemicals Inc.

Fig.1 Laboratory members in 2004

2. Brief Summary of Research Activities

We have focused on four main research topics in these five years: laser processing for 3D micro fabrication, DNA metrology, affective shape design, surface modification, and precision machining.

2.1 Laser 3D Micro Fabrication

① Porous bone substitutes

The Green Tape Laser Sintering (GTLS) Method is employed to fabricate bone substitutes. The GTLS method is one of the rapid prototyping (RP) techniques and its novelty lies in the use of a titanium tape formed with micro powder, organic binder and solvents. A 3D-CAD data file of a bone model is converted into a sliced STL data file. And then, the sliced layers representing the cross-sections of the bone are scanned on titanium green tapes to sinter powder particles using a laser beam. Repeated scans for all layers produce a full bone structure. Laser parameters and sintering conditions are carefully controlled to fabricate a replica of the original bone (Figs. 2 and 3). We use a fine salt to keep the porous structure during the lamination process.

Fig.2 Fabricated bone and its base model

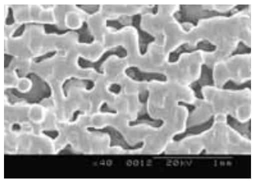


Fig.3 Surface moorphology of fabricated bone

② Cellular dental implants

We develop a dental implant with interconnected pores that enable tissue engineering. The implant can be fabricated by a combined technology of rapid prototyping with spark plasma sintering (SPS) using titanium tape made of a pure powder. Both open-cell and closed-cell structures can be designed and

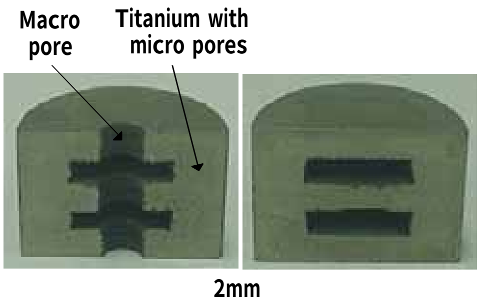


Fig.4 Cross-sectional view of Ti implant structures

assembled with a reasonable accuracy (Fig. 4).

③ **Eco-processing using recycled powders**

It is a difficult task to recycle steel scrap when it involves other impure metals. Copper is one of the elements difficult to separate from steel. We have investigated sintering and lamination characteristics of Fe-Cu atomized powder to meet requirements on recycling of automobiles and manufacture of lightweight structure. The GTLS method using Nd:YAG pulse laser and powder tape called "greentape" is employed for the fabrication of Fe-Cu porous structure. This work is being collaborated with NIMS.

④ **Improvements in dimensional accuracy and mechanical properties of RP parts**

On top of maintaining dimensional accuracy, metal infiltration is necessary to increase mechanical strength of RP parts. Using resin-coated stainless steel powder of around 40 μm in diameter, we fabricate rotor blades by the selective laser sintering (SLS) process. Bronze is infiltrated into the SLS part in nitrogen atmosphere to reach a tensile strength of 536 MPa. Via machining and assembly, a stainless-steel bladed wheel is completed (Fig. 5). It was used for a performance test.

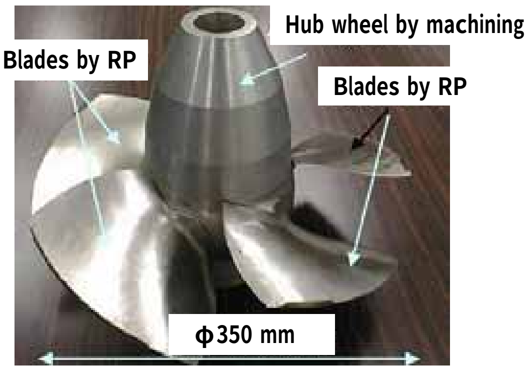
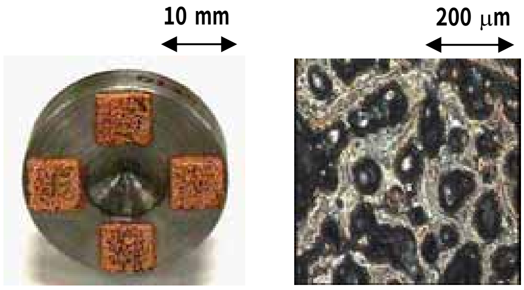


