Transmission Gratings for X-ray and Atom-Beam Spectroscopy and Interferometry.

Personnel

J. M. Carter, T. A. Savas, E. Murphy, H. I. Smith and M. L. Schattenburg

Sponsorship

X-OPT, Inc.

Transmission gratings with periods of 100 to 1000 nm are finding increasing utility in applications such as X-ray, vacuum-ultraviolet, and atom-beam spectroscopy and interferometry. Over 30 laboratories around the world depend on MIT-supplied gratings in their work. For X-ray and VUV spectroscopy, gratings are made of gold and have periods of 100 to 1000 nm, and thicknesses ranging from 100 to 1000 nm. The gratings are most commonly used for spectroscopy of the X-ray emission from high-temperature plasmas. Transmission gratings are supported on thin (1 micron) polyimide membranes, or made self supporting (“free standing”) by the addition of crossing struts (mesh). (For short X-ray wavelengths, membrane support is desired, while for the long wavelengths, a mesh support is preferred in order to increase efficiency.) Fabrication is performed by interference lithography combined with reactive-ion etching and electroplating. Progress in this area tends to focus on improving the yield and flexibility of the fabrication procedures.

Another application is the diffraction of neutral-atom and molecular beams by mesh-supported gratings. Lithographic and etching procedures have been developed for fabricationg free-standing gratings and grids in thin silicon nitride (SiNx) membranes supported in a Si frame. Figure 68 shows a free-standing 100 nm period grating in 100 nm-thick silicon nitride. Figure 69 shows a 100 nm-period grid in a 100 nm-thick SiNx membrane. Such a grid is used in experiments as a “molecular sieve.”

We have established a collaboration with the Max-Planck Institute in Göttingen, Germany, in which they utilize our gratings of 100 nm period in diffraction experiments using atomic, molecular, and helium-cluster beams. As shown in Figure 70 the diffraction of atomic and molecular beams reveals striking deviations from Kirchhoff’s optical diffraction theory. The analysis of the diffraction intensities allowed for a quantitative determination of the attractive atom(molecule)-surface van der Waals interaction at the silicon nitride surface for various atomic and molecular species including He, Ne, Ar, Kr, He*, Ne*, D_2, and CH_3F. The diffraction of cluster beams by a transmission grating has been established as a unique technique for the non-destructive mass selection and detection of small and weakly bound van der Waals clusters. Recently, the Göttingen group discovered bound states in mixed-isotope helium clusters, e.g. ${}_3He^4He_2$, ${}^3He^4He_3$, etc., by diffraction from one of our 100-nm-period gratings as shown in Figure 71. In addition, they employed the grating to measure the bond length of the helium dimer, ${}^4He_2$, which is assumed to be the weakest molecular bond. Future experiments based on the transmission gratings include the study of cluster formation dynamics and the search for the Efimov effect in the helium trimer.

Data obtained by helium-atom-beam diffraction at large incident angles showed Lyman ghosts in the spectrum. This data led to the development of new fabrication techniques to improve the quality of the free-standing gratings in silicon nitride. Diffraction spectra from gratings made with the improved process show no Lyman ghosts, illustrating the important synergy between applications and nanofabrication.

Highly successful diffraction experiments with beams of buckyballs (C60) have been carried out with our 100 nm-period, free-standing SiNx gratings by Dr. Markus Arndt of the University of Vienna.

Our 100 nm-period free-standing SiNx gratings are also used for atom interferometry by two groups: those of Prof. David Pritchard of MIT and Prof. Bruce Doak of the State University of Arizona. Pritchard’s group interferes neutral beams of sodium atoms while Doak’s group interferes helium beams (performed at the Max Planck Institute in Göttingen, Germany in collaboration with P. Toennies).

