Materials Fabrication Laboratory
Chief Scientist: Hitoshi Ohmori (Dr. Eng.)

(0) Research field

CPR Subcommittee: Engineering, Physics

Keywords:

ELID grinding, Ultra/nano precision machining, Microfabrication, Surface modification, Pico-precision

(1) Long-term goal of laboratory and research background

The main objective of our research is the development of revolutionary and new material processing technologies in grinding, lapping, polishing, cutting and forming for an extensive range of materials. Through advanced research activities on ultraprecision, ultrafine, nanoprecision and ultra-smooth machining processes, required for the fabrication of advanced functional devices such as optical and electronic components, we launched the research of a new field of micro-mechanical fabrication technologies in addition to surface functional modification, transcription, process control and optimization techniques, aiming at a wide variety of materials, precision, mechanics and scale ranging from micrometer to nano/pico meter level, to meet practical and applied industrial needs.

(2) Current research activities (FY2021) and plan (until Mar. 2025)

<R&D on Electrolytic In-process Dressing technology>

Following our advanced research on the ultraprecision, nanoprecision and ultrasmooth machining processes required for fabricating advanced functional devices, we have undertaken research in new fields of micromechanical fabrication, in particular the electrolytic in-process dressing (ELID) grinding technique. In our study, a variety of parameters were studied to help achieve a fine surface finish in ductile-mode machining. We succeeded in realizing highly efficient, high-precision grinding of the following hard, brittle materials:

- Advanced ceramics: CVD SiC, ZrO_2, Fused silica, SiC wafer, TiN, Yb:YAG
- Sapphire as substrate for LED and a heat filter
- Metallic biomaterials (e.g. Co–Cr alloy, SUS304)
- Electrical device materials (e.g. Cr–N alloy)
- Hardened steel
- Plastic sheets for medical applications

An outstanding achievement was our development of an aspheric lens for Kyushu University, as a part of the Kyushu Satellite for Earth Observation System Demonstration (QSat-EOS). QSat-EOS is a microsatellite developed at Kyushu University as a small scientific payload for the observation of the Earth, a study of the Earth's magnetic field, an assessment of microdebris in orbit and an observation of water vapour in the upper atmosphere. Another task that the satellite will fulfil is the demonstration of a de-orbit sail for space debris mitigation.

In addition, ELID-ground Ti substrates have been analyzed and it has been confirmed that not only bio-compatibility but also anti-bacterial properties could be added. In collaboration with the Akita Cerebrospinal and Cardiovascular Center, we confirmed the antibacterial effect for Ti and SUS substrates on Staphylococcus aureus and Escherichia coli in spinal cages. We are proceeding with its technological development for practical applications.

<Research on combined process technology >

Based on the above knowledge, we attempted to grind silica substrates with ELID, and combined CMP in collaboration with Kurokawa Lab. in Kyushu Univ. A finished silica substrate can be used for X-ray mirror. Also for CVD SiC substrates, the combined process was tried to be applied. On the other hand, if ELID grinding and CMP are combined in certain conditions, finished surfaces can obtain features with magnified ground marks which are expected to provide new functions.

As development of desktop type ultra/nanoprecision machine tools has been promoted to aim at employment of AI functions, adaptive control of feed and cutting depth has been tried to be applied for stable machining of difficult-to-machine materials with avoiding excessive load.

Reducing the reliance on experts has become a problem in the grinding field. In one example, a cutting depth appears a difference between experts and non-experts. Non-experts tend to make a cutting depth shallower at an inexperienced specimen. They choose another setting parameter when the ground product shows an unfortunate result. It will increase trial and error consequently and spends their time to find appropriate grinding conditions. We investigated friction characteristics which were resembled grinding in minute cutting depth by tribometer. As a result, friction coefficient and its variance increased at the smaller load. It shows a potential to expansion of explainable grinding phenomena of which non-experts easily fail.

<Development of critical components>

We have been developing critical components such as optics, sensors, and specific microdevices for advanced analyzers applying ultra/nanoprecision machining processes. As requirements for manufacturing are updated, machining processes and their system have been updated.