Fig.5 Stainless-steel bladed wheel built by SLS process (Courtesy Hitachi Corporation)

⑤ **Smart structures and hybrid composites**

Metal-bonded grinding wheels have a low grinding capability due to insufficient porosity. In the process of the GTLS process, super abrasives such as diamond and cBN were supplied to form a copper-bonded tool with a porosity of 30 % (Fig. 6). Multi-layered printed circuit boards are also being developed in which metal NanoPaste is utilized by means of a combined process of ink-jet printing and laser sintering. This wiring technology realizes a waste-free, short lead-time process compared with the conventional photolithographic method.

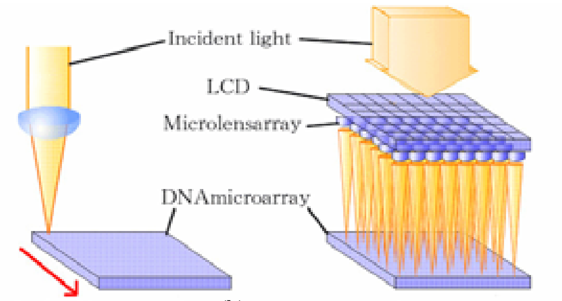


(a) Appearance (b) CCD image of surface

Fig.6 cBN (325/400) grinding wheel with copper binder

2.2 LCD-multiprobe DNA Microarrayscanner

A method of quick analysis of DNA microarray is being developed to determine the DNA sequence by detecting the position and intensity of fluorescence on DNA chip. This method is widely used in the field of medical treatment and medicine development to analyze vast amount of individual DNA information including the monitoring of gene polymorphism. We have proposed a simultaneous multipoint detection system by the incorporation of a LCD (liquid crystal



(a) Confocal laser scanning (b) LCD multi-spot fluorescent detection

Fig.7 Multispot fluorescent detection

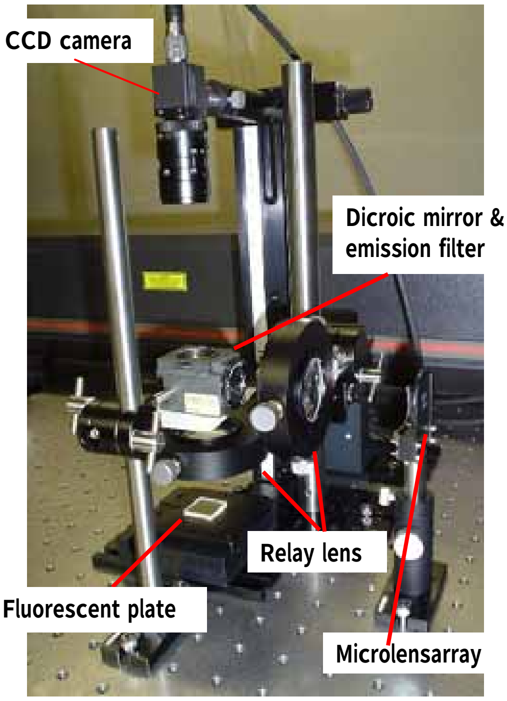


Fig.8 Fluorescence detection optical system

display) into multispot fluorescence detection technology (Fig. 7). It leads to improvements in detection speed of the fluorescence information from DNA microarray and detection sensitivity by reducing cross-talk noise on neighboring spots. Fig. 8 shows the optical system for fluorescence detection.