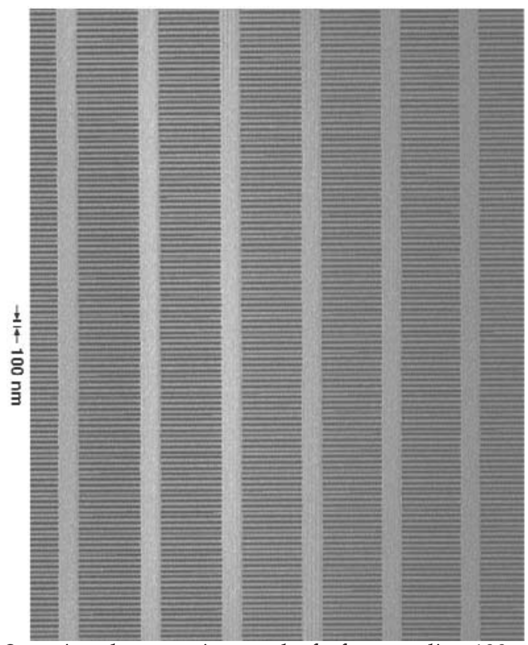

Fig. 7: Scanning electron micrograph of a free-standing 100 nm-period grating (50 nm-wide bars) in a silicon nitride membrane of area 500 microns by 5 mm.

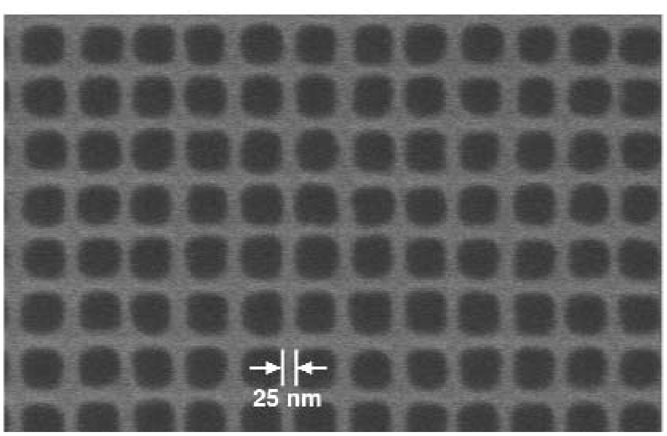

Fig. 8: Scanning electron micrograph of a free-standing 100 nm period grid in a silicon nitride membrane of area 500 micron by 5 mm. Such grids are used in experiments to separate out Helium trimers from other clusters.

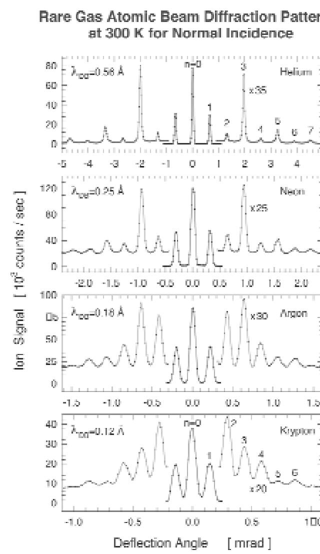

Fig. 9: Rare-gas atom-beam diffraction patterns. These results were obtained by Wieland Schöllkopf and Peter Toennies at the Max-Planck Institute in Göttingen, Germany, using a free-standing, 100nm-period grating.

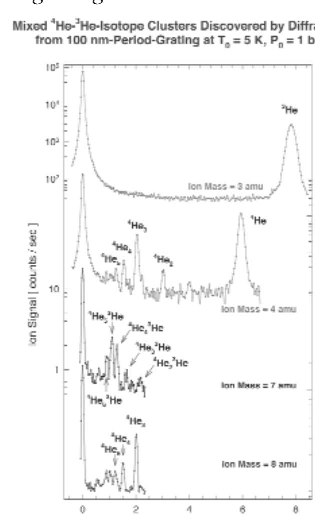

Fig. 10. Non-destructive mass separation of small mixed-isotope helium clusters. These results were obtained by Wieland Schöllkopf and Peter Toennies at the Max-Planck Institute in Göttingen, Germany, using a free-standing, 100nm-period grating.