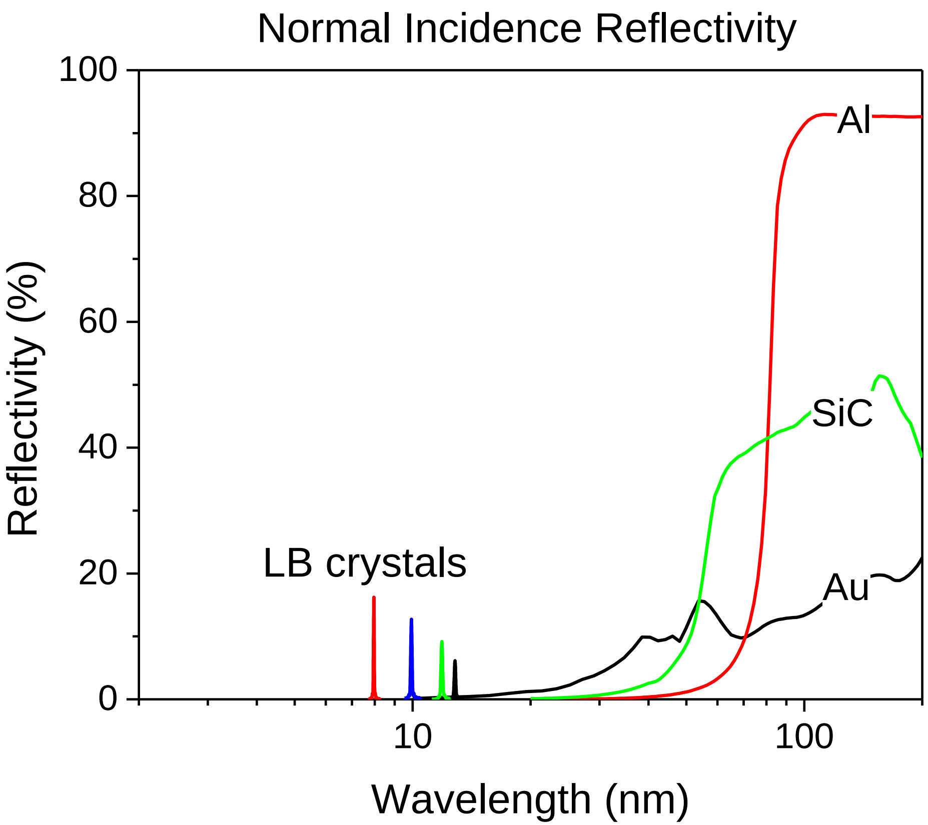
Refectometry and Scattering at the ALS: 25 Years

Eric Gullikson

CXRO

Prior to the 70's
x-ray optics = grazing incidence

Imaging with grazing incidence optics is limited by severe aberrations.



1970's - Pioneering EUV Multilayers

Eberhard Spiller

1972

Low-Loss Reflection Coatings Using Absorbing Materials

Eberhard Spiller
IBM Thomas J. Watson Research Center, Yorktown Heights, New York 10598
(Received 5 January 1972)

A new design principle is described which allows construction of mirrors that are of reasonable reflectivity ($R > 25\%$) in the extreme ultraviolet ($\lambda = 50$ to 500 Å). The measured performance of a first mirror for the near uv using this design principle is given.

⇩

1981

Imaging peformance of a normal incidence soft x-ray telescope

J. Patrick Henry [a]
Center for Astrophysics, Cambridge, Massachusetts 02138
Eberhard Spiller
IBM Thomas J. Watson Research Center, Yorktown Heights, New York 10598
Martin Weisskopf
Marshall Space Flight Center, Huntsville, Alabama 35812

(Received 3 August 1981; accepted for publication 20 October 1981)

We have made the first measurements of the imaging performance of a normal incidence soft x-ray telescope at BKα (0.183 keV, 67.6 Å). The performance is quite good; at 1.5' off axis the resolution is about 1 arcsec full width at half-maximum and 50% of the reflected power within 512 arcsec is contained within a diameter of 5 arcsec.

1981 - Imaging with a normal incidence x-ray mirror

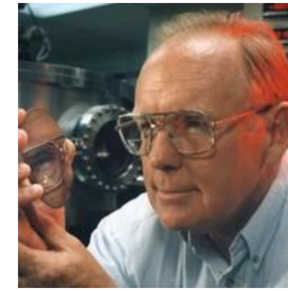
Soft X-ray imaging with a normal incidence mirror

Nature **294**, 429 (1981)

James H. Underwood
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

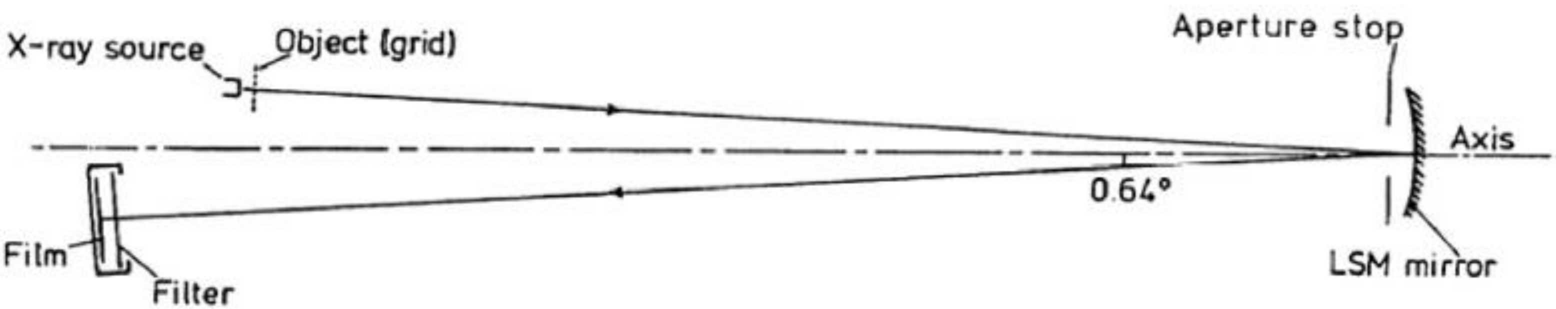
Troy W. Barbee Jr
Department of Materials Science
Stanford University, California

James Underwood



Troy Barbee

λ = 4.48 nm
W/C multilayer



1981 – High resolution soft x-ray optics

Conference Summary
High resolution soft x-ray optics

A. Franks
Division of Mechanical and Optical Metrology
National Physical Laboratory, Teddington, Middlesex TW11 OLW, United Kingdom

Abstract

The main topics discussed at the Conference were multilayer mirror optics and their applications, the manufacture and metrology of X-ray optical components, and microfabrication, particularly of zone plates for X-ray microscopy. The attainment of high resolution and the full potential of multilayer mirrors will require advances to be made in manufacturing technology, metrology and in the selection of suitable substrate materials.

