FINAL REPORT

Micro-System Technology for X-ray Astronomy
NASA Grant NAG5-5271 (OSP 6890567)
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MIT Center for Space Research
Dr. Mark L. Schattenburg, Principal Investigator
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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 (λ=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.

Bibiography (2000-2002)

Journal Articles and Conference Proceedings

"Development of segmented x-ray mirrors for Constellation-X," R. Petre, C. Chen, L.M. Cohen, D.A. Content, R.J. Harms, G. Monnelly, T.T. Saha, M.L. Schattenburg, P.J. Serlemitsos and W.W. Zhang, in *Proc. SPIE* **4012,** *X-Ray Optics, Instruments and Missions III,* eds. J.E. Truemper and B. Aschenbach, 370-378 (2000). (*CSR reprint 00-115*)

"Microcomb design and fabrication for high accuracy optical assembly," C.G. Chen, R.K. Heilmann, P.T. Konkola, O. Mongrard, G.P. Monnelly and M.L. Schattenburg, *J. Vac. Sci. Technol. B* **18**, 3272-3276 (2000). (*CSR reprint 00-46*)

"Relativistic corrections in displacement measuring interferometry," R.K. Heilmann, P.T. Konkola, C.G. Chen and M.L. Schattenburg, *J. Vac. Sci. Technol. B* **18**, 3277-3281 (2000). (*CSR reprint 00-34*)

"Beam steering system and spatial filtering applied to interference lithography," P. Konkola, C.G. Chen, R.K. Heilmann and M.L. Schattenburg, *J. Vac. Sci. Technol. B* **18**, 3282-3286 (2000). (*CSR reprint 00-47*)

"Progress toward meeting the Constellation-X performance goals using segmented x-ray mirrors," R. Petre, L.M. Cohen, D.A. Content, J. Hein, T.T. Saha, M.L. Schattenburg and W.W. Zhang, *Proc. SPIE* **4138,** *X-Ray Optics, Instruments and Missions IV,* eds. R.B. Hoover and A.B.C. Walker, 16-24 (2000). (*CSR reprint 00-51*)

"Precision assembly station for high-resolution segmented optics," H. Bergner, L.M. Cohen, M.L. Schattenburg and G. Monnelly, *Proc. SPIE* **4138,** *X-Ray Optics, Instruments and Missions IV,* eds. R.B. Hoover and A.B.C. Walker, 134-145 (2000). (*CSR reprint 00-50*)

"High-accuracy x-ray foil optic assembly," G.P. Monnelly, O. Mongrard, D. Breslau, N. Butler, C.G. Chen, L. Cohen, W. Gu, R.K. Heilmann, P.T. Konkola, G.R. Ricker and M.L. Schattenburg, *Proc. SPIE* **4138,** *X-Ray Optics, Instruments and Missions IV,* eds. R.B. Hoover and A.B.C. Walker, 164-173 (2000). (*CSR reprint 00-49*)

"Image metrology and system controls for scanning beam interference lithography," C.G. Chen, P.T. Konkola, R.K. Heilmann, G.S. Pati and M.L. Schattenburg, *J. Vacuum Sci. Technol. B* **19**, 2335-2341 (2001). (*CSR Reprint 01-64*)

"Digital heterodyne interference fringe control system," R.K. Heilmann, C.G. Chen, P.T. Konkola, G.S. Pati and M.L. Schattenburg, *J. Vacuum Sci. Technol. B* **19**, 2342-2346 (2001). (*CSR Reprint 01-53*)

"From nanometers to gigaparsecs: the role of nanostructures in unraveling the mysteries of the cosmos," M.L. Schattenburg, *J. Vacuum Sci. Technol. B* **19**, 2319-2328 (2001). (*CSR Reprint 01-85*)

"Scanning beam interference lithography," P.T. Konkola, C.G. Chen, R.K. Heilmann, G. Pati and M.L. Schattenburg, *Proceedings of the Sixteenth Annual Meeting of the American Society for Precision Engineering* (American Society for Precision Engineering, Raleigh, NC), 15-18 (2001). (*CSR Reprint 01-102*)

