Nanofabricated Metal Transmission Gratings

Personnel

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Sponsorship

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Wire-grid metal transmission gratings have many useful and novel optical properties that are enhanced when the grating period and/or slit dimensions are comparable to, or smaller than, the wavelength of light. These benefits are particularly attractive in the UV to X-ray bands where the performance of conventional optics is poor. However, this generally requires control of the grating period and feature dimensions in the nanometer to picometer range. In this research effort we are advancing metal transmission gratings past the already highly sophisticated technology developed in the NanoStructures Lab (NSL) and Space Nanotechnology Lab (SNL) over the past twenty years.

Our research group is the world leader in metal transmission grating fabrication technology applied to a wide variety of laboratory and space research applications. Over forty laboratories worldwide use MIT-fabricated transmission gratings for research, ranging from materials science to laser plasma fusion (see Table 1). Nine NASA missions have also flown hundreds of MIT-fabricated transmission gratings in space research instruments ranging from X-ray spectrographs to atom imagers.

Metal transmission gratings are generally fabricated with electroplated gold and supported by submicron-thick polyimide membranes or by coarse meshes of electroplated gold or nickel. The thin and flimsy grating members require a carefully engineered coarse support mesh and metal frame to withstand the rigors of rocket launch and the space environment. Transmission grating periods down to 100 nm and sizes up to 30x30 mm have been fabricated. Grating pattering is performed by Interference Lithography (IL) using a variety of novel tri-level resists schemes, followed by reactive-ion etching and metal electroplating. We have developed the most advanced IL tools in the world and have facilities for high-yield volume production of transmission gratings.

High-dispersion X-ray and Extreme UltraViolet (EUV) transmission gratings were fabricated for NASA missions including the Solar EUV Monitor (SEM) on the *Solar and Heliospheric Observatory* (SOHO) mission, launched December 2, 1995, the *Chandra* X-ray telescope, launched July 23, 1999, and the *Geostationary Operational Environmental Satellites* (GOES N, O, P, Q) missions. The *Chandra* telescope provides high-resolution imaging and spectroscopy of X-ray-emitting astrophysical objects, with unprecedented power and clarity, which is significantly widening our view of the Universe. The SOHO and GOES satellite series perform solar EUV monitoring which provides early warning of solar flare events that could imperil satellite and astronaut operations.

A scanning-electron micrograph of a 200 nm-period gold grating from the *Chandra* mission is shown in Figure 12. This grating is used in the High Energy Transmission Grating Spectrometer (HETGS) which provides high-resolution X-ray spectroscopy in the λ=0.1-14 nm band. Period control of 40 picometers was required to meet telescope resolution requirements.

Transmission grating filters were also fabricated for the *Medium Energy Neutral Atom* (MENA) instrument on the NASA *Magnetospheric Imaging Medium-Class Explorer* (IMAGE) mission, launched March 25, 2000, and also for the NASA *Two Wide-Angle Imaging Neutral-atom Spectrometers* (TWINS A, B) Missions. Instruments on these missions provide neutral atom imaging of Earth's magnetosphere. Transmission gratings are used to block the intense Hydrogen Lyman Alpha (λ=121.6 nm) deep-UV radiation that would otherwise overwhelm the sensitive atom detectors. Figure 74 depicts a 200 nm period atom nanofilter grating with 45 nm-wide slots that is designed to block the deep-UV radiation. Slot widths need to be controlled to within a few nanometers for optimal UV blocking.

The current research effort seeks to boost grating transmission efficiency, reduce defect levels, and improve control of grating feature geometry.

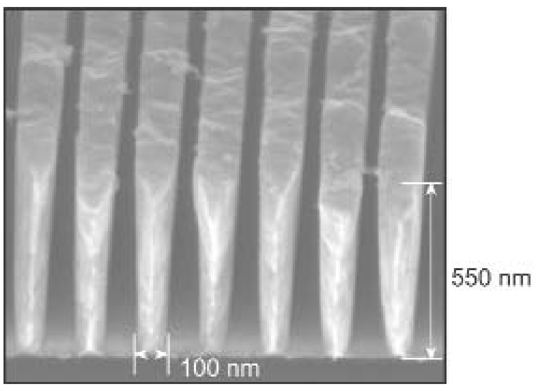

Figure 12: Scanning-electron micrograph of a 200 nm-period gold X-ray transmission grating used in the HETGS instrument on the Chandra Observatory, cleaved to show the grating line sidewalls. The HETGS provides high-resolution X-ray spectroscopy in the λ=0.1-14 nm band. The gold bars are 100 nm wide, or approximately 400 gold atoms.

