# Metalized Polyimide Filters for X-Ray Astronomy and other Applications

Forbes R. Powell”, Ritva A.M. Keski-Kuha[b], Martin V. Zombeck[c], Richard E. Goddard”,
George Chartas[d], Leisa K. Townsley[d], Eberhard Mobius”, John M. Davis’, Glenn M. Mason[g]

[a]Luxel Corporation, Friday Harbor, WA 98250
[b]NASA Goddard Space Flight Center, Greenbelt, MD 20771
“Harvard/Smithsonian Center for Astrophysics, Cambridge, MA 02 13 8
[d]The Pennsylvania State University, University Park, PA 16802
“University of New Hampshire, Durham, NH 03824
‘NASA Marshall Space Flight Center, Huntsville, AL 35812
[g]University of Maryland, College Park, MD 20742

## ABSTRACT

Filters fabricated from metalized polyimide have been specified for a number of x-ray astronomy missions, including the Advanced X-ray Astrophysics Facility (AXAF), the X-Ray Spectrometer (XRS) on Astro-E, the Advanced Composition Explorer (ACE), and the Geostationary Operational Environmental Satellite (GOES). Polyimide offers greater strength, improved temperature stability, and effectiveness in blocking unwanted ultraviolet radiation compared to polymeric films previously employed. This paper reviews the various x-ray astronomy missions and the particular challenges that were met with polyimide filters. The paper also reviews the development of free standing thin foils of polyimide with mechanical properties optimized for x-ray astronomy and other applications, such as synchrotron research.

**Keywords:** x-ray filters, x-ray windows, polyimide, submicron polyimide, EUV filters, soft x-ray filters

## 1. INTRODUCTION

Filters comprised of submicron thickness metal-polymer foils have been successfully flown on soft x-ray astronomy missions, including ROSAT, EUVE and Yohkoh. The metals block the visible light and shape the bandpass in the soft x-ray region of the spectrum, while the polymer serves as a structural support for the ultrathin metal foil and also shapes the transmission of the filter in the region of interest. Carbon-containing polymeric films are especially useful for blocking unwanted EUV radiation longer than 400Å wavelength. In the 1980’s, polycarbonate (Lexan) was the polymer of choice because it proved much stronger than materials previously used, such as polypropylene and Parylene. In the 1990’s, polyimide is becoming the material of choice because it is stronger yet. Table 1 compares the strength of common polymers prepared as bulk samples. The table suggests that polyimide offers much greater strength, and therefore filters can be thinner, thus improving their transmission characteristics. Polyimide is also desirable for solar astronomy because it is stable across a wider temperature range than the other common filter materials.

| | Tensile Strength ($kg/cm^2$) | Flexural Strength ($kg/cm^2$) |
|---|---|---|
| polypropylene | 343 | 490 |
| polycarbonate | 630 | 945 |
| polyimide | 1190 | 1100 |

Table 1. Bulk Strength Properties of Polypropylene, Polycarbonate, and Polyimide’

Polyimide comes in many different formulations and its thin film properties depend not only on which formulation is used, but also on how it is cured or imidized. In order to meet the requirements of x-ray astronomy, including being able to withstand launch and space environments, and in some cases, pressure differentials, there needs to be a compromise between strength and ductility. For example, polyimide imidized at too high a temperature may increase in strength, but the ductility may be reduced such that it will not withstand shock and vibration as well as foils cured using another temperature profile. Because of this, selecting a polyimide formulation and optimizing the cure cycles to produce the desired material properties for soft x-ray filters has required considerable development effort. In Luxel's work, burst pressure has been used as an indication of relative strength, and a comparison of the optimized polyimide and Lexan is shown on Figure 1. In this case, the inside diameter of the test aperture was 7 mm. Figure 2 shows the burst pressure for polyimide as a function of aperture size for various film thicknesses. From this data it was possible to derive equations to predict burst pressure as a function of aperture size and film thickness; the predicted values based on these calculations are shown as solid lines on the figure. This serves as a useful design tool for some applications.