"High precision assembly and metrology of x-ray foil optics," O. Mongrard, N. Butler, C.G. Chen, R.K. Heilmann, P.T. Konkola, M. McGuirk, G. Monnelly, G.S. Pati, G.R. Ricker, M.L. Schattenburg and L. Cohen, *Proceedings of the Sixteenth Annual Meeting of the American Society for Precision Engineering* (American Society for Precision Engineering, Raleigh, NC), 40-43 (2001). (*CSR Reprint 01-103*)

"A novel sub-microradian beam diagnostic and alignment system," C.G. Chen, R.K. Heilmann, P.T. Konkola, G.S. Pati and M.L. Schattenburg, *Proceedings of the Sixteenth Annual Meeting of the American Society for Precision Engineering* (American Society for Precision Engineering, Raleigh, NC), 216-219 (2001). (*CSR Reprint 01-104*)

"The critical role of metrology in nanotechnology," M.L. Schattenburg and H.I. Smith, *Nanostructure Science, Metrology and Technology, Gaithersburg, Maryland, 5-7 September, 2001*, eds. M.C. Peckerar and M.T. Postek, Jr., *Proc. SPIE*, Vol. **4608** (SPIE, Bellingham, WA), 116-124 (2001). (*CSR Reprint 01-105*)

"Progress towards a general grating patterning technology using phase-locked scanning beams," M.L. Schattenburg, C.G. Chen, R.K. Heilmann, P.T. Konkola and G.S. Pati, *Proc. SPIE* **4485**, *Optical Spectroscopic Techniques and Instrumentation for Atmospheric and Space Research IV*, eds. A.M. Larar and M.G. Mlynczak, 378-384 (2002). (*CSR Reprint 01-83*)

"Novel methods for shaping thin-foil optics for x-ray astronomy," R.K. Heilmann, G.P. Monnelly, O. Mongrard, N. Butler, C.G. Chen, L.M. Cohen, C.C. Cook, L.M. Goldman, P.T. Konkola, M. McGuirk, G.R. Ricker and M.L. Schattenburg, *Proc. SPIE* **4496**, *X-ray Optics for Astronomy: Telescopes, Multilayers, Spectrometers and Missions*, eds. P. Gorenstein and R.B. Hoover, 62-72 (2002). (*CSR Reprint 01-82*)

"Analysis of vector Gaussian beam propagation and the validity of paraxial and spherical approximations," C.G. Chen, P.T. Konkola, J. Ferrera, R.K. Heilmann and M.L. Schattenburg, *J. Optical Society of America A* **19**, 404-412 (2002). (*CSR Reprint 00-48*)

"Beam alignment and wavefront metrology for scanning beam interference lithography," C.G. Chen, R.K. Heilmann, C. Joo, P.T. Konkola, G.S. Pati and M.L. Schattenburg, *J. Vac. Sci. Technol. B*, Nov./Dec. 2002 (*submitted June 2002*). (CSR Reprint 02-34)

"Nanometer-accurate fringe metrology using a Fresnel zone plate," C. Joo, G.S. Pati, C.G. Chen, P.T. Konkola, R.K. Heilmann, M.L. Schattenburg, A. Liddle and E.H. Anderson, *J. Vac. Sci. Technol. B*, Nov./Dec. 2002 (*submitted June 2002*). (CSR Reprint 02-35)

"A generalized scanning beam interference lithography system for patterning gratings with variable period progressions," G.S. Pati, R.K. Heilmann, P.T. Konkola, C. Joo, C.G. Chen, E. Murphy and M.L. Schattenburg, *J. Vac. Sci. Technol. B*, Nov./Dec. 2002 (*submitted June 2002*). (CSR Reprint 02-35)

"Constellation-X Spectroscopy X-ray Telescope (SXT)," R. Petre, W.W. Zhang, D.A. Content, T. T. Saha, J. Stewart, J.H. Hair, D.Nguyen, W.A. Podgorski, W.R. Davis, Jr., M.D. Freeman, L.M. Cohen, M.L. Schattenburg, R.K. Heilmann, Y. Sun and C. Forest, *Proc. SPIE* **4851**, *X-ray and Gamma-ray Telescopes and Instruments for Astronomy* (SPIE, Bellingham, WA), eds. J.E. Truemper and H.D. Tananbaum (*submitted September 2002*).

