OPTICAL METROLOGY

The Optical Metrology Laboratory (OML) at the ALS, under the leadership of V. Yashchuk, is tasked with characterizing, understanding, and developing synchrotron radiation optics. The OML staff is actively working to improve metrology instruments (Figure 2) and to develop new measurement techniques, with improved accuracy and resolution, for characterization of x-ray optics with surface slope errors of less than 0.25 µrad (rms). The need for higher-precision metrology is driven by a need to improve optics commensurate with the steady increase in storage-ring performance over the last few years and the increased emphasis on experiments where coherence preservation is required.

The long trace profiler (LTP) was last upgraded about 10 years ago. At that time, an optical reference channel was added, allowing for monitoring the LTP systematic error on the level of ~1 µrad. To incorporate the reference channel, a detector based on two linear photodiode arrays was used. Over the years, the detector and the dedicated data acquisition system have become the most unreliable parts of the instrument. They became dated and very difficult to replace and upgrade. Because of detector failure, we were forced to accelerate the modernization of this LTP.

In just two months of extremely intensive work, the LTP modernization was successfully completed. This included (1) reassembly and readjustment of the LTP-II linear translation stage to allow assured operation under the National Instruments (NI) motion control system, with the increased load of a new detector; (2) a distance-measuring interferometer, incorporated into the system for precise positioning of the LTP optical head; (3) development of motion control and data acquisition software based on the NI LabView™ platform; (4) design and fabrication of a new detector system based on a high-resolution (7.4 x 7.4 µm^2 pixel size) CCD camera (Figure 3); (5) assembly and use of an efficient experimental setup for precise, ~0.5%, flat-field calibration of the camera pixel-to-pixel photo-response nonuniformity; and (6) development of new software for carrying out LTP measurements and data analysis.

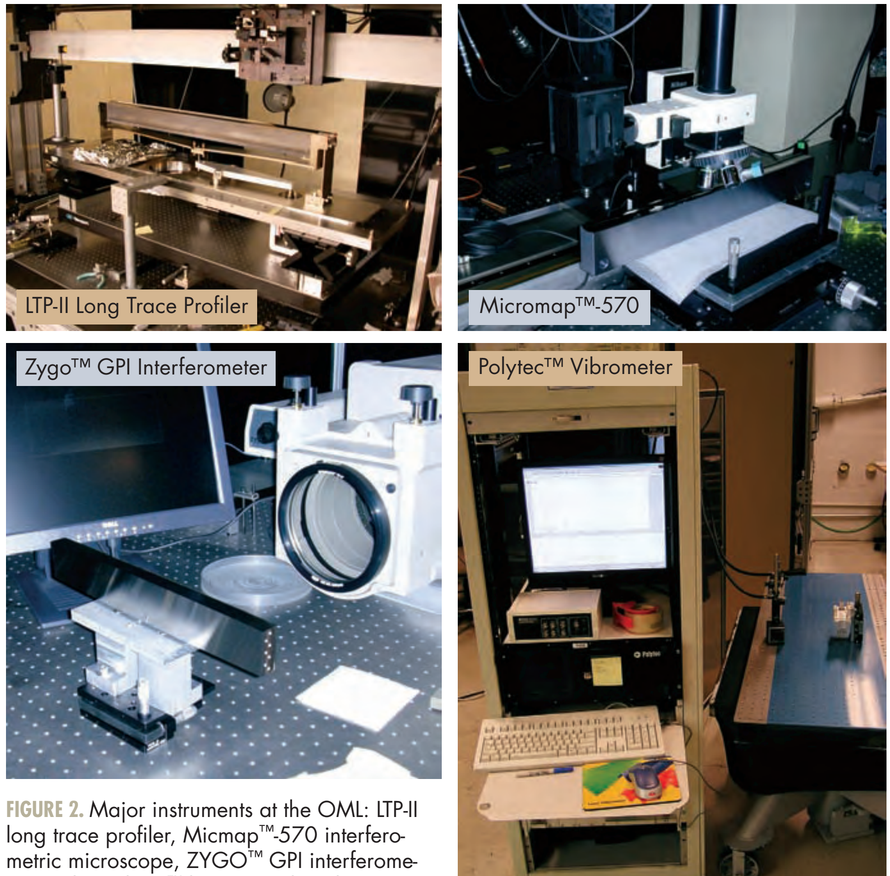

FIGURE 2. Major instruments at the OML: LTP-II long trace profiler, Micmap™-570 interferometric microscope, ZYGO™ GPI interferometer, and a Polytec™ laser Doppler vibrometer.

After the modernization and calibration and testing were completed, the first metrology work with the upgraded LTP was performed on a superpolished grating substrate with a spherical radius of ~18.7 m, fabricated by InSync, Inc. for the MERLIN project. The rms slope variation for the substrate was specified to be < 0.5 µrad. The measurement performed at the OML indicates a slope variation of < 0.37 µrad for the central part of the substrate (Figure 4). Such measurements have only been possible because of the upgraded LTP. With further improvements, we expect that the overall accuracy of LTP measurements will improve to the 0.1-µrad level.