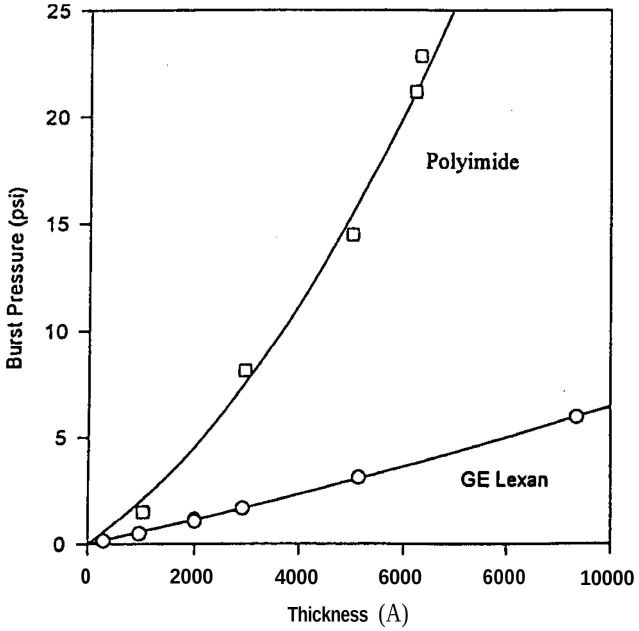

Figure 1. Burst pressure vs. Thickness for Lexan and polyimide

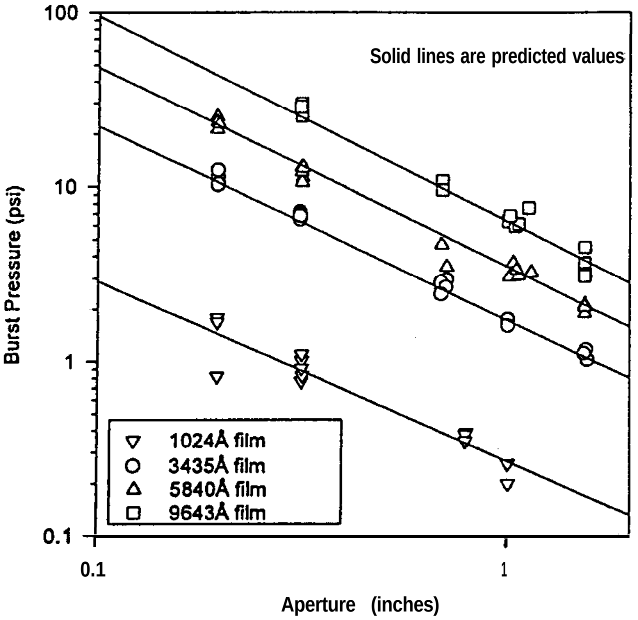

Figure 2. Burst pressure vs. Aperture size for various thicknesses of polyimide

In addition to improved mechanical characteristics, polyimide offers optical characteristics similar to Lexan with one surprising difference (discussed in a later section). The x-ray transmission of polyimide and Lexan is shown on Figures 3 and 4. The thicknesses have been adjusted to account for differences in density of the two materials. The performance predictions are based on Henke scattering coefficients'. As can be seen, the transmission of Lexan and polyimide are essentially identical in this portion of the spectrum. Numerous tests have shown that the Henke scattering coefficients are quite accurate for predicting performance out to a wavelength of about 1200Å. For example, Figures 5 and 6 show the transmission of 10008, of polyimide vs. photon energy and wavelength. Henke predictions are shown along with empirical data from two independent tests, and the correlation is excellent.

Over the last few years, free standing submicron polyimide films have been well characterized both optically and mechanically and have been shown to be improved replacements for Lexan in soft x-ray applications. The particular challenges of space-borne telescopes: acoustic and vibrational loads of launch and attitude control in space; the temperature extremes at telescope entrances in space; ability to model expected x-ray performance in order to optimize mission goals; as well as other program-specific problems, can be met with polyimide supported filters. Indeed, in the past several years a number of major spacecraft programs have chosen to utilize polyimide filters for optical blocking filters for x-ray astronomy and as windows for proportional counters and particle counters. Many of these missions began their test programs specifying Lexan supported filters but made the change to polyimide as the development of that material progressed. Brief descriptions of the various projects and their use of polyimide follow.