"Constellation-X Spectroscopy X-ray Telescope assembly and alignment," W.A. Podgorski, D.A. Content, J.H. Hair, R. Petre, T.T. Saha, M.L. Schattenburg, J. Stewart and W.W. Zhang, *Proc. SPIE* **4851**, *X-ray and Gamma-ray Telescopes and Instruments for Astronomy* (SPIE, Bellingham, WA), eds. J.E. Truemper and H.D. Tananbaum (*submitted September 2002*).

"Precision shaping, assembly and metrology of foil optics for x-ray reflection gratings," C.R. Forest, M.L. Schattenburg, C.G. Chen, R.K. Heilmann, P. Konkola, J. Przbylowski, Y. Sun, J. You, S.M. Kahn and D. Golini, *Proc. SPIE* **4851**, *X-ray and Gamma-ray Telescopes and Instruments for Astronomy* (SPIE, Bellingham, WA), eds. J.E. Truemper and H.D. Tananbaum (*submitted September 2002*).

"Constellation-X soft x-ray telescope segmented optic assembly and alignment implementation," J.H. Hair, J. Stewart, R. Petre, W.W. Zhang, D.A. Content, T.T. Saha, W.A. Podgorski, P.E. Glenn, M.L. Schattenburg, R.K. Heilmann, Y. Sun and G. Nanan, *Proc. SPIE* **4851**, *X-ray and Gamma-ray Telescopes and Instruments for Astronomy* (SPIE, Bellingham, WA), eds. J.E. Truemper and H.D. Tananbaum (*submitted September 2002*).

"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, M. McGuirk, C. Joo and M.L.Schattenburg, *Proc. of the Seventeenth Annual Meeting of the American Society for Precision Engineering* (ASPE, Raleigh, NC) (*submitted August 2002*).

"Precision assembly and metrology of x-ray foil optics," C.R. Forest, M.J. Spenko, Y. Sun, M. McGuirk, M.L. Schattenburg and A.H. Slocum, *Proc. of the Seventeenth Annual Meeting of the American Society for Precision Engineering* (ASPE, Raleigh, NC) (*submitted August 2002*).

"Interference fringe locking using Fresnel zone plates," C. Joo, G.S. Pati, C.G. Chen, P.T. Konkola, R.K. Heilmann and M.L. Schattenburg, *Proc. of the Seventeenth Annual Meeting of the American Society for Precision Engineering* (ASPE, Raleigh, NC) (*submitted August 2002*).

Presentations

"Nanometrology," M.L. Schattenburg, presented at the *MIT Nanogathering*, Cambridge, Massachusetts, January 6, 2000.

"Space Nanotechnology Laboratory," M.L. Schattenburg, private briefing to Lt. Gen. Spence (Sam) M. Armstrong, NASA Associate Administrator, Cambridge, Massachusetts, March 22, 2000.

"Microcomb design and fabrication for high accuracy optical assembly," C. Chen, O. Mongrard, L. Cohen, R.K. Heilmann, P. Konkola, G. Monnelly and M.L. Schattenburg, poster presented at the *MIT Microsystems Technology Laboratories Student Research Review,* Dedham, Massachusetts, January 10, 2000.

"Development of segmented x-ray mirrors for Constellation-X," R. Petre, C. Chen, L.M. Cohen, D.A. Content, R.J. Harms, G. Monnelly, T.T. Saha, M.L. Schattenburg, P.J. Serlemitsos and W.W. Zhang, poster presented at *SPIE Astronomical Telescopes and Instrumentation 2000 -- X-Ray Optics, Instruments and Missions III,* Munich, Germany, March 27-31 2000 (*paper 4012-36*).

