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 (FY2020) 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

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.

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 on the surfaces.

<Applications of the ELID technique to physics and bio-application>

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. Other collaborations in physics are being promoted on application of ELID-technique.

In collaboration with the Akita Cerebrospinal and Cardiovascular Center, we confirmed the antibacterial effect of titanium and stainless steel materials on Staphylococcus aureus and Escherichia coli in spinal cages. We are proceeding with its technological development for practical applications.

<Development of ultra/nanoprecision mechanical fabrication processes and space telescope development support>

We are associated with International Collaboration on the Extreme Universe Space Observatory (EUSO) mission, which will launch the EUSO Telescope onto the International Space Station(ISS). 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. To produce those lenses, we have successfully developed a large-scale ultraprecision turning machine and strategic machining processes with novel software to employ the specific cutting paths.

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. We are starting to apply this process for microgrinding of polycrystalline diamond (PCD) which is used for cutting tools.

Furthermore, we developed a desktop-type machine tool targeting at pico-fabrication, and combined AI-based adaptive-control functions for difficult-to-machine materials. A new grinding system with adaptive/learning control based on grip analysis of composite wear-resistant tools was developed as well.

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 addition, we performed high-precision and high-efficiency processing of a nano-polycrystalline diamond tool, using the femtosecond laser.

<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. In this study, we investigated the feasibility of a newly developed ion-shot coolant for such applications. 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 the 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.

In evaluating the lubrication characteristics of Ti alloys and cBN tools, which are also used as medical materials, nanocarbon-added coolants with optimized concentrations showed lower friction than water-soluble processing liquids; thus, improving the surface properties of Ti alloys.

(3) Members as of March, 2020

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(Trainee)
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(4) Representative research achievements

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3. Albert J. Shih, Berend Denkena, Thilo Grove, David Curry, Hong Hocheng, Hung-Yin Tsai, Hitoshi Ohmori, Kazutoshi Katahira, ZJ Pei, 2018, Fixed abrasive machining of non-metallic materials, CIRP Annals – Manufacturing Technology 67(2), 767-790.
4. Hitoshi Ohmori, Yunji Kim, Yoshihiro Uehara, Teruko Kato, Hiroshi Kasuga, Shinjiro Umezu, Syuhei Kurokawa, 2019, Finishing Properties of X-ray Mirror by ELID-CMP Combined Process, Advanced Micro-Fabrication and Green Technology -,Transactions of MIRAI, Vol.7,p80.
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Laboratory Homepage
https://www.riken.jp/en/research/labs/chief/mater_fab/index.html