2.3 Shape Design That Make Life Comfortable

It is difficult to evaluate shape design in relationship to human sensitivity. A frequency analysis is introduced to evaluate geometric features included in three-dimensional objects such as pottery. To discriminate between handmade design by a ceramist and machine-made one, the outer surface of ceramic teabowls is measured with the CCD laser displacement sensor system. Surface topography is then analyzed by the first Fourier transformation to plot a correlation between its power spectrum and the spatial frequency that is defined by the number of waves per unit distance. The power spectrum decreases with increasing spatial frequency on the double logarithmic plot, being approximated by a linear curve. Especially, the 1/f-fluctuation pattern appears on the handmade tea bowl. The frequency characteristics are then utilized to design surface texture of an artificial 3D object. A nylon tea bowl with the 1/f-fluctuation surface texture is substantiated by means of stereolithography (Fig. 9). This approach leads to shape design that makes our life comfortable.

(a) CG model (b) Rapid prototype

Fig.9 Tea bowl with 1/f-fluctuation surface texture

2.4 Surface Modification and Enhanced Functionality

① Fluxless laser soldering of antenna wires for noncontact IC cards

The development of noncontact IC cards is in a rapid progress toward their practical use. A process of connecting an IC chip with antenna wires poses problems from viewpoints of mass productivity and antenna characteristics. The present paper proposes a method of laser soldering of antenna wires for noncontact IC cards: fluxless laser soldering that consists of heating a copper wire with an Nd:YAG laser beam and pressing it onto the chip and solder bump successively. Comparing with the conventional pulse heat method, some advantages are confirmed: shorter soldering time and maintenance-free

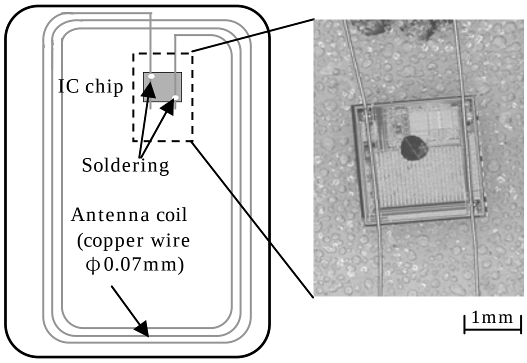


Fig.10 Laser soldering of antenna wire of IC card

operation. The soldered part shows a good wettability and a sufficient tensile strength of 3.64 MPa

② Laser surface alloying for mercury-target container

The effect of varying temperature of the type 316 stainless steel substrate on the structure and properties of laser alloyed layer was investigated. The material for alloying (Al-Si powder mixture) was placed on the surface of stainless steel substrate by pasting. The surface was scanned by a pulsed Nd:YAG laser beam to achieve surface alloying. The temperature of substrate continuously increased during laser treatment to about 830°C. The microstructure, chemical and phase composition and microhardness of the modified layer were studied then. It has been found that four different types of structure were formed in the alloyed zone depending on the temperature of substrate. These structures

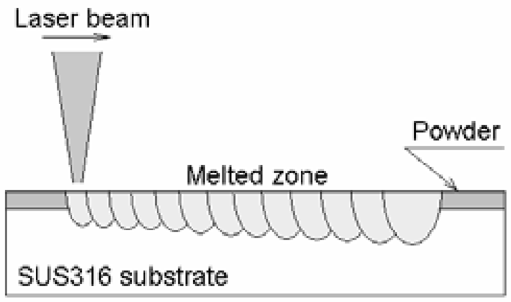


Fig.11 Schematic of laser surface alloying using pwder

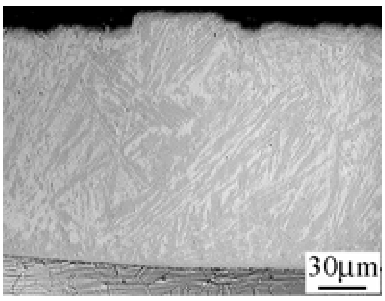


Fig.12 Microstructure of laser-alloyed intermetallic compound

differ from each other in phase composition, microhardness and relation to cracking. Based on the results, optimal parameters for the production of a uniform, crack-free layer with a high hardness were developed.

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