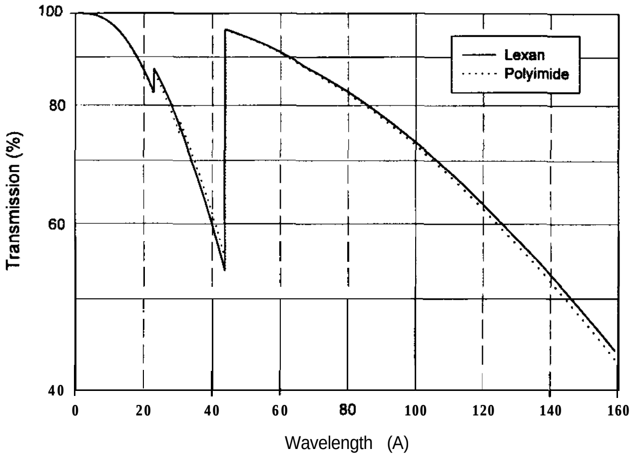

Figure 3. Transmission of 11 00Å polyimide and 1300Å Lexan

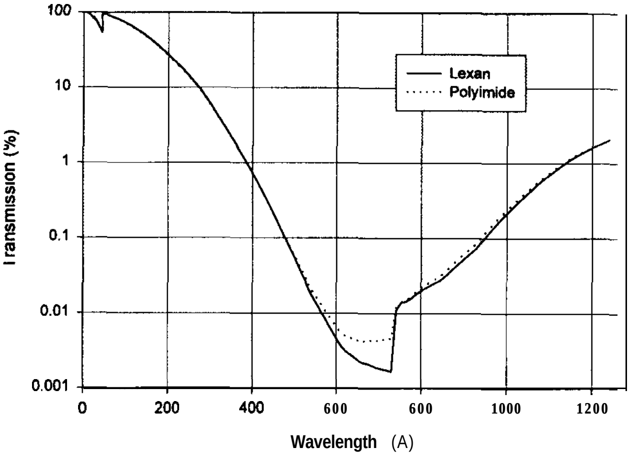

Figure 4. Transmission of 1100Å polyimide and 1300Å Lexan

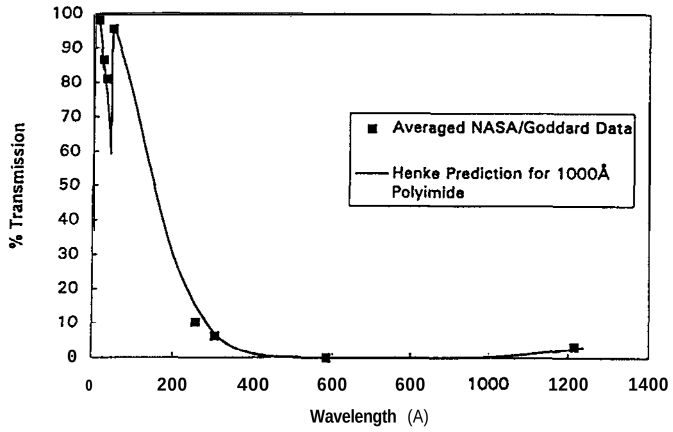

Figure 5. Percent transmission vs. wavelength for 1000Å polyimide

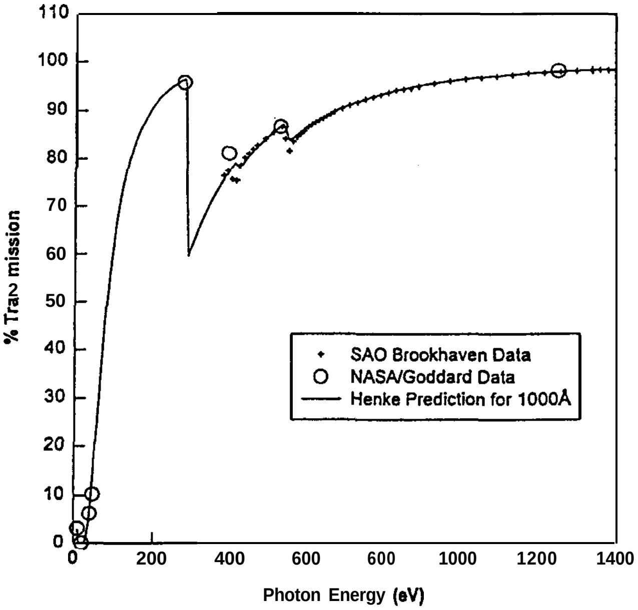

Figure 6. Percent transmission vs. photon energy for 10008, polyimide

## 2. The Advanced X-ray Astrophysics Facility (AXAF)

AXAF has two focal plane instruments: the High Resolution Camera, (HRC) built by the Harvard/Smithsonian Center for Astrophysics (CFA), and the AXAF Charge-Coupled Device (CCD) Imaging Spectrometer (ACIS) built by MIT/Penn State[3,4]. Both use freestanding aluminized polyimide for their light blocking filters. The HRC uses microchannel plate (MCP) detectors and thus the required filters are larger, being 4 x 4 in. for the imager, and for the spectrometer the filter is 1 x 12 in., and it is comprised of three patterned 4 inch long sections. The ACIS filters are 2 x 2 in. for the imager and 1 x 6 in. for the spectrometer. AXAF also has a ground calibration system which utilizes Flow Proportional Counters (FPCs).

Many detectors used for the high resolution imaging of astronomical x-ray sources are also sensitive to UV and visible light. CCD-based and MCP-based detectors are particular examples, the former having high visible light sensitivity, but little sensitivity to UV, the latter having significant UV sensitivity and very low, but non-negligible, visible light sensitivity. The design problem faced by developers of these detectors is to construct a filter of sufficient mechanical strength to survive the severe acoustical and vibrational loads of a rocket launch, block UV and visible light, but still possess high transmission of soft x-ray (0.1 to 10 keV) radiation.

**HRC Filters**- Partly to obtain the proper amount of ultraviolet and visible light rejection, and partly because of its size, the filter for the imager is composed of 5200Å of polyimide vacuum coated with 800Å of aluminum on one side. The spectrometer center section is 2500Å of polyimide patterned with either 300 or 1000Å of aluminum, and the outer sections are 2000Å of polyimide patterned with either 300 or 2000Å of aluminum. Transmission measurements of these filters have been reported by Meehan et al[5]. More recently, transmission measurements were taken on witness filters made from the same exact material used in the flight filters. The results of the measurements for the flight imager filter are shown on Figure 7. The fit between the model, which is based on Henke scattering coefficients, and the actual transmission measurements is excellent.

