Editorial

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Optical metrology for precision engineering

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Precision engineering is the discipline related to the design, production and applications of high precision components, machines and systems. Although measurement is a cornerstone of most engineering areas, it is much more important for precision engineering because proper measurements are essential for realizing the "precision" of a component, a machine or a system. Achieving higher precision is always the highest priority and biggest motivation in the long history of precision engineering. Nanotechnology, one of the frontiers of precision engineering, was defined by Professor Norio Tanighchi in 1974, as the production technology to get the extra high accuracy and ultra fine dimensions, i.e., the preciseness and fineness of the order of 1 nm, 10^{-9} m in length. To support activities in nanotechnology, nanometric or even sub-nanometric precision measurement is required. On the other hand, more and more precision components and machines are required to be made in a shorter amount of time to reduce the production costs. The shapes of the components and the motions of the machines are also becoming more and more complex. These factors are bringing greater challenges to measurement technologies for precision engineering. Measurement technologies using optical methods, which are referred to as optical metrology, have the advantages of non-contact, high accuracy and fast speed. Optical metrology is thus expected to provide good solutions to such challenges.

The aim of this special issue is to provide a forum for researchers and practitioners to present and review the state-of-the-art development of optical metrology for precision engineering, and to identify directions for future research and development in related fields. Nine papers, including one review article, six research articles and two letters, have been accepted for publication in this special issue after careful reviews by multiple referees.

The review article, by Kuang-Chao Fan, provides a comprehensive overview about multi-degree-of-freedom (MDOF) measurement on the linear motion errors of precision machines. A precision machine used in precision engineering, such as a precision machine tool or a coordinate measuring machine, is composed of one or more axes for providing precision motions to a cutting tool or a measuring probe. The motion errors of each of the axes have to be measured to six degrees of freedom. This article traces the advances of MDOF motion error measurement over the past 20 years, from which optical techniques of MDOF measurement systems for precision linear, planar and XYZ stages are summarized. Comments are also given for the applicability to practical uses.

The first two research articles are on measurement of displacement and distance which are related to length, one of the seven SI base quantities as well as being the most important quantity for precision engineering. In the article by Nektarios Koukourakis et al., a concept for miniaturization of a laser Doppler distance sensor with common-path detection is investigated. A diffractive optical element containing a diffracting lens is designed and used to increase the numerical aperture of the common-path detection, without affecting the sensor size. It is proven by experiments that the new element can reduce the relative systematic measurement uncertainty by a factor of 10. The other article, by Hung-Lin Hsieh et al., demonstrates wavelength-modulated heterodyne grating shearing length interferometry using a birefringent crystal for two-dimensional displacement measurement. This new technique combines the anti-noise ability of heterodyne detection and the high stability advantage of grating length interferometer.

The third research article, by David Serrano Garcia, reports on a Mach Zehnder interferometer for surface profile measurement that is capable of retrieving the phase information in a single shot. Since the data are collected simultaneously, the effects of vibration and turbulence are greatly reduced and temporal data measurement can

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be done. The fourth and fifth research articles are related to microscopes. The article, by Abraham Mario Tapilouw et al., presents a high-speed optical microscope based on the stroboscopic coherence scanning interferometry (SCSI) technique for inspection of micro-electro-mechanical-system (MEMS) components. Resonant frequencies of vibrating MEMS can also be measured from deformation of interferogram fringes for out-of-plane vibration and from image correlation for in-plane vibration. The measurement bandwidth of the developed system can be tuned up to 3 MHz or higher for both in-plane and out-of-plane measurement of MEMS. The article, by Masaki Michihata et al., presents a scanning probe microscope. A new technique is proposed for imaging the microstructure surface texture using a laser-trapped microsphere, which enables the simultaneous measurement of the surface position and surface texture. The last research article, by Hiroki Yokozeki et al., concerns laser scanning imaging for nano defects detection, which is required in semiconductor wafer surface inspection. The method presented in this article has the capability to allow lateral spatial super-resolution imaging with resolution beyond the diffraction limit.

The first letter, by So Ito et al., reports on a compact XYZ directional three-axis vibration sensor, in which a two-directional XY diffraction grating is mounted on the object as the target. A laser beam from the sensor is projected onto the grating and the X- and Y-directional positive and negative first-order diffracted beams are superimposed with those from a reference grating within the sensor to generate the interference signals on the photodetectors of the sensor. The XYZ directional three-axis vibration components at the laser beam incident point of the object can thus be simultaneously obtained from the interference signals. The next letter, also the last, by Yuankun Liu et al., is related to absolute phase measuring deflectometry (PMD). A phase-shift technique is demonstrated where a one-dimensional N-phase shift allows for the acquisition of the two orthogonal phases, with only N exposures instead of 2N exposures. As a result, the PMD can be implemented by a one-dimensional translation of the fringe pattern, instead of the common two-dimensional translation.

As guest editors, we believe that this special issue presents the newest information on optical metrology for precision engineering. We would like to thank all the authors for their excellent contributions to this special issue and the reviewers for their careful reviews of the papers. We would also like to express our thanks and appreciation to Prof. Dr. Michael Pfeffer, Editor-in-Chief of *AOT – Advanced Optical Technologies* for his kind offer of publication of this special issue, and to Dr. Andreas Thoss, Managing Director, THOSS Media GmbH, for his dedicated efforts making this special issue possible.

Wei Gao received his Bachelor of Precision Intrumentation from Shanghai Jiao Tong University, China, in 1986, followed by MSc and PhD from Tohoku University, Japan, in 1991 and 1994, respectively. He is currently a Professor and the Director of the Research Center for Precision Nanosystems, Department of Nanomechanics of Tohoku University. His research interests include precision metrology and micro/nano-metrology. He is a fellow of CIRP, and the International Society for Nanomanufacturing. He serves as the Vice-Chairman of The Scientific Technical Committee Precision Engineering and Metrology of CIRP. He is also an associate editor of a number of international academic journals including the *Journal of Precision Engineering*, and *IEEE Transactions on Instrumentation and Measurement*. Professor Gao has published 150 journal papers and applied 50 patents (20 issued). He is the author of the book "Precision Nanometrology – Sensors and Measuring Systems for Nanomanufacturing" (Springer). He has won five Paper Awards from The Japan Society for Precision Engineering (1998, 2003, 2004, 2010, 2011).

Bernd Bodermann studied Physics at the university of Hannover, Germany with a focus on quantum optics, laser physics and optical frequency standards. He has worked since 1999 at the Physikalisch-Technische Bundesanstalt (PTB), Germany, on different aspects of laser physics, interferometry and refractometry. Since 2005 he has served as the head of the working group "Ultra High Resolution Microscopy" working on quantitative microscopy, nonlinear microscopy, scatterometry, rigorous optical modelling and optical metrology for industrial applications, especially for semiconductor industry. Bodermann is chair of the bi-annual SPIE conference on Modelling Aspects in Optical Metrology and will chair in 2014 the EOS topical meeting on Frontiers in Optical Metrology.