LTP metrology of this substrate became possible because of the use of a novel technique developed at the OML for suppression and measurement of the LTP systematic error. The technique utilizes the new two-dimensional de-

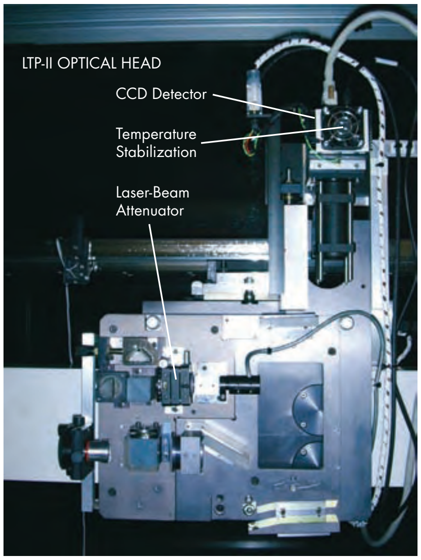

FIGURE 3. Optical sensor of the upgraded LTP with a new detector system based on a precisely calibrated CCD camera with home-made active temperature stabilization. A new laser-beam attenuator was designed to simplify alignment of the instrument.

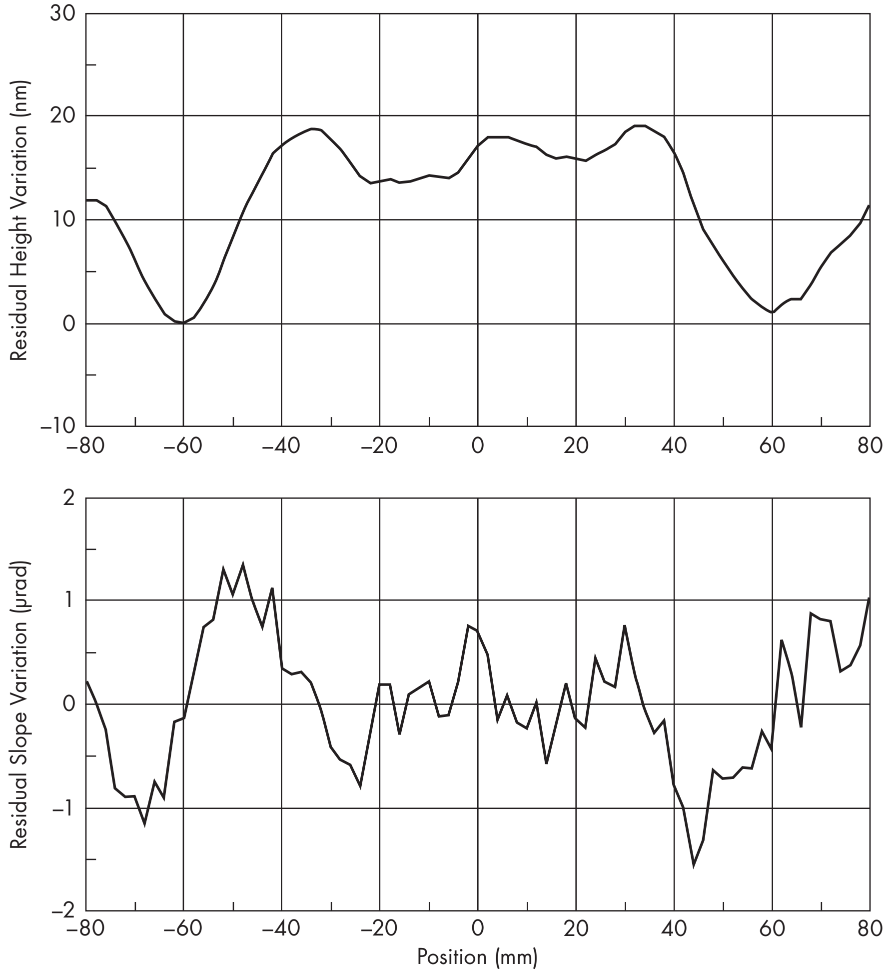

FIGURE 4. Residual slope and corresponding height profiles of the superpolished grating substrate with a spherical radius of ~18.7 m, fabricated by InSync, Inc. for the MERLIN project. The slope variation of the central part of the substrate as measured with the modernized LTP is less than 0.37 μrad (rms).

tector of the LTP. With this detector, it is possible to perform repeated measurements over the same trace on the mirror surface, but at different sagittal tilts of the mirror with respect to the LTP. By averaging over these measurements, the higher-spatial-frequency systematic errors of the LTP optics are significantly suppressed.

We still need a sophisticated calibration system for precise calibration and control for the lower-spatial-frequency systematic errors of the upgraded LTP. The current calibration, extracted from the test measurement of the 40-m curved "round robin" mirror, provides only a one-point calibration and does not account for all of the nonlinearity of LTP curvature measurements. Ideas for a more sophisticated technique for calibration of slope-measuring instruments (based on a universal test mirror to simulate a mirror with a known shape) has been developed at the OML and is being fabricated in collaboration with a worldwide collaboration of the ALS, BESSY, and the PTB (the German national standards institute).

A new generation of high-brightness sources (LCLS, NSLS-II, ALS at low-emittance top-off mode) is being developed in the United States to enable nanofocusing applications and high-coherence experiments including diffraction imaging, scattering, and speckle measurements. To deliver on this potential, beamline optics of unprecedented quality are required. The corresponding metrology will be essential in order to achieve high-efficiency sub-100-nm focusing. The beamline optics will have to have sub-100-nrad slope error tolerances. This is now the worldwide goal for manufacturing and metrology of x-ray optics. The next generation of mirror-measurement tools must achieve sensitivity and accuracy well below these values. It has become apparent that without a concentrated nationwide research and development effort in x-ray metrology, costly increases in source brightness may not translate into increased experimental capabilities because "if you cannot measure, you cannot make it, nor use it."