Until recently, aluminized Lexan (polycarbonate) films were the blocking filters of choice for spaceborne MCP-based x-ray detector&‘. However, these detectors have suffered from a significant sensitivity to the non-x-ray radiation of hot stars that has compromised the investigation of these objects in the x-ray band. This sensitivity had been attributed to a “leak” in the Lexan in the Far-UV (FUV) region, peaking at around 1500Å. However, recent investigations[8,9] have demonstrated that aluminized Lexan films act like Fabry-Perot filters in the near-UV and visible, especially when aluminized on both sides, and have higher than previously thought near-UV and visible light transmissions. This results from the high transmission above 2000Å of the Lexan and the constructive interference effects in the multilayer filter. Near-UV photons are a significant fraction of the photons detected from hot stars by MCP detectors employing these filters”. Given this circumstance, the developers of the HRC[11], after having first procured Lexan filters for the detector, investigated other materials to be used for the construction of blocking filters.

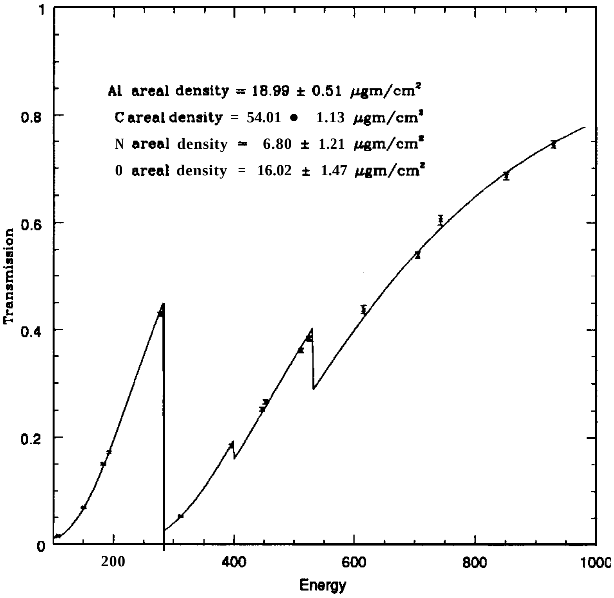

Figure 7. HRC Imager flight filter transmission

Extreme Ultraviolet (EUV) and UV transmission measurements carried out at the Space Sciences Laboratory, UC Berkeley, CA and theoretical modeling calculations indicated that polyimide coated with aluminum on one side would reject UV and visible light at the required level, and yet have sufficient transmission in the soft x-ray band to meet mission requirements. The use of polyimide combined with coating only one side with aluminum reduces the UV and constructive interference considerably. The transmission of the imager filter in the visible band is 4 x $10^{-5}$, and the transmission decreases sharply below 3500Å. At 2537Å in the UV band, the transmission is 6 x $10^{-12}$, and at 1470Å in the FUV it is 5 x $10^{-11}$. This filter meets the mission requirements for rejection of visible, UV, and EUV, will survive launch with sufficient margin, and its x-ray transmission is nearly identical to the original Lexan blocking filter at all x-ray wavelengths of interest.

**ACIS Filters**- The CCD detectors on ACIS require primarily visible light blocking filters. With the filter material thicknesses chosen, both visible and UV rejection are sufficient to meet mission requirements. The imager filter is 310Å aluminum / 2000Å polyimide / 1350Å aluminum, and the spectrometer filter is 300Å aluminum / 2000Å polyimide / 1000Å aluminum.

The original specifications called for aluminized Lexan filters, but the Lexan test filters proved to be marginal under acoustic load testing. Partial failures occurred with some cracking of the aluminum coating along the edges of the filter as the Lexan stretched under load. The filters did not fail completely, but the resulting light leaks were deemed marginal for the mission. The program changed to polyimide and solved this problem. The polyimide filters passed acoustic testing, and the transmission performance in the x-ray region meets mission requirements.

The ACIS instrument team was particularly interested in the uniformity of the filters and detailed mapping of the filters was performed using the synchrotron radiation facility at the University of Wisconsin. Maps were made at three different energies, 273, 522, and 775 eV. Samples of this data from the chosen flight Imager filter are shown on Figure 8. The image is enlarged to nearly 3 times full size. The image was taken at 775 eV, and the average transmission was 75.3%. The irregularities that appear as lines in the image and squares at the edges are artifacts caused by the raster scanning of the image when the data was taken, printed and scanned by the computer. In actuality, any real non-uniformities tend to be circular because of the nature of the metalizing process. The shading from white to black represents a variation in transmission of +/- 2%. As can be seen, the filters are more uniform than that, and further testing has shown the actual flight filters are uniform to better than +/- 1%.

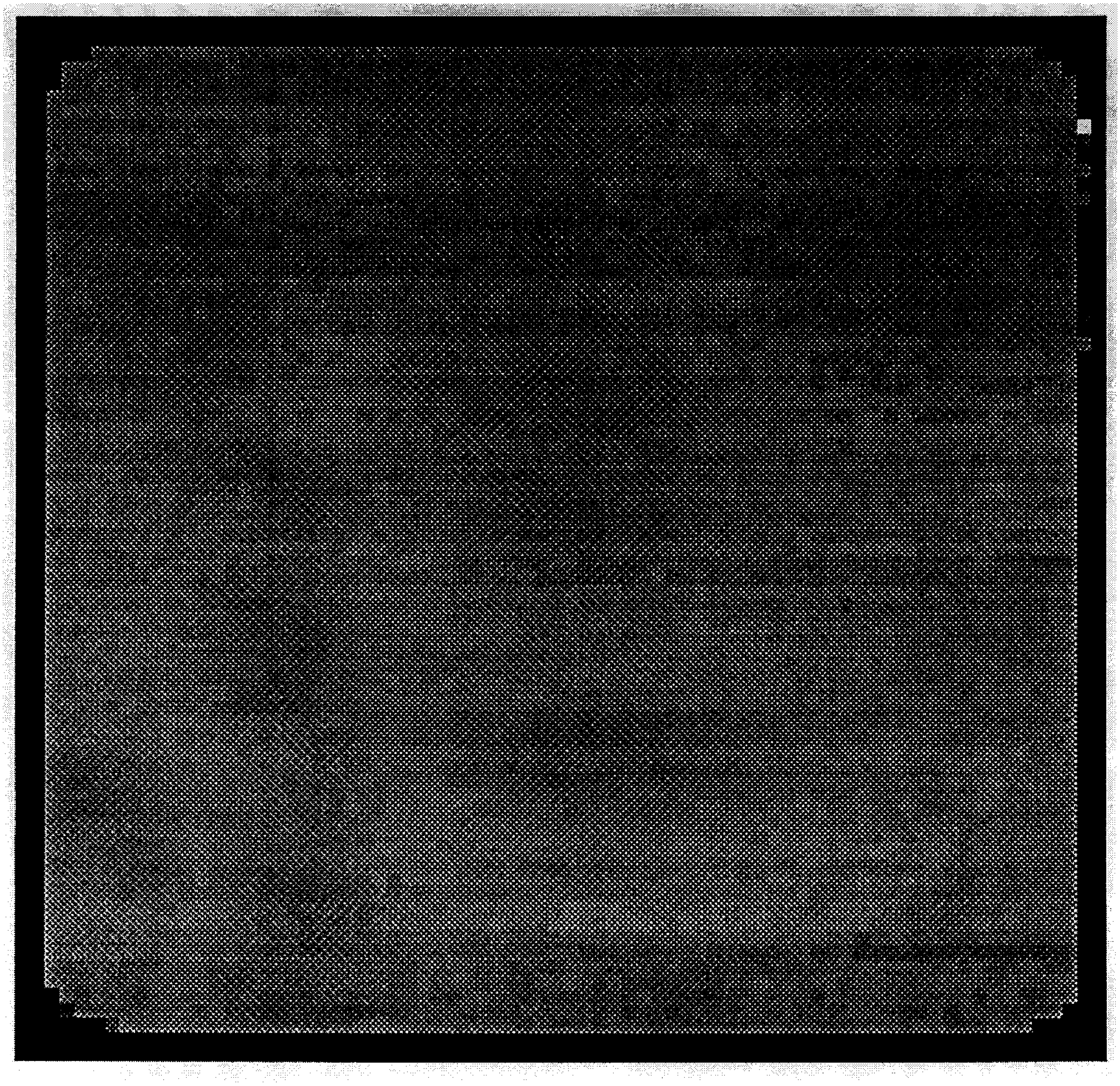

Figure 8. ACIS Imager flight filter transmission map

Detailed measurements of the ACIS engineering model filter materials were performed at Brookhaven and were previously reported.[12] The measurements were made with a very tine resolution in the energy range from 260 eV to 3.0 keV. Again, there is very good correlation between the test data and the Henke predictions.

**HXDS-** The AXAF High Resolution Mirror Assembly (HRMA) X-ray Detection System (HXDS) is being used for pre-flight calibration of the AXAF X-ray telescope. The requirement was to build a system capable of "one percent accuracy." This includes measuring the counting rate linearity of the flight detectors (HRC and ACIS) to within 0.5% and the effective area of the HRMA, gratings, and flight detectors to within 1%.

The Flow Proportional Counters are an important part of this system, and they contain 1.5" by 5" windows fabricated from 1 μm polyimide coated with 200Å of aluminum. The windows are supported by 2 mm pitch 100 μm diameter gold coated tungsten wire strung in a square pattern. The fill gas is 400 torr P10 (90% argon and 10% CH,); it was used over the entire energy range being measured.

To achieve the AXAF calibration goals, the HXDS must itself be calibrated, and its operation is monitored continuously. Local temperature and pressure are recorded every 2 minutes. As part of the design verification for the FPCs, leak rates were measured on 15 different windows and were found to average 1.2 std.-cc/hr. Leak rate vs. aging at 400 torr was measured and it was found that after about 40 cycles there was essentially no change in leak rates as the pressure was cycled up to 100 cycles.

## 3. Astro-E X-Ray Spectrometer (XRS)

The X-Ray Spectrometer (XRS) that will fly on Astro-E consists of a calorimeter array detector, which is cooled to 65 mK by an adiabatic demagnetization refrigerator (ADR), inside a liquid helium cryostat, which in turn is inside a solid neon dewar. Gold-coated foil mirrors mounted on an extendible optical bench direct radiation into the dewar aperture. A set of 5 blocking filters prevents UV, visible, and IR radiation from reaching the detector, while not overly attenuating X-ray (0.1 to 10 keV) radiation. The filters also serve an important thermal purpose: they shield the detector from thermal radiation and they minimize the heat load on the cryogen. The aperture diameters range from 6.5 mm to 30.5 mm and the operating temperature ranges from 65 mK to 270 K depending on the location of the filter. The present baseline filter compositions include 500Å to 1000Å of aluminum on 750Å to 1000Å of polyimide depending on the filter, with one of them supported by a 70 line per inch (lpi) nickel mesh. The filter frame material is aluminum for unsupported filters and nickel for mesh supported filters.

Because of the cryogenic operating environment, the filters must survive thermal cycling from room temperature to as low as 4 K without developing cracks and pinholes. To make filters survive cold cycling required development in three areas. First, the filter under test had to be mounted in a fashion that evenly loaded the filter all around the frame; otherwise cracks could develop wherever the pressure points were. Second, the rate of cooldown had to be controlled to about 10 K per minute. Finally, in the case of mesh mounted filters, some changes had to be made to the manufacturing process to allow the filter foils and meshes to be mounted more loosely on the frame. This looser mounting compensated for the thermal expansion differences between the metals. Whether similar mounting steps will be necessary with aluminized polyimide filters remains to be determined.

The XRS instrument is launched cold, so the filters must survive high vibrational loads while at cryogenic temperatures. Furthermore, any particles present inside the dewar (even microscopic ones) will be accelerated during launch and may potentially puncture the filters. This has already been seen in the test dewar; particles were responsible for most of the early vibration test failures. When there are no particles present, freestanding filters survive vibration testing of 30 seconds per axis both at room temperature and at 77 K. However, to flight qualify the XRS filters they must survive an additional 90 second vibration per axis, and so the testing will continue with strict contamination control measures.

The original XRS blocking filter baseline included a 20 lpi support mesh on four of the five filters. This mesh was chosen because of its higher transmittance compared to the standard 70 lpi mesh, 92% vs. 82%. Filters supported by this mesh could be made to survive cold cycling as discussed earlier, however, most of the 20 lpi nickel mesh-supported filters have not survived vibration testing at XRS loads even for 30 seconds per axis. Most filters with a mesh suffer minor damage at room temperature and minor to major damage at 77 K. Possible causes include resonance in mesh-supported filters, particulate contamination in the test dewar, and the thermal expansion mismatch (even though both the mesh and frame are nickel) combined with high loads.

Early on there was a concern with flying freestanding filters because of the belief that they would fail catastrophically, whereas filters with mesh would fail one square at a time in a fashion that would have less effect on the mission. However, the high transmission mesh tested revealed unexpected mechanical problems. On the other hand, filters fabricated from polyimide seem to be quite robust, and they tend to fail gracefully. Initially, they develop light leaks where the aluminum coating shows cracks similar to pin holes even as the polyimide remains intact. More severe damage results in pin holes through the polyimide as well as the aluminum, but even then, the damage tends to be confined to specific areas. Thus the XRS filter design has evolved from one in which 4 of the 5 filters were mesh mounted to one in which only one of the filters, the outer most Dewar Main Shell (DMS) filter is mesh mounted. Based on considerable testing, it is believed that the resulting system design is safe, and mission performance is improved substantially.

## 4. Advanced Composition Explorer (ACE)

**SEPICA-** The ACE carries a number of instruments including the Solar Energetic Particle Ionic Charge Analyzer (SEPICA). SEPICA will simultaneously determine the energy, nuclear charge and ionic charge of incoming energetic ions. This is accomplished in three sensor fans that each combine a multi-slit collimator with an electrostatic analyzer, a proportional counter and solid state detectors.

The counters are operated with a constant flow of isobutane such that an operational pressure of approximately 20 torr is maintained. They have two windows, front and rear, and in order to minimize the energy loss the windows must be as thin as possible. The chosen window material is 5000Å of polyimide with 250Å of aluminum to provide a conducting surface. The windows are supported by a stainless steel triangular mesh with 0.5 mm line thickness and 10 mm equilateral triangles. The windows have withstood a pressure of up to 60 torr without any signs of permanent stretching. Much higher overpressures could be applied without rupture. The danger of destruction due to micrometeorites is very low. Due to the presence of a slit collimator in front of the proportional counter, the probability of damage to the windows from micrometeroid impact during a 5 year mission lifetime is estimated to be <0.5%.

The window design allowed for a significant reduction in energy loss compared to sensors previously flown on the International Sun Earth Explorer (ISEE) spacecraft in 1978. For example, in SEPICA, the energy loss of $^4$He at 0.34 MeV/nucleon has been reduced to a total of 0.24 MeV through both polyimide windows. Together with the 20 mm of isobutane at 20 torr in the counter, a reduction of the total energy loss by 40% has been achieved, thus allowing for a significant reduction of the low energy threshold for the SEPICA instrument.

**ULEIS-** Another instrument on the ACE is the Ultra Low Energy Isotope Spectrometer (ULEIS). It is a time-of-flight mass spectrometer which utilizes windows of 2000Å of polyimide coated on one or both sides with 300Å of aluminum. The windows are biased to approximately -4000 volts. One aluminum surface is utilized as a secondary electron emitting surface. The electrons are guided to microchannel plates where they trigger Start and Stop signals for the time of flight measurement. The instrument does not see direct sunlight, but the aluminum coating thickness is sufficient to block out interplanetary backscattered solar Lyman-a.

The windows are supported by a combination of 4 lpi and 16 lpi mesh. However, because of the mechanical configuration of the instrument, it was difficult to find a polymer that would survive the launch vehicle vibration and acoustic environmental requirements. The additional strength of polyimide was sufficient to solve the problems.

## 5. Geostationary Operational Environmental Satellite (GOES)

Starting with GOES-M to be launched in 1999, and all future flights, the GOES weather satellite will have an on-board x-ray telescope for solar observation to report on solar flares and coronal mass ejections that may adversely affect telecommunications, GPS navigation, and power grid transmission. To function properly, GOES will have both entrance or pretilters and analysis filters.

Because of the solar heat load, the x-ray telescope has entrance filters composed of 3000Å of polyimide coated on the outside with 1000Å of titanium and 1250Å of aluminum on the inside. The titanium faces out because it has a lower absorptance emittance ratio which will allow the pretilters to operate at a lower temperature under solar illumination. The prefilters reduce the heat load while also blocking the ultraviolet and visible light. Titanium is unique in its ability to absorb the intense He11 spectral line at 304Å while also helping to attenuate the visible light, and it is utilized in these filters for this reason. Overall, the entrance filters reduce all radiation to acceptable levels relative to the x-ray flux; and at 304Å, the transmittance is $<1 \times 10^{-7}$ relative to the soft x-ray flux of interest which is between 6 and 60Å. Polyimide's ability to withstand temperatures in excess of 300" C is also a great advantage in this application.

Additional analysis filters are mounted in a filter wheel. Some are thick beryllium varying in thickness from 12.7 to 50.4 µm. Others are metal coated polyimide of three different thicknesses: 3000Å polyimide / 1000Å aluminum / 800Å titanium, 5000Å polyimide / 1500Å aluminum / 800Å titanium, and 8000Å polyimide / 3000Å aluminum / 800Å titanium.

Choosing filter pairs provides the ability to cover a temperature range from 1.8 to 8.0 MK. Overall dynamic range, which is the combination of the dynamic range of the CCD detector, the range of exposure times possible and the choice of the analysis filter is approximately $10^8$.

## 6. Joint European X-ray Telescope (JET-X)

JET-X utilizes filters that have an inside diameter of 54 mm. The filter material is mounted on a custom nickel mesh which becomes wider near the edge to improve the filters' ability to withstand shock and vibration. Originally the filter material was aluminized Lexan, but transmission measurements showed significant leakage in the optical band with interference effects resulting in narrow band transmission in the UV. In short, this program discovered the same problem of UV "leaks" that had been found on the early AXAF HRC filters. Thus, JET-X has chosen to procure polyimide filters for the flight instrument. The filter material is 1000Å of aluminum on 2000Å of polyimide.

Optical broad band measurements were carried out on engineering model filters from 1000 to 10,000Å and the light leakage level was less than $1 \times 10^{-5}$ and well within specification. X-ray measurements of the filters were carried out from 50 to 5 keV with 1 eV resolution for mapping of edges, and the filter transmission was very close to that predicted from the modeling. Spatial uniformity was better than +/- 0.5% at the lowest JET-X energy[13].

## 7. The Solar and Heliospheric Observatory (SOHO) EUV Imaging Telescope (EIT)

Luxel produced entrance filters as a backup for the SOHO EIT. Since SOHO is a solar observatory, it was felt that polyimide would have a greater ability to withstand the solar heat load. The filter material is 1500Å of aluminum on 700Å of polyimide. This is the thinnest polyimide produced to date for a spacecraft program.

## 8. Other applications

Submicron polyimide films are finding application in other fields besides x-ray astronomy. For example, the strength of polyimide has made it possible to fabricate laser targets which contain gas at a one atmosphere pressure differential even though the 2.75 mm polyimide windows are only 3500Å thick. These targets have been utilized to produce ignition-scale plasmas essential to the design of the National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory (LLNL)[14]. Also, submicron polyimide windows are increasingly being used in research efforts utilizing synchrotron radiation because of polyimide's ability to withstand high levels of radiation.

## 9. Conclusions

As has been shown, polyimide filters can solve many problems in meeting x-ray astronomy mission requirements. Polyimide exhibits 1) superior strength which allows for thin windows that can withstand some pressure differential, 2) strength and ductility that allows for even thinner filters and windows that will survive space mission environments while improving mission through put, 3) greater temperature stability, which is particularly important in solar missions, 4) the ability to reject unwanted UV radiation between 2000 and 4000Å and 5) a graceful failure mode that can survive impacts encountered in testing and in space without catastrophic loss. The superior strength and temperature resistance were expected, but the difference in UV transmission compared to Lexan was somewhat of a surprise.

Luxel has been working with polyimide since 1991 and continues to make improvements in the manufacturing processes for producing submicron films and the methods for adding metal coatings by vacuum deposition. It is expected that future missions and applications will benefit from further improvements in the material properties of the polyimide and the combination of polyimide and various metals. Specifically, it is expected that metalized polyimide may even replace mesh-supported metal foils in applications for the shorter wavelengths, and for detectors in which the filters are close to the focal plane, because of its ability to take extreme loads without failure.

## Acknowledgments

The development of the manufacturing processes for making submicron polyimide films suitable for x-ray astronomy and other applications was supported in large part by Phase I and II Small Business Innovation Research (SBIR) contracts from the NASA Goddard Space Flight Center.

## References

1. R.B. Seymour and C.E. Carraher, *Polymer Chemistry,* p. *451,* Marcel Dekker Inc., New York, N.Y. (1981).
2. Henke, E.M. Gullikson, and J.C. Davis, “X-ray interactions: photoabsorption, scattering, transmission, and reflection, E=50-30,000 eV, Z=l-92, *“Atomic Data and Nuclear Data Tables”,* 54(2), p. *18* 1 (1993)
3. M.C. Weisskopf and L.P. Van Speybroeck, “The Advanced X-Ray Astrophysics Facility (AXAF)“, *Optics & Photonics News,* pp. 17-22, April 1996
4. M.V. Zombeck,, “Advanced X-ray Astrophysics Facility (AXAF)“, to be published in the *Proc. of the International School of Space Science Course on “X-ray Astronomy”,* Aquila, Italy, 1994. CFA Preprint No. 4003, 1994.
5. G.R. Meehan, A.T. Kenter, R.P. Kraft, S.S. Murray, M.V. Zombeck, K. Kobayashi, J.H. Chappell, M. Barbera, and A. Collura, “Measurement of the transmission of the UV/Ion Shields for the AXAF High Resolution Camera”, *Proc. SPIE* Vol. 2808, pp. 210-217 (1996)
6. B. Taylor, R. Andresen, A. Peacock, and R. Zobl, “The European X-ray Observatory Exosat -Its Mission and Scientific Instruments” , *Space Sci. Rev., 30, pp.479 (1981)*
7. M.V. Zombeck, L.P. David, F.R. Harnden Jr., and K. Keams, “Orbital Performance of the High Resolution Imager (HRI) on ROSAT”, *Proc. SPIE* Vol. 25 18, pp.304 (1995)
8. M. Barbera, A. Collura, A. Dara, S. Serio, and M.V. Zombeck, “Calibration of the AXAF-HRC UV/Ion shields at the Osservatorio Astronomico di Palermo G.S. Vaiana: IV - UV rejection measurements”, *Proc. SPIE* Vol. 2808, pp.108-119 (1996)
9. M. Barbera, A. Collura, A. Dara, M. Leone, F.R. Powell, S. Serio, S. Varisco, and M.V. Zombeck, “Effects of Interference and Oxidation on the UV/Visible Rejection Properties of Filters for Soft X-ray Detectors”, Submitted to *Experimental Astronomy, (1997)*
10. M.V. Zombeck, M. Barbera, A. Collura, and S.S. Murray, “An Explanation of the ROSAT High Resolution Imager (HRI) UV Sensitivity”, Submitted to The Astrophysical Journal Letters, (1997)
11. A.T. Kenter, J.H. Chappell, G. Fraser, R.P. Kraft, G.R. Meehan, S.S. Murray, M.V. Zombeck, “The High Resolution Camera on AXAF”, *Proc. SPIE,* Vol. 2808, pp. 626-649 (1996)
12. G. Chartas, G. Garmire, J. Nousek, L.Townsley, F. Powell, R. Blake, and D. Graessle, “ACIS UV/Optical Blocking Filter Calibrations at the National Synchrotron Light Source”, *Proc. SPIE* Vol. 805, pp. