Overview

International 21st Century COE Symposium on “Atomistic Fabrication Technology”

In 2003, our research group in Osaka University was selected as one of the “21st Century COE Programs” supported by the Japanese Ministry of Education, Culture, Sports, Science and Technology. We formed the “Center for Atomistic Fabrication Technology” to promote the development of surface creation systems in order to realize nanometer-level accuracy.

I here introduce the “atomistic fabrication technology” and our 21st Century COE Program. The realization of specific types of optical or electronic devices with atomic-level accuracy frequently is a key factor in achieving breakthrough in basic sciences and advanced industries of the 21st century. Examples of such optical devices are ultraprecise mirrors that are used for X-ray free electron lasers, hard-X-ray microscopes and extreme-ultraviolet lithography. Next-generation silicon-on-insulator devices and wide-band-gap semiconductor SiC or GaN devices are examples of electronic devices. It is impossible to fabricate these extremely precise “products” by extending conventional manufacturing technologies, even if such technologies were improved and made sophisticated on the basis of experience. To fabricate the new devices required in pioneering fields, it is necessary to develop new concepts for manufacturing technologies, which we call “atomistic fabrication technology”, on the basis of science itself.

In our 21st Century COE Program, we start with studies on clarifying natural phenomena applicable to new fabrication technologies through computer simulations based on the first principles of quantum mechanics. We then develop ingenious machining equipment with which such phenomena may be precisely controlled, produce actual optical and electronic devices, and finally measure and evaluate the performance of these devices. The aims of this COE Program are to develop “atomistic fabrication technology”, and, by collaborating with other laboratories of basic sciences and advanced industry, to produce the desired “key devices” that will contribute to driving the advancement of the frontier research. Furthermore, by allowing graduate students to participate in such cutting-edge research projects, we will educate future research leaders for next-generation production technology.

This special issue of Science and Technology of Advanced Materials is the proceedings of the “International 21st Century COE Symposium on Atomistic Fabrication Technology”, which was held in Osaka University on October 19–20, 2006. The purposes of this symposium were to present the interim report on achievements in our 21st Century COE Program, and to share our experiences and knowledge regarding the theory, new developments, and possible applications of atomistic fabrication technologies. The symposium consisted of 6 single sessions, including 10 invited talks, 20 contributed oral talks and 48 poster presentations. The topics at the symposium were thin-film deposition and materials science, ultraprecision machining, methods and tools for nano- and microscale functional analysis, computational engineering design, and advanced solid-state and nanoelectronic devices.

This special issue contains 20 papers on the above topics. The first three papers are related to Si and metal thin-film growth. Kakiuchi et al. report the formation of stoichiometric silicon dioxide layers at low temperatures (150–400 °C) by atmospheric-pressure plasma oxidation of silicon, which is an alternative method for fabricating gate oxide layers for TFTs. Ikuta et al. report selective epitaxial Si growth with a high arsenic concentration of 2.2 × 10^{19} atoms/cm^3 by chemical vapor deposition under atmospheric pressure. Namazu et al. measured the mechanical properties of gold–tin (Au–Sn) eutectic solder films by the tensile test with in situ X-ray diffraction measurement and shear deformation. The tensile and shear characteristics measured will be useful in designing Au–Sn soldering packages for microelectromechanical systems.

The next 6 papers are about precision optics finishing and unconventional machining. Jacobs discusses how to manipulate mechanics and chemistry in modern precision optics finishing, placing particular importance on magnetorheological finishing that enables polishing of soft optical polymers such as PMMA, CVD polycrystalline ZnS, and water-soluble, single-crystal KDP. Numerically controlled local wet etching (NC-LWE) has been developed by Yamamura as a novel noncontact subaperture deterministic figuring method for fabricating ultraprecision optics or for finishing functional materials. Hara et al. applied...
catalyst-referred etching (CARE) to Si planarization and achieved flat and undamaged surfaces. They have developed CARE as a new damage-free planarization method that is superior to conventional chemical mechanical polishing. Yagi et al. report the fabrication of damascene Cu wirings using solid acidic catalyst. The technique is most promising for fabricating Cu wirings for electronic devices such as LSI. Kanaoka et al. report the removal properties of low-thermal-expansion materials (ULE and Zerodur) by rotating-sphere elastic emission machining that is known for its high-smoothing performance of single-crystalline silicon to a RMS surface roughness of 0.1 nm. An ultraprecision grinding system of micro-lens-array molding dies and a new truing method of resinoid bonded diamond wheels were developed by Yamamoto et al. Form accuracies of 0.12 μm P–V or less were achieved for micro-lens-array molding dies of a fine-grain tungsten carbide tested with a resinoid bonded diamond wheel.

The next two papers are about a profiler for X-ray EUV optics and SNOM. Higashi et al. developed a surface-gradient-integrated profiler to measure the surface profiles of large X-ray and EUV mirrors. They achieved the measurement repeatability of 0.28 μrad RMS for the 1000-mm-long flat mirror. Oshikane et al. report the observation of nanostructure with vertical spatial resolution of 5 nm or smaller using a scanning near-field optical microscope with a small spherical probe of 500 nm.

The next 5 papers are related to engineering designs using first-principles calculations. Torres presents theoretical studies of atomic-scale platinum contacts, and demonstrated that a short monatomic wire freely suspended between tips is seen to vibrate as its tensile load increases, and the main vibration mode is transversal for low tension and longitudinal for high tension up to the breaking of the nanowire. Takeuchi et al. carried out first-principles molecular dynamics simulations of Al deposited on tris (8-hydroxyquinoline) aluminum (Alq3) layers. Their results show that even though the Alq3 molecular structure is retained, weak N-Al and C-Al bonds induce gap states. Nakayama et al. investigated the electronic structures of the peanut-shaped polymerized fullerene with P55, P56 and P66 tubular linkage structures. The electronic structures change drastically depending on the bonding interaction between the tubes. Iwami et al. investigated also the electronic structures of five types of carbon nanotubes: the nondeformed (6,6) tube, the tube uniformly stretched along the tube axis, the uniformly compressed tube, the partially stretched tube and the partially compressed tube. According to the first-principles calculation, based on the real-space finite-difference approach, of the electronic structures of the interfaces between Si substrate and SiO2, Kutsuki et al. indicated that the defects around the interface lead to a drastic change of the electronic structure of the interface under an electric field and an enhanced leakage current through the SiO2 films.

The last four papers are focused on advanced Si devices and a light guide. Funamoto et al. propose nano-hot-embossing using a curved stage to improve the replication ratio of nanostructures near the edge of a thick (sub-mm-order thickness) polymer substrate. They demonstrate replications of antireflection nanostructures, which have pitch and height both of 200 nm, onto a 0.75-mm-thick light-guide for the light-emitting diode (LED) front-light systems used in cellular phones. Veloso et al. review and discuss the latest developments and technology options for the 45 nm node and below, where scaled planar bulk MOSFETs and MuGFETs are the emerging devices. Yoshida et al. systematically investigated the thermal stability of TiN/HSiON gate stacks. They found that the formation of a polycrystalline TiO2 interlayer at the TiN/HSiON interface is an intrinsic reaction at temperatures of 700 °C or more. Mihara et al. report their experimental investigation of the degradation of magnetic tunnel junctions with an AlOx barrier, by the constant voltage stress measurement method. They observed the gradual increase of stress-induced leakage current with stress time prior to breakdown.

I would like to ask the readers of this special issue to direct their attention to our 21st Century COE Program and discuss with us the contents of papers on “Atomistic Fabrication Technology”. I would like to close by saying that your continued support and cooperation will be greatly appreciated.

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