Multilayer mirror optics

It is not difficult to select the one topic which provided most overall interest at the Conference, not only by the number of papers which were presented, but also because multilayers and their applications were probably the most talked about topic outside the Conference as well.

The enhanced reflectivity resulting from the use of multilayer optics gives rise to improvements in optical aperture, which may be very substantial, although this is coupled with a reduction in bandwidth. The latter can be turned to advantage in some cases, where, for example, it is required to filter the radiation. Some other advantages of multilayer optics are that the abilty to reflect X-rays at large grazing angles or even at normal incidence, leads to a reduction in aberrations and thus to a higher resolution over a larger field of view. Because spherical optics can be employed, manufacturing methods are simpler than those for the traditional aspherical X-ray optics, and are more likely to achieve the very demanding requirements on tolerance, which are necessary at the larger incidence angles.

We have now reached the stage where the multilayer manufacturing methods and the high reflectivities at normal incidence are taken for granted, and we are moving perceptibly into the applications area. Here I must be careful to separate the facts from the more speculative contributions to the Conference.

To deal with the facts first of all: Underwood[1] and Spiller[2] described experimental results obtained with normal incidence imaging systems. The latter discussed the performance of a 3 inch diameter spherical mirror used in a telescope configuration, and compared it with the Einstein telescope, showing it to be superior in off-axis resolution and in scattering performance.

1980's - The renaissance of x-ray optics

1984 – CXRO formed at LBL by David Attwood, Jim Underwood and others

1985 – Demonstration of Mo/Si by Barbee at al.

1986 – First demonstration of soft x-ray projection lithography by Hiroo Kinoshita.

1988 – First high resolution EUV images of the solar corona.

Vish More of Plant Engineering (center, at desk) describes the laboratory facilities which will soon be available at LBL's new Center for X-ray Optics. Behind More are, from left to right, David Attwood, consultant Gary Sommargren of Zygo Corporation, James Underwood, Kwang-Je Kim, Malcolm Howells and Al Thompson.

Physics Today 1984

The renaissance of x-ray optics

New optical elements such as multilayer mirrors and zone-plate lenses allow the extension of imaging and holography techniques to the spectral region below 300 Å.

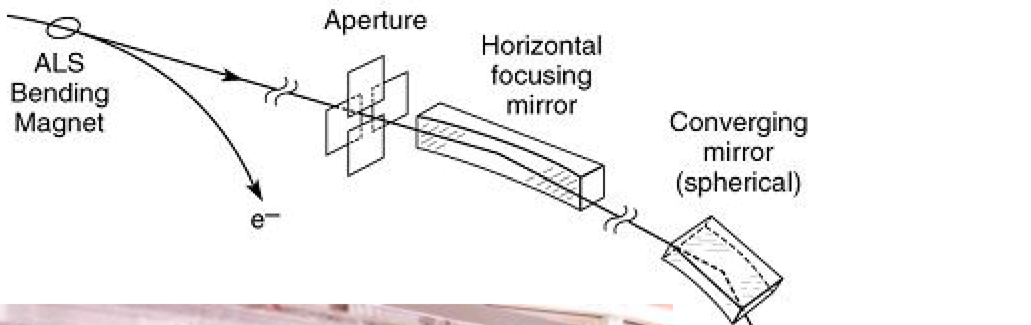
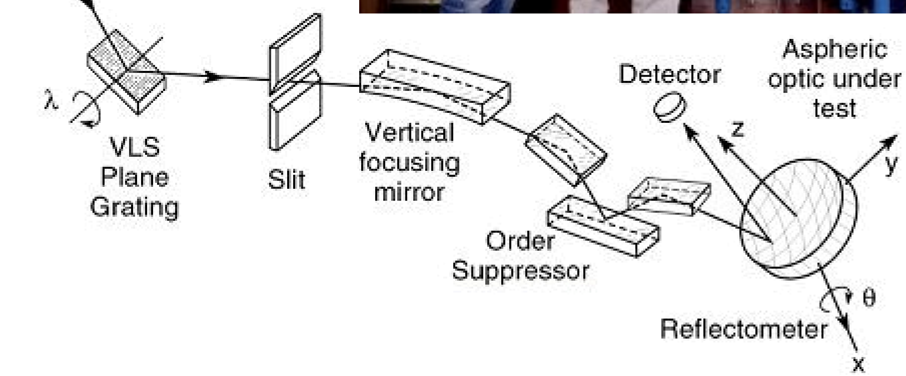
James H. Underwood and David T. Attwood

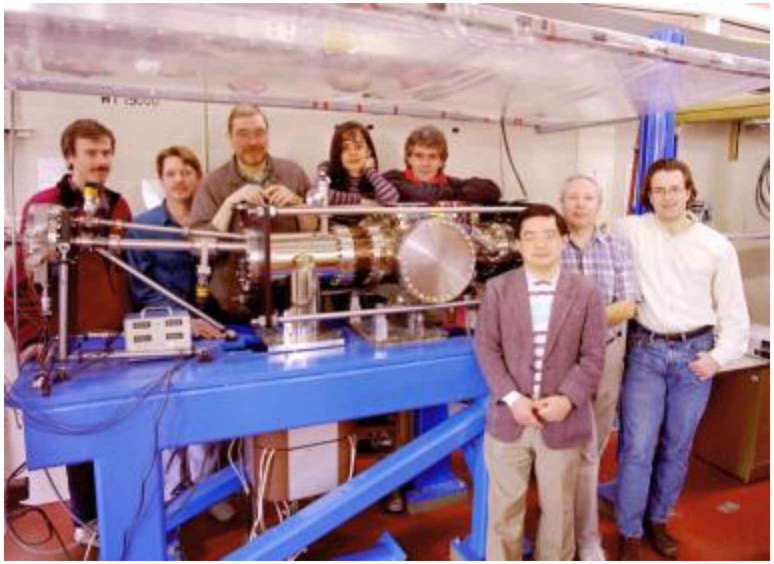
Anthony Yen, "EUV lithography from the very beginning to the eve of manufacturing." Proc. SPIE 9776 (2016).