We are associated with International Collaboration on the Extreme Universe Space Observatory (EUSO) mission. This project aims to open up a new field of astronomy and astrophysics involving highly charged particles. The advanced astronomical optics will comprise two Fresnel lenses made of ultraviolet light transmitting plastic and a diffractive lens, developed in collaboration with Ebisuzaki Computational Astrophysics Lab. In addition to the above-mentioned EUSO telescope, other projects have involved the realization of prototypes for application of the similar purposed telescope system. The EUSO-balloon is one of them, and comprises a prototype fluorescence telescope mounted aboard a stratospheric balloon. The objective of this mission was to test the validity of the concepts and the technical trials for the EUSO telescope, and for any subsequent projects for observing air showers induced by energetic cosmic rays from space.

On the other hand, Soyus launched the Mini-EUSO telescope applying two ultraprecision Fresnel lenses on the ISS in August 2019, and the goals are to look at bio-luminescence from plankton in the ocean, helping to understand sea life and pollution, and to observe high-altitude atmospheric lighting and meteoroids entering the atmosphere.

<Research on micro fabrication processes>

Developed micro fabrication system provides multi-axis simultaneous control drive mechanisms with a resolution of 1 nm and is capable of fabricating micro optical, biological devices, their molds, and other complex shapes with free form surfaces to an ultrahigh precision and ultrafine dimensions using small diameter tools.

ELID-grinding has met practical applications and has been increasingly used to achieve mirror surface grinding by electrolytic dressing of conductive grinding wheels with fine grains. A new method has been developed that uses electrodes in nozzles to feed the grinding fluid and generate ions by electrolysis. These ions are injected on the grinding wheel, wherein they conduct dressing by chemically dissolving the conductive grinding wheel components.

Sapphire capillaries with high efficiency and precision are needed in the laser-plasma accelerators. A hybrid manufacturing process, combining femtosecond-laser machining and diamond tool micro-milling, was applied. In particular, polished and unpolished PCD tools with different diamond abrasive protrusion heights were used, and the difference in the machining characteristics of sapphire between the two was verified. In addition, we performed high-precision and high-efficiency processing of a nano-polycrystalline diamond tool, using the femtosecond laser. A collaborative research on micro-grooving of Co-Cr alloy by polycrystalline diamond ultra-fine end mill for development of metallic cell culture vessels" was performed continuously.

We have been studying microfluidic chips for bioanalysis. This year, we have developed a simple replication method for microfluidic chips. Microfluidic chips are often made of poly (dimethylsiloxane) (PDMS). They are fabricated by pattern transfer from a negative master mold, which is usually prepared through photolithography. The photolithography process requires a large facility and a long period of time. Therefore, an easy method for making a backup copy of the negative mold is useful. For this purpose, we tried pattern transfer from a PDMS surface to an ultraviolet-curable resin (UV resin). Using inexpensive, hobby-use products of a UV resin and a UV lamp, we have succeeded in pattern transfer from the PDMS surface to the UV resin with a satisfactory precision.

<Research on tribo-fabrication technology>

Tribology is the science and technology of friction, wear, and lubrication. It is concerned with phenomena that occur at the machine contact surfaces; thus it supports fundamental technologies and production of mechanical systems. Phenomena that occur at the contact point between the tool and the workpiece in various lubrication states during the removal machining process can be expressed as tribological problems. We propose the new term "tribo-fabrication" to describe technologies that involve both tribology and machining/manufacturing interactions.

Increasing demand for mold and die fabrications of harder materials with high form accuracy and surface quality requires the use of diamond tools on ferrous materials. For such application, a special coolant system was developed, which consisted of an electrolytic liquid and nanometer-sized carbon particles. The application of this coolant to the cutting interface of ferrous workpiece induced a chemical reaction on the work surface, including pitting that may change the crystallographic behaviour of the workpiece. The nanometer-sized carbon particles may prevent wear to the diamond tool. By applying this new process using a diamond cutting tool, we have succeeded in realization nano-level surface quality for ferrous material such as stainless steel, aiming at production of plastic injection molds.

Furthermore, a new surface modification system that combines a femtosecond pulsed laser and a dielectric barrier discharge type atmospheric pressure plasma unit was developed. By using the system, we succeeded in imparting the superior friction and wear characteristics to Ti-6Al-4V sample surfaces.

(3) Members

as of March, 2021

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(Part-time Worker)
Kumi Takishima, Naoya Ohno, Taichi Takahashi, Shohta Imagawa, Yukari Inahashi

(4) Representative research achievements

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Laboratory Homepage
https://www.riken.jp/en/research/labs/chief/mater_fab/index.html