This research investigation was devoted to developing micro-system and nanotechnology for x-ray astronomy optics. The goal was to develop and demonstrate new types of lightweight, high accuracy x-ray optics for future high throughput, high resolution x-ray telescopes such as Constellation X (Con-X) and MAXIM.

A number of significant accomplishments were reported under this program, which are summarized below. Most of this work has been reported in journal and conference proceedings and in presentations to NASA and at international meeting (see Bibliography).

**Developed microsheet shaping technology.**
We developed and demonstrated several methods for shaping thin sheets of silicon and glass by thermal forming (slumping), block lapping methods and magneto-rheologic polishing. We demonstrated shaping of 100 mm-diameter, 400 micron-thick silicon sheets to below 0.8 micron error which meets the goals of the Con-X reflection gratings.

**Improved silicon microcomb technology.**
We fabricated silicon microcombs with improved accuracy. The microcombs are key components in our precision assembly tool (see below).

**Demonstrated precision assembly technology.**
We built a second-generation assembly truss for assembling thin foil optics and demonstrated sub-400 nm assembly repeatability of thin substrates.

**Improved foil metrology.**
We built and demonstrated a unique and very accurate deep-UV Shack-Hartmann test facility using a deep UV laser ($\lambda=220$ nm). The short wavelength eliminates backside reflection from the glass foils.

**Built and tested constant-period SBIL system.**
We built and tested a scanning-beam interference lithography system (SBIL) for constant period patterning. This system is designed to pattern the large, chirped period gratings that will be needed for high-throughput x-ray spectroscopy missions such a Con-X.

**Built and tested variable-period SBIL system.**
We built and demonstrated a prototype optical system for variable-period fringe generation during SBIL.
Journal Articles and Conference Proceedings


“A generalized scanning beam interference lithography system for patterning gratings with


Presentations


"Interference lithography for space optics, nanometrology and integrated optics,” M.L. Schattenburg, MIT EECS/RLE Seminar Series on Optics and Quantum Electronics, Cambridge, Massachusetts, November 29, 2000 (invited).


"From nanometers to gigaparsecs: the role of nanostructures in unraveling the mysteries of the cosmos,” M.L. Schattenburg, MIT Nanostructures Seminar, Cambridge, Massachusetts, March 14, 2001 (invited).


“Pattern placement metrology in the nanometer domain,” M.L. Schattenburg, Seminar of the Laboratory of Photonics and Nanostructures, National Center for Scientific Research, Bagneux, France, August 9, 2001 (invited).

“Pattern placement metrology in the nanometer domain,” M.L. Schattenburg and H.I. Smith, talk and poster presented at the SPIE/NIST/ONR Workshop on Nanostructure Science, Metrology and Technology, Gaithersburg, Maryland, September 5-7, 2001 (invited).


“The importance of nanotechnology and nanometrology for space instrumentation,” M.L. Schattenburg, Space Nano-technology Workshop, Tsukuba Space Center, National Space Development Agency of Japan, Tsukuba, Japan, November 27, 2001 (invited).


Massachusetts, July 3, 2002.


“The Space Nanotechnology Laboratory,” M.L. Schattenburg, poster presented at the *Summer School on: Nano and Giga Challenges in Microelectronics Research and Opportunities in Russia*, Department of Physics, M.V. Lomonosov Moscow State University, Moscow, Russia, September 10-11, 2002 (invited).


“Fabrication of ultra-high accuracy diffraction gratings for nanometrology and spectroscopy applications.” *P. N. Lebedev Physical Institute of the Russian Academy of Sciences (FIAN)*, Moscow, Russia, September 11, 2002 (invited).

“Precision microcomb design and fabrication for Constellation-X soft x-ray telescope segmented optic assembly,” Y. Sun, C.G. Chen, R.K. Heilmann, C. Forest, M. Spenko, P.T. Konkola,


Student Theses and Internship Reports

Vincent Guillaume, Thin Foil Optic, Internship Report, Department of Mechanical Engineering, École Nationale d'Ingénieurs de Saint-Étienne (ENI), Saint-Étienne, France, June 2002.


Patents