"Beam steering system and spatial filtering applied to interference lithography," P. Konkola, C.G. Chen, R.K. Heilmann and M.L. Schattenburg, poster presented at the *44th International Conference on Electron, Ion and Photon Beam Technology & Nanofabrication,* Palm Springs, California, May 30-June 2, 2000 (*paper P7-1*).

"Microcomb design and fabrication for high accuracy optical assembly," C. Chen, L. Cohen. R.K. Heilmann, P. Konkola, O. Mongrard, G. Monnelly and M.L. Schattenburg, presented at the *44th International Conference on Electron, Ion and Photon Beam Technology & Nanofabrication,* Palm Springs, California, May 30-June 2, 2000 (*paper 16-4*).

"Relativistic corrections in displacement measuring interferometry," R.K. Heilmann, P. Konkola, C. Chen and M.L. Schattenburg, presented at the *44th International Conference on Electron, Ion and Photon Beam Technology & Nanofabrication,* Palm Springs, California, May 30-June 2, 2000 (*paper 16-5*).

"High-accuracy x-ray foil optic assembly," G.P. Monnelly, D. Breslau, N. Butler, C.C. Chen, L. Cohen, W. Gu, R.K. Heilmann, P.T. Konkola, O. Mongrard, G.R. Ricker and M.L. Schattenburg, presented at the *SPIE Conference on X-Ray Optics, Instruments, and Missions,* San Diego, California, July 30-31, 2000 (*paper 4138-23*).

"Precision assembly station for high-resolution segmented optics," L.M. Cohen, H. Bergner, M.L. Schattenburg and G. Monnelly, presented at the *SPIE Conference on X-Ray Optics, Instruments, and Missions,* San Diego, California, July 30-31, 2000 (*paper 4138-20*).

"Progress toward meeting the Constellation-X performance goals using segmented x-ray mirrors," R. Petre, L.M. Cohen, D.A. Content, J. Hein, T.T. Saha, M.L. Schattenburg and W.

W. Zhang, presented at the *SPIE Conference on X-Ray Optics, Instruments, and Missions,* San Diego, California, July 30-31, 2000 (*paper 4138-06*).

"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*).

"Alignment and control architecture for scanning beam interference lithography," C. Chen, P. Konkola, R.K. Heilmann and M.L. Schattenburg, poster presented at the *MIT Microsystems Technology Laboratories Student Research Review*, Dedham, Massachusetts, January 9, 2001.

"Advanced interference lithography and applications," M.L. Schattenburg, *University of Central Florida, School of Optics/CREOL Seminar*, Orlando, Florida, February 15, 2001 (*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*).

"Metrology for the sub-100 domain via fiducial grids," M.L. Schattenburg, C. Chen, R.K. Heilmann, P. Konkola and H.I. Smith, *National Institute of Standards and Technology -- Manufacturing Engineering Laboratory Seminar*, Gaithersburg, Maryland, March 30, 2001 (*invited*).

"Metrology for the sub-100 nm domain via fiducial grids," M.L. Schattenburg, C. Chen, R.K. Heilmann, P. Konkola and H.I. Smith, *Defense Advanced Research Projects Administration - Advanced Lithography Program Review*, Charleston, South Carolina, April 2-5, 2001 (*invited*).

"X-ray reflection grating update," M.L. Schattenburg, *Constellation X-ray Mission Facility Science Team Meeting*, Cambridge, Massachusetts, May 4, 2001.

"From nanometers to gigaparsecs: the role of nanostructures in unraveling the mysteries of the cosmos," M.L. Schattenburg, *45th International Conference on Electron, Ion and Photon Beam Technology and Nanofabrication*, Washington, D.C., May 30, 2001 (*invited plenary talk 1-1*).

"Image metrology and system controls for scanning beam interference lithography," C.G. Chen, P.T. Konkola, R.K. Heilmann, G.S. Pati and M.L. Schattenburg, *45th International Conference on Electron, Ion and Photon Beam Technology and Nanofabrication*, Washington, D.C., May 29-June 1, 2001 (*invited paper P7-1*).

"Digital heterodyne interference fringe locking system," R.K. Heilmann, C.G. Chen, P.T. Konkola, G.S. Pati and M.L. Schattenburg, *45th International Conference on Electron, Ion and Photon Beam Technology and Nanofabrication*, Washington, D.C., May 29-June 1, 2001 (*paper 4-5*).

"Novel methods for shaping thin-foil optics for x-ray astronomy," R.K. Heilmann, G.P. Monnelly, O. Mongrard, N. Butler, C.G. Chen, L.M. Cohen, C.C. Cook, L.M. Goldman, P.T. Konkola, M. McGuirk, G.R. Ricker and M.L. Schattenburg, presented at the *SPIE Conference on X-ray Optics for Astronomy: Telescopes, Multilayers, Spectrometers and Missions*, San Diego, California, July 30, 2001 (*paper 4496-06*).

"Segmented x-ray mirror for the Constellation-X Spectroscopy X-ray Telescope," R. Petre, L.M. Cohen, D.A. Content, T.T. Saha, M.L. Schattenburg, J. Stewart and W.W. Zhang, *SPIE Conference on X-ray Optics for Astronomy: Telescopes, Multilayers, Spectrometers and Missions*, San Diego, California, July 30, 2001 (*paper 4496-10*).

"Wavefront sensors for x-ray and EUV optics fabrication," M. McGuirk, G.P. Monnelly, M.L. Schattenburg and C.R. Canizares, *SPIE Conference on X-ray Optics for Astronomy: Telescopes, Multilayers, Spectrometers and Missions*, San Diego, California, July 30, 2001 (*paper 4496-12*).

"Progress towards a general grating patterning technology using phase-locked scanning beams," M.L. Schattenburg, C.G. Chen, R.K. Heilmann, P.T. Konkola and G.S. Pati, *SPIE Conference on Optical Spectroscopic Techniques and Instrumentation for Atmospheric and Space Research IV*, San Diego, California, August 2, 2001 (*paper 4485-61*).

"Alignment combs - status review and outlook," R.K. Heilmann, G.P. Monnelly, D. Breslau, N. Butler, C.G. Chen, L.M. Cohen, W. Gu, P.T. Konkola, O. Mongrard, G.R. Ricker, Jr. and M.L. Schattenburg, *Constellation-X SXT Optics Team Meeting*, NASA Goddard Space Flight Center, Greenbelt, Maryland, August 7-8, 2001.

"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*).

"MIT precision machine design: x-ray optics alignment project," C.R. Forest, *Dover Instrument Corporation*, Westborough, Massachusetts, October 12, 2001 (*invited*).

"Microcomb/alignment bar design update," R.K. Heilmann, C.G. Chen, O. Mongrard, M.L. Schattenburg and Y. Sun, *Constellation-X SXT Engineering Unit Technical Interchange Meeting,* NASA Goddard Space Flight Center, Greenbelt, Maryland, November 6, 2001.

"Scanning beam interference lithography," P.T. Konkola, C.G. Chen, R.K. Heilmann, G. Pati and M.L. Schattenburg, presented at the *Sixteenth Annual Meeting of the American Society for Precision Engineering*, Arlington, Virginia, November 10-15, 2001 (*invited paper I-1*).

"High precision assembly and metrology of x-ray foil optics," M.L. Schattenburg, O. Mongrard, N. Butler, C.G. Chen, R.K. Heilmann, P.T. Konkola, M. McGuirk, G. Monnelly, G.S. Pati, G.R. Ricker and L. Cohen, presented at the *Sixteenth Annual Meeting of the American Society for Precision Engineering*, Arlington, Virginia, November 10-15, 2001 (*paper II-4*).