Hiroo Kinoshita and Obert Wood: "EUV Lithography: An Historical Perspective" Chapter 1 of EUV Lithography

Reflectometry and Scattering Beamline (ALS 6.3.2)

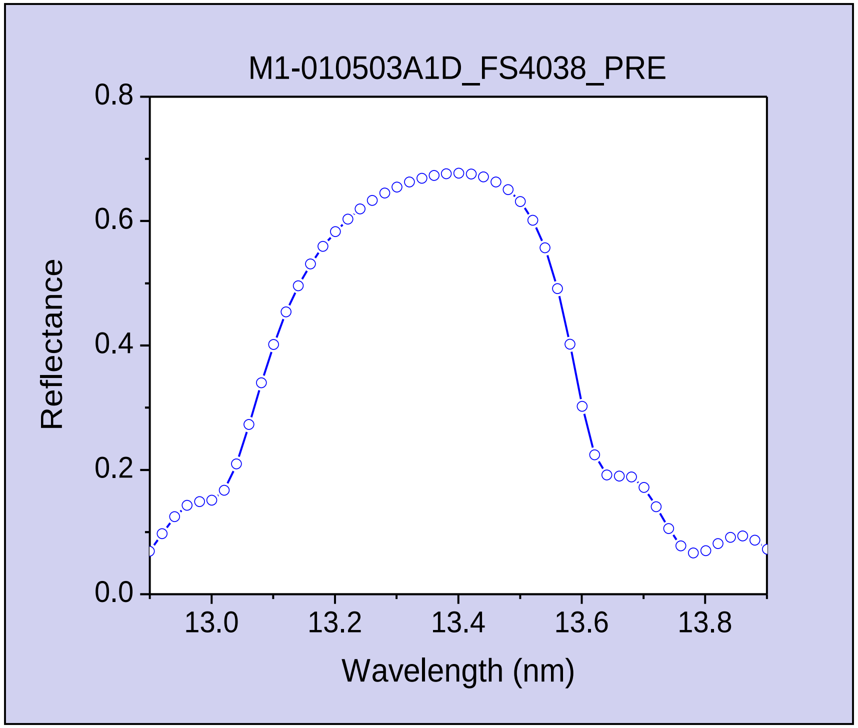
Commissioned Oct 1994

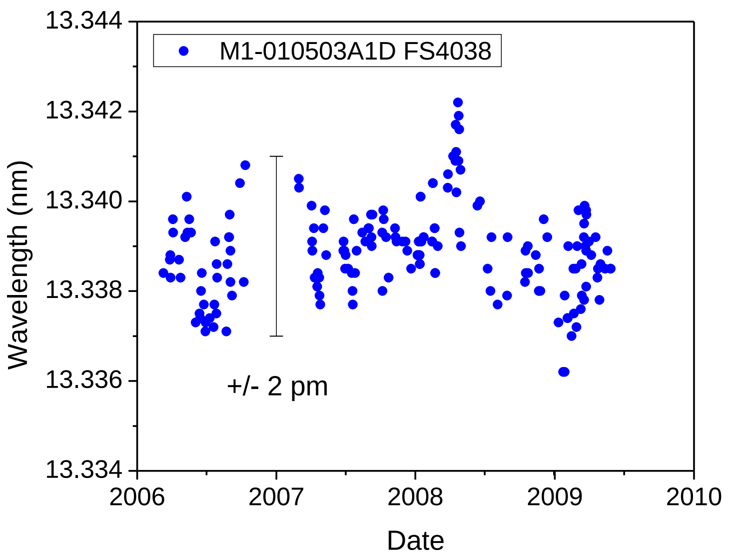



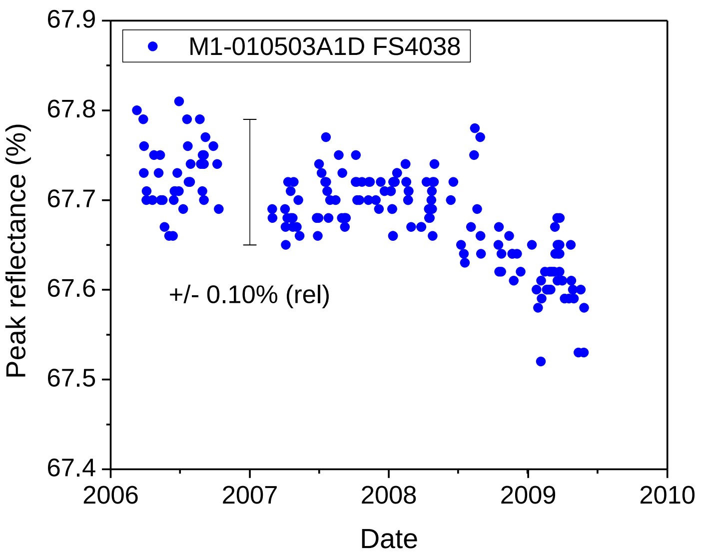


- High accuracy reflectometry
- High spectral purity
- Wavelengths from 1-25 nm

High precision is achieved



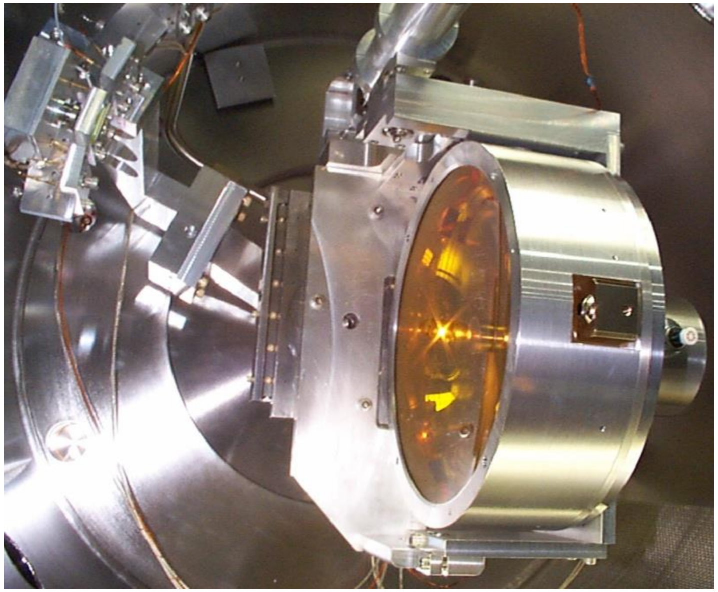


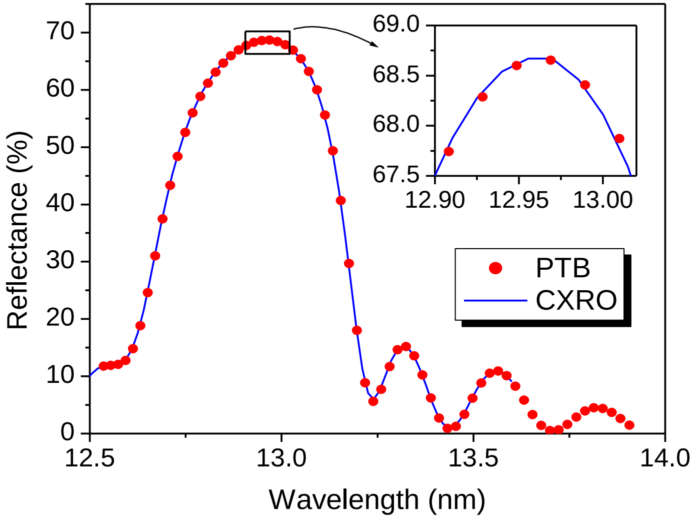


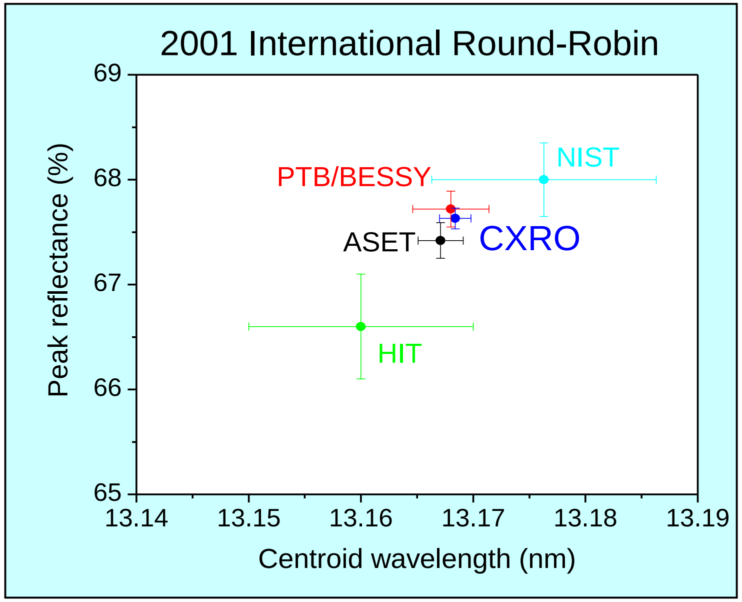