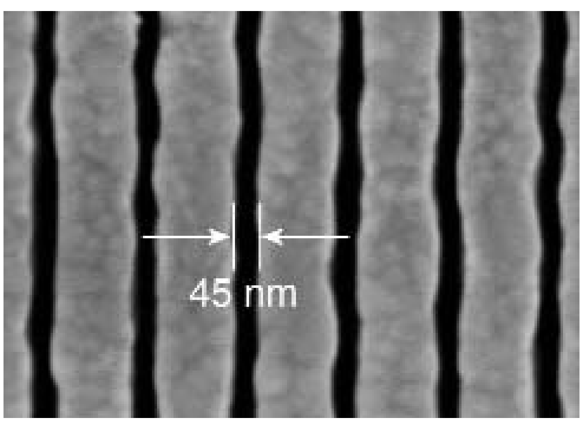

Figure 13: Scanning-electron micrograph of a deep-UV blocking grating used in atom telescopes on the NASA IMAGE and TWINS missions. The grating blocks deep-UV radiation while passing energetic neutral atoms. Due to the narrow slot width of 45 nm and the large slot depth (~500 nm), the UV transmission is extremely low (~10^{-6} at λ=121.6 nm), while decreasing the transmitted atomic flux by only a factor of 10.

Table 1. Laboratories supplied with SNL-fabricated gratings and lithography calibration standards.

Aerospace Corporation (P. R. Strauss)
Avance Inc., Japan (Yachiyo Kimpara)
AWE Aldermaston Goods Inwards (Richard T. Eagleton)
BESSY-Zentrales, Berlin, Germany (H.R. Molter)
Commonwealth Technology (John Seely, Drew Fielding)
Danish Space Research Institute (Herb Schnopper)
Duke University (Louis Johnson)
Etablissement de Bruyeres-le-Chatel, France (Michele Courtin)
Foreign Economic Association, Russia (Akademintorg)
French Atomic Energy Commision (B. Erlinger)
Hampshire Instruments (Irving Plotnik)
Hampshire Instruments (Robert Frankel)
Indian Dept. of Atomic Energy (K. Visvanathan)
John Hopkins University (Vlad Soukhanovskii)
Kernforschungszentrum Karlsruhe GmBH (H. Tebbert)
Laboratory for Laser Energetics, Rochester University (Fred Marshall)
Laboratory for Laser Energetics, Rochester University (Justin Peatross)
Lawrence Berkeley National Laboratory (Eric Gullikson)
Lawrence Berkeley National Laboratory (Phil Heiman)
Lawrence Livermore National Laboratory (Nat Ceglio)
Lawrence Livermore National Laboratory (Joseph Nilsoen)
Los Alamos National Laboratory (Earl Scime)
Los Alamos National Laboratory (Gary Stradling)
Los Alamos National Laboratory (Jim Cobble)
Los Alamos National Laboratory (Peter Lee)
Martin Marietta/Oak Ridge (J. A. Stokes)
Max Planck Institute for Quantum Optics (Eidman)
Max Planck Institute fur Biophys. Chemie (Kuhnle)
Max Plank Gesellschaft at the Friedrich-Schiller Universitaet (E. Foerster)
MIT (Prof. Pritchard)
MIT Nuclear Engineering Lab (Eugene DiSalvatore)
National Synchrotron Light Source - Brookhaven (David Eaterer)
Panametrics Corp. (Frederick Hanser)
Pennsylvania State University (Gordon Garmire)
Sandia National Laboratory (Larry Ruggles)
Sandia National Laboratory (Tina Tanaka)
Sandia National Laboratory (John Porter)
Stanford Synchrotron Radiation Laboratory (Pierro Pianetta)
University of Florida (Chuck Hooper)
University of Illinois at Chicago (G. Gnutek)
University of Southern California (Howard Ogawa)
US Department of Energy (J. Snyder)