"A novel sub-microradian beam diagnostic and alignment system," C.G. Chen, R.K. Heilmann, P.T. Konkola, G.S. Pati and M.L. Schattenburg, poster presented at the *Sixteenth Annual Meeting of the American Society for Precision Engineering*, Arlington, Virginia, November 10-15, 2001.

"Silicon microcombs for precision x-ray foil assembly," Y. Sun, O. Mongrard, C. Chen, R.K. Heilmann, C. Forest, J. You, M. Spenko and M.L. Schattenburg, presented at the *Constellation X Mission Facility Science Team Meeting,* NASA Goddard Space Flight Center, Greenbelt, Maryland, November 15-16, 2001.

"X-ray reflection grating update," C.R. Forest, A. Lapsa, O. Mongrard, J. Przybylowski, M. Spenko, Y. Sun, J. You, M.L. Schattenburg, presented at the Constellation X Mission Facility Science Team Meeting, NASA Goddard Space Flight Center, Greenbelt, Maryland, November 15-16, 2001.

"Proposed off-plane reflection grating fabrication process," M.L. Schattenburg and G.R. Ricker, presented at the *Constellation X Mission Facility Science Team Meeting*, NASA Goddard Space Flight Center, Greenbelt, Maryland, November 15-16, 2001.

"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*).

"Advanced technology for future x-ray astronomy missions," M.L. Schattenburg, *Institute for Space and Astronautical Science*, Sagamihara, Japan, November 28, 2001 (*invited*).

"Space nanotechnology," M.L. Schattenburg, private briefing to the *Council for Science and Technology Policy, Japanese Cabinet Office*, Tokyo, Japan, November 29, 2001 (*invited*).

"Nanometrology," M.L. Schattenburg, *US/Germany Joint Meeting on Nanoscale Science and Engineering at MIT*, Cambridge, Massachusetts, December 5-6, 2001 (*invited*).

"MIT 2.75 Precision Machine Design Project: x-ray optics assembly truss," C. Forest, Y. Sun, M. Spenko, M.L. Schattenburg and A. Slocum, *MIT Precision Machine Design Class (2.75) Final Presentation*, Cambridge, Massachusetts, December 12, 2001.

"MIT Space Nanotechnology Lab x-ray optics assembly truss," C. Forest, Y. Sun, M. Spenko, M.L. Schattenburg and A. Slocum, *Constellation-X SXT Engineering Unit Technical Interchange Meeting,* NASA Goddard Space Flight Center, Greenbelt, Maryland, January 23, 2002.

"Nanometrology research at MIT," M.L. Schattenburg and H.I. Smith, *University of Central Florida, School of Optics/CREOL Seminar*, Orlando, Florida, February 19, 2002 (*invited*).

"Nanometrology research at MIT," M.L. Schattenburg and H.I. Smith, *International SEMATECH -- Metrology Council Meeting*, Austin, Texas, February 26, 2002 (*invited*).

"The critical role of metrology in nanotechnology," M.L. Schattenburg, *MIT Mechanical Engineering Department Seminar*, Cambridge, Massachusetts, March 1, 2002 (*invited*).

"Grating-based nanometer metrology," M.L. Schattenburg, C. Chen, C. Joo, R.K. Heilmann, P. Konkola, G.S. Pati and H.I. Smith, *Defense Advanced Research Projects Administration - Advanced Lithography Program Review*, New Orleans, Louisiana, April 9-11, 2002.

"Reflection Grating Spectrometer (RGS) progress report," M.L. Schattenburg and R.K. Heilmann, *Constellation X Mission Facility Science Team Meeting*, Greenbelt, Maryland, May 1, 2002.

"Technology for a large-area reflection grating spectrometer on Constellation-X," S.M. Kahn, F. Paerels, A. Rasmussen, M.L. Schattenburg, G.R. Ricker, M.W. Bautz, J.P. Doty, G.Y. Prigozhin, J. Nousek, D. Burrows, J.E. Hill and W. Cash, *Constellation X Mission Facility Science Team Meeting*, Greenbelt, Maryland, May 1, 2002.

"Beam alignment and wavefront metrology for scanning beam interference lithography," C.G. Chen, R.K. Heilmann, C. Joo, P.T. Konkola, G.S. Pati and M.L. Schattenburg, abstract submitted to the *46th International Conference on Electron, Ion and Photon Beam Technology and Nanofabrication*, Anaheim, California, May 28-31, 2002 (*paper 10B4*).

"Nanometer-accurate fringe metrology using a Fresnel zone plate," C. Joo, G.S. Pati, P.T. Konkola, C.G. Chen, R.K. Heilmann, E.H. Anderson and M.L. Schattenburg, abstract submitted to the *46th International Conference on Electron, Ion and Photon Beam Technology and Nanofabrication*, Anaheim, California, May 28-31, 2002 (*paper 10B5*).

"A generalized scanning beam interference lithography system for patterning gratings with variable period progressions," G.S. Pati, P.T. Konkola, C.G. Chen, C. Joo, R.K. Heilmann and M.L. Schattenburg, abstract submitted to the *46th International Conference on Electron, Ion and Photon Beam Technology and Nanofabrication*, Anaheim, California, May 28-31, 2002 (*poster PG7*).

"Nanoaccuracy in nanolithography," H.I. Smith and M.L. Schattenburg, presented at the *US-Korea Nanofabrication Workshop*, Hanyang University, Seoul, Korea, June 3-5 (2002).

"Thin foil optic," V. Guillaume, Internship Presentation, MIT Center for Space Research, Cambridge, Massachusetts, June 19, 2002.

"Grating production methods," M.L. Schattenburg and R.K. Heilmann, *Constellation X-ray Mission Reflection Grating/CCD Team Technical Working Meeting*, Cambridge, Massachusetts, July 3, 2002.

"Shack-Hartmann surface metrology system," C.R. Forest, *Precitech Corporation*, Keene, New Hampshire, July 27, 2002 (*invited*).

"Shack-Hartmann surface metrology system," C.R. Forest, *Zygo Corporation*, Milford, Connecticut, July 28, 2002 (*invited*).

"Constellation-X spectroscopy x-ray telescope (SXT)," R. Petre, W.W. Zhang, D.A. Content, T. T. Saha, J. Stewart, J.H. Hair, D.Nguyen, W.A. Podgorski, W.R. Davis, Jr., M.D. Freeman, L.M. Cohen, M.L. Schattenburg, R.K. Heilmann, Y. Sun and C. Forest, *SPIE Conference on X-ray and Gamma-ray Telescopes and Instruments for Astronomy*, Waikoloa, Hawaii, August 25-28, 2002 (*paper 4851-50*).

"Constellation-X soft x-ray telescope assembly and alignment," W.A. Podgorski, D.A. Content, J.H. Hair, R. Petre, T.T. Saha, M.L. Schattenburg, J. Stewart and W.W. Zhang, *SPIE Conference on X-ray and Gamma-ray Telescopes and Instruments for Astronomy*, Waikoloa, Hawaii, August 25-28, 2002 (*paper 4851-57*).

"Precision shaping, assembly and metrology of foil optics for x-ray reflection gratings," C.R. Forest, M.L. Schattenburg, C.G. Chen, R.K. Heilmann, P. Konkola, J. Przbylowski, Y. Sun, J. You, S.M. Kahn and D. Golini, *SPIE Conference on X-ray and Gamma-ray Telescopes and Instruments for Astronomy*, Waikoloa, Hawaii, August 25-28, 2002 (*paper 4851-62*).

"Constellation-X soft x-ray telescope segmented optic assembly and alignment implementation," J.H. Hair, J. Stewart, R. Petre, W.W. Zhang, D.A. Content, T.T. Saha, W.A. Podgorski, P.E. Glenn, M.L. Schattenburg, R.K. Heilmann, Y. Sun and G. Nanan, *SPIE Conference on X-ray and Gamma-ray Telescopes and Instruments for Astronomy*, Waikoloa, Hawaii, August 25-28, 2002 (*poster 4851-76*).

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