Reflectivity measurements of a standard multilayer mirror demonstrate the high precision in reflectivity and wavelength.

World class accuracy

- BL 6.3.2 achieves the highest accuracy for EUV reflectivity measurements.
- Demonstrated by international reflectometry round-robins.





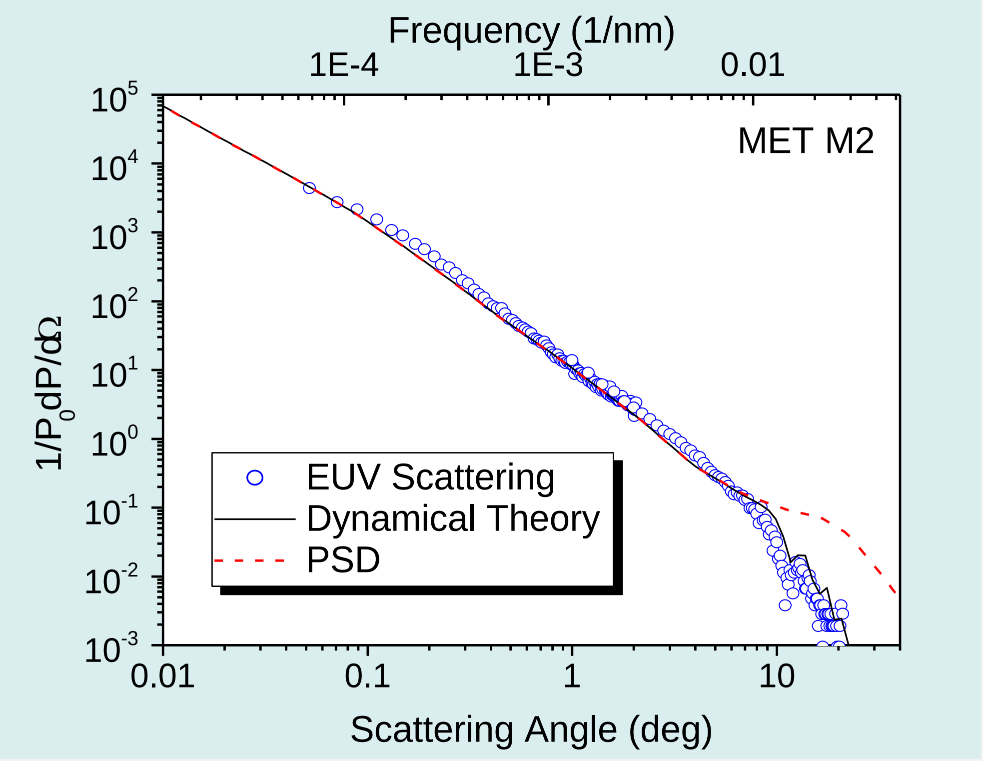


Scattering is determined by substrate roughness

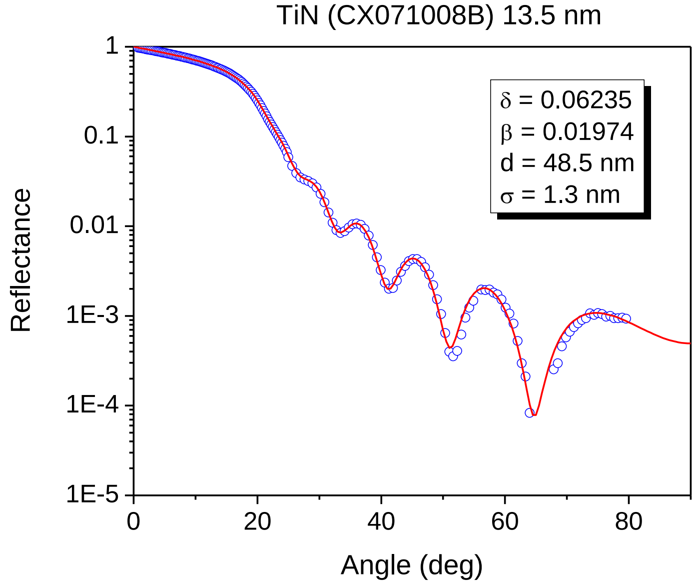
The angular distribution is proportional to the Power Spectral Density at the small angles relevant to flare.

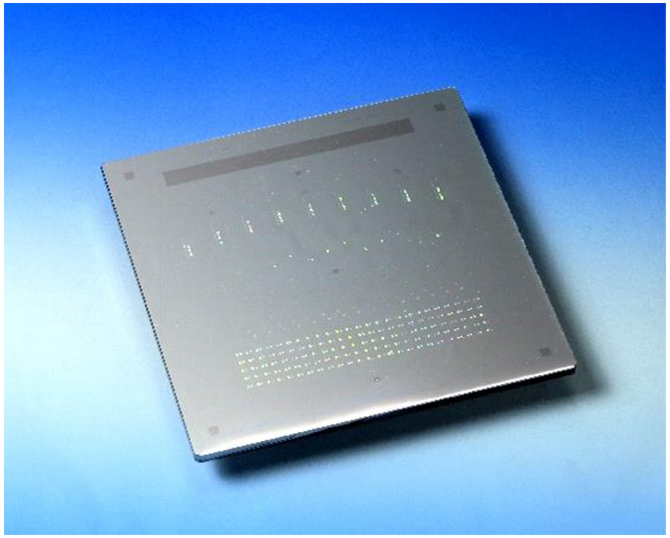
$$\frac{1}{P_0}\frac{dP}{d\Omega} \approx \frac{16\pi^2}{\lambda^4} R \cdot PSD(f)$$

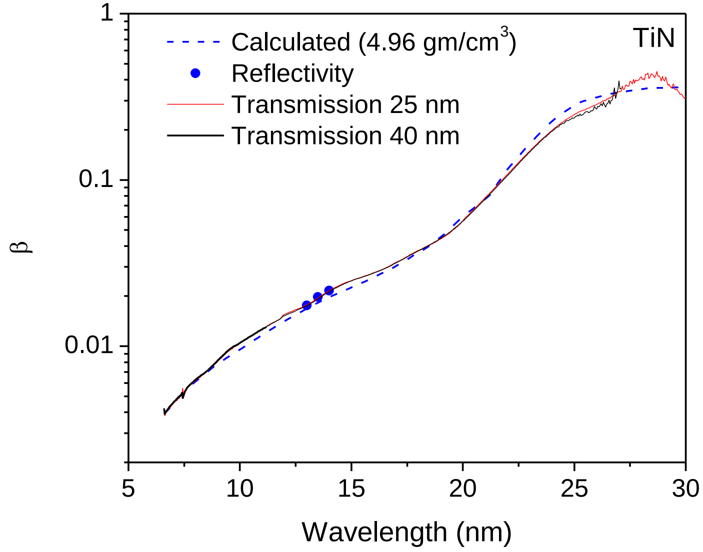
$$f = \sin\theta / \lambda$$

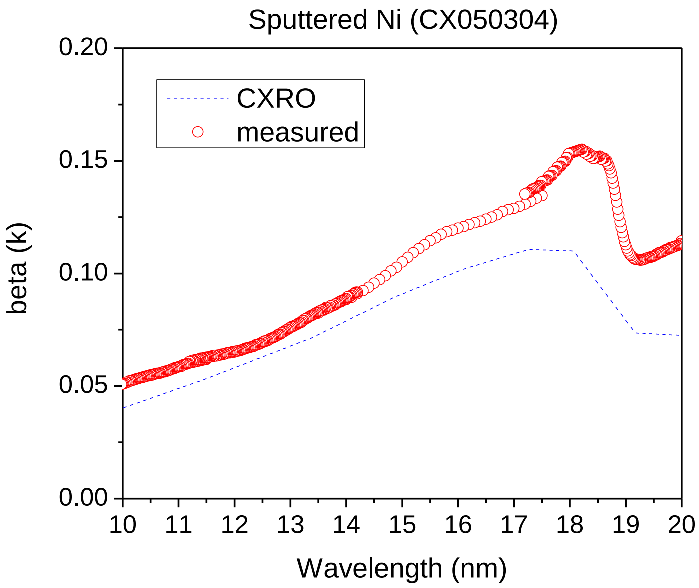


Measurements of EUV optical constants of mask relevant materials



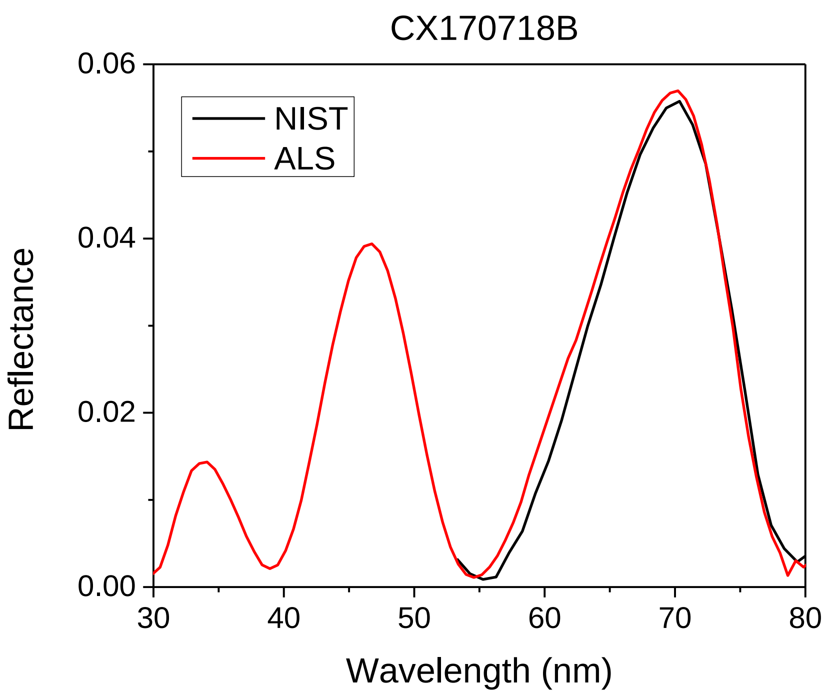


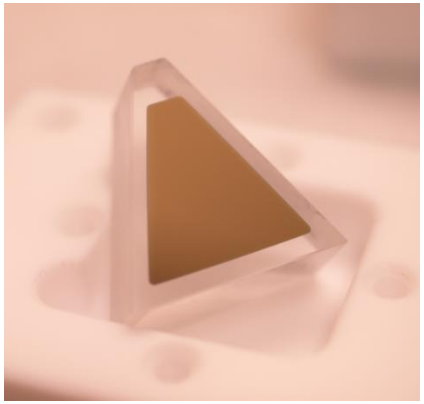


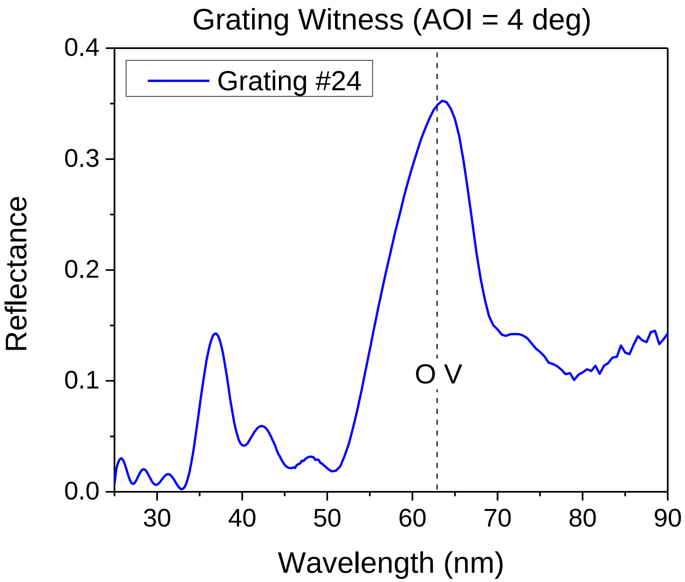


Measurement range extended from 50 to 90 nm

Al/Mg/SiC coating for solar imaging spectrograph



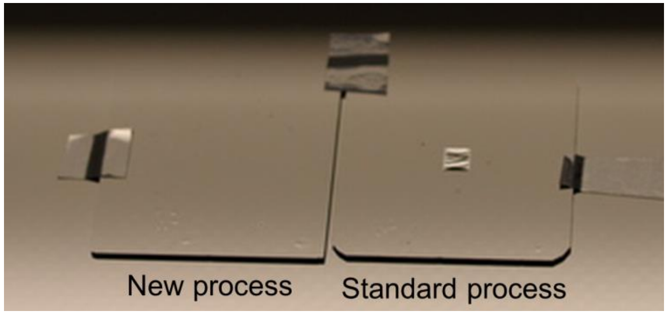




Comparison with NIST using the same multilayer test sample.

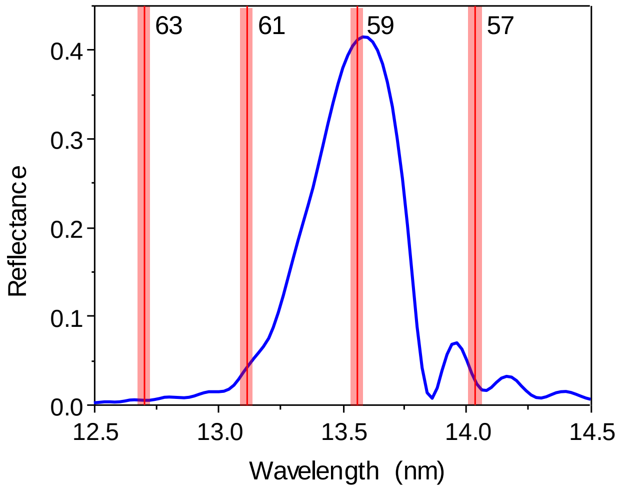
Development of narrow bandwidth mirrors

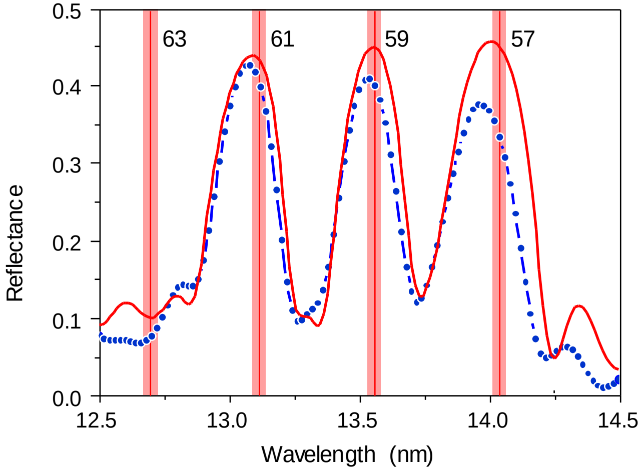
Farhad Salmassi preparing the multilayer deposition system.



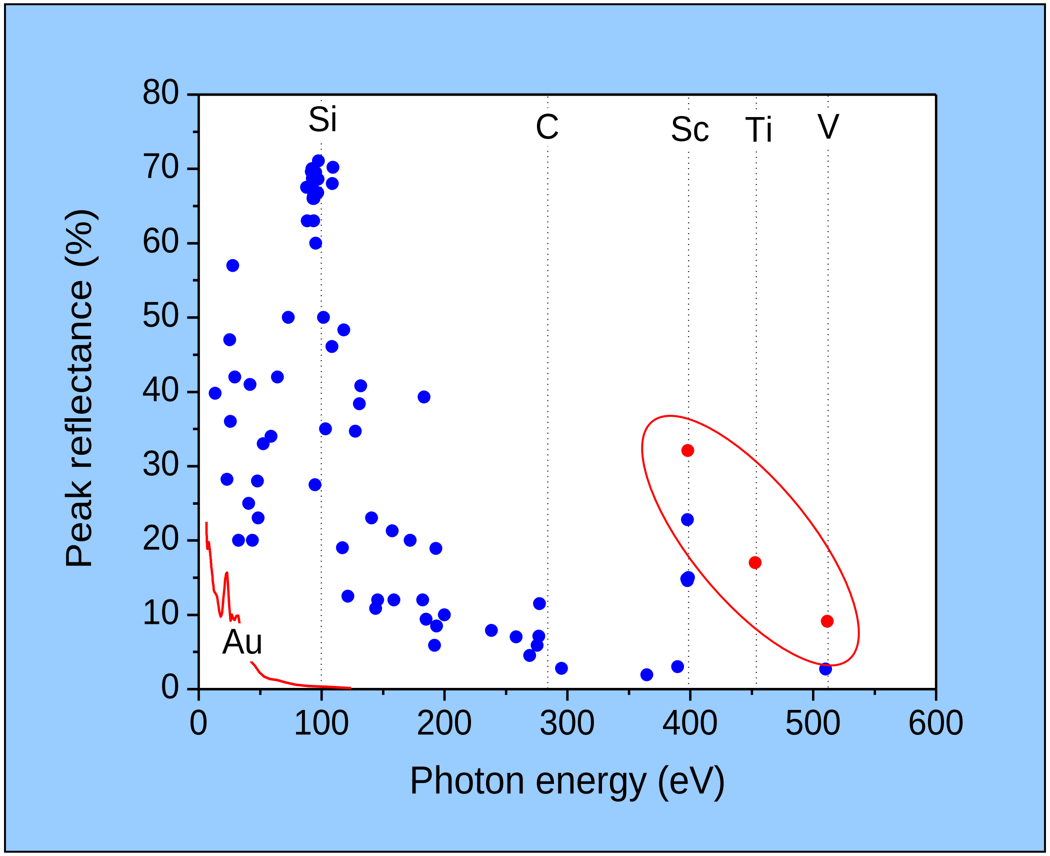
Beamsplitter mirrors

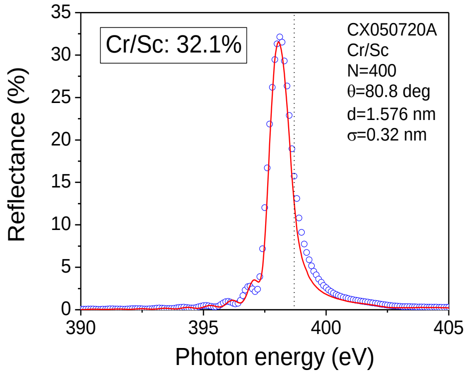
Harmonic selecting mirrors

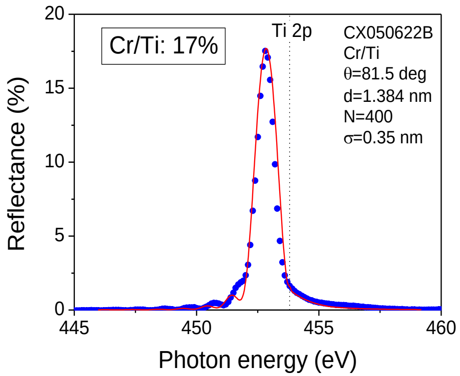


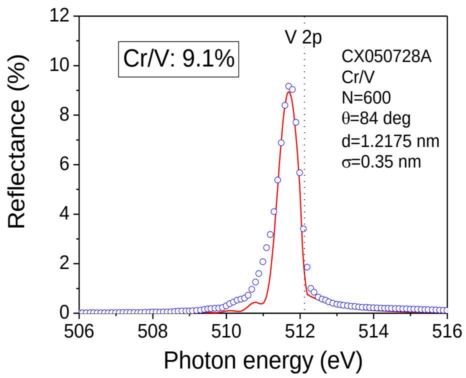


Multilayers for the water window (2.3 – 4.4 nm)





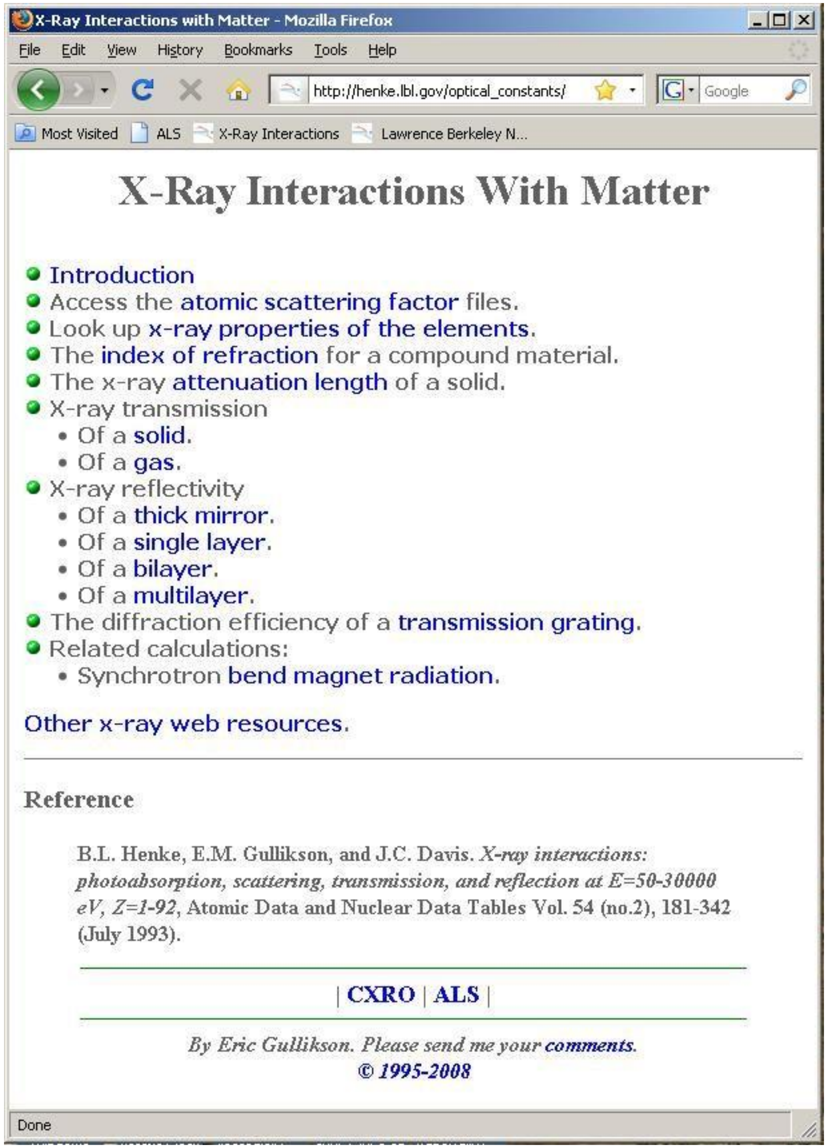




See Franck Delmottes presentation tomorrow.

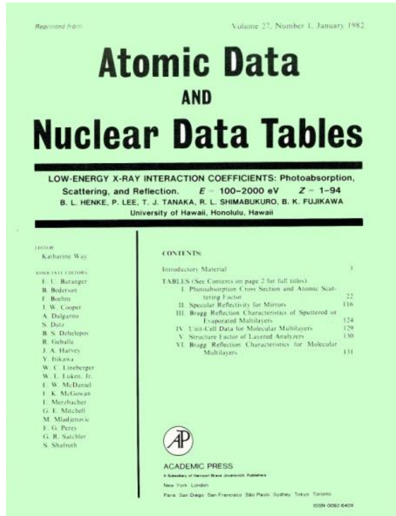
X-Ray Interactions with Matter website

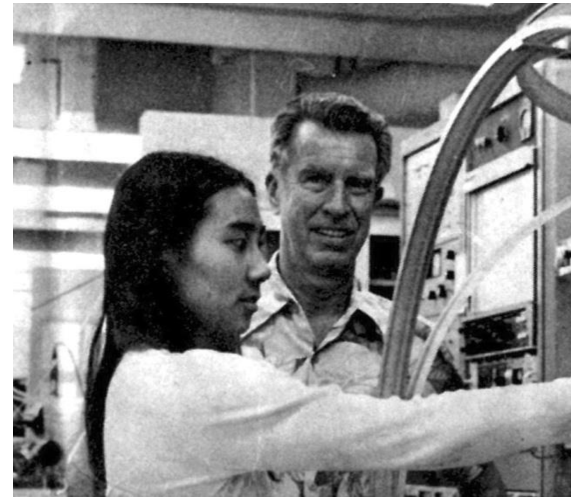
- December 1993 –
  Mosaic browser released.
- October 1994 –
  First Netscape browser.
- October 1995 –
  X-ray interactions with matter website introduced.
- Today –
  ~ 3 million hits per year.



Atomic Scattering Factors (the Henke Tables)

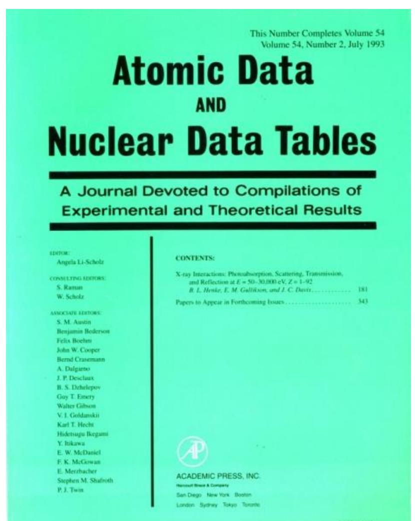
1982
U. Hawaii

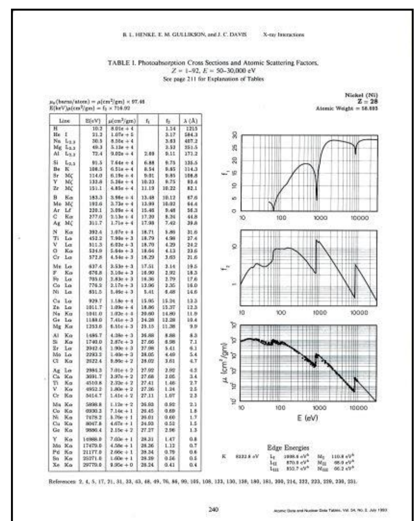




Burt Henke (1981)

1993
LBL/CXRO



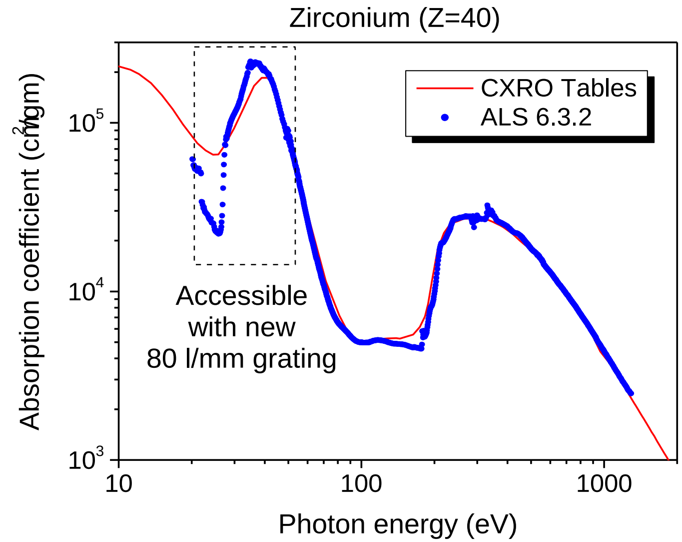


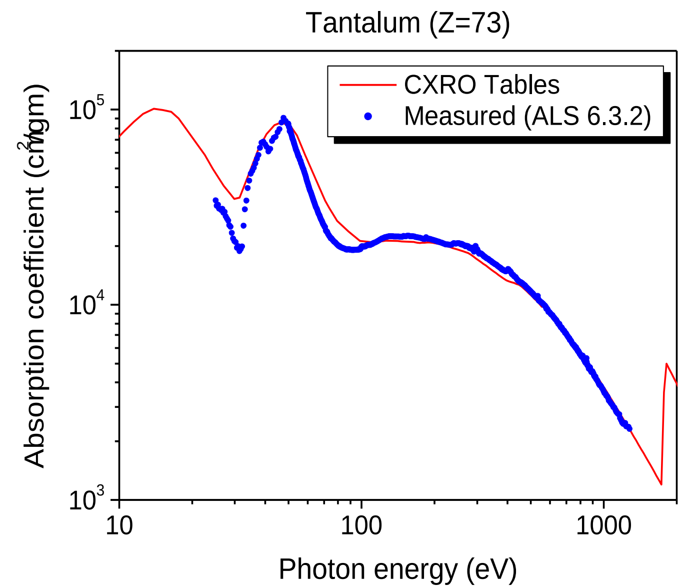
The atomic scattering factors are revised as new measurements are available

- Using BL 6.3.2, new measurements have been made for many materials.
- Lots of room for improved measurements particularly at long wavelengths.
- See Regina Soufli's presentation tomorrow.

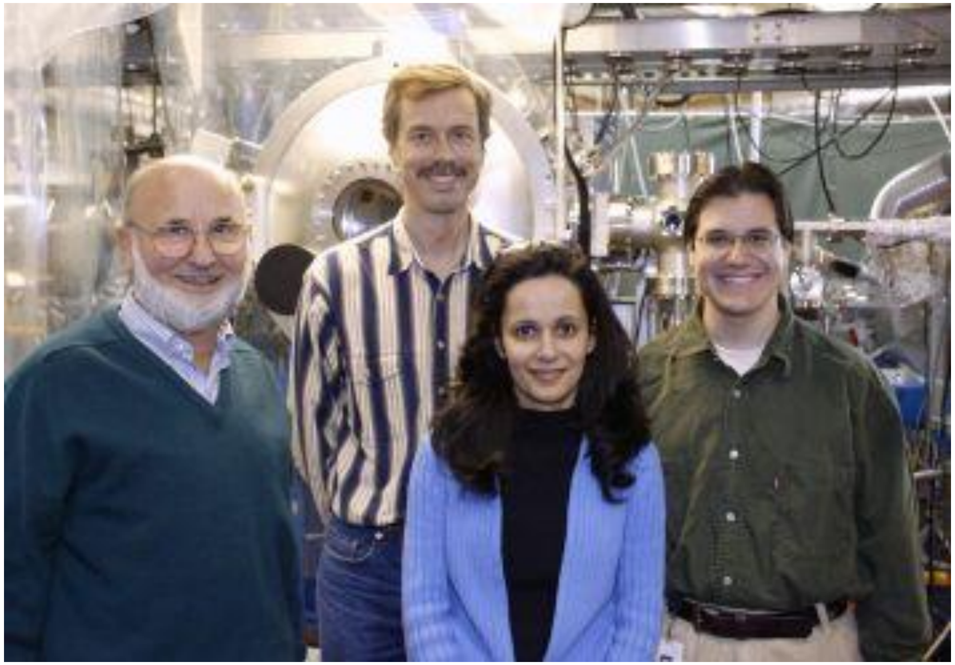
H																	He
Li	**Be**											**B**	C	N	O	F	Ne
Na	**Mg**											**Al**	**Si**	P	S	Cl	Ar
K	Ca	**Sc**	Ti	V	**Cr**	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	**Y**	**Zr**	**Nb**	**Mo**	Tc	**Ru**	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba		Hf	**Ta**	**W**	Re	Os	Ir	**Pt**	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra																
			La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
			Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Measured on BL632 (highlighted)





BL 6.3.2 has played an important role in the development of EUVL over the past 25 years



intel

euvtech

APPLIED MATERIALS

make possible

Rigaku

NTT AT

Lasertec

SAMSUNG

ASML

ZEISS CARL ZEISS SMT

CYMER

NIST

FOM

TNO

imec

IOF

Institut Angewandte Optik und Feinmechanik

LUXEL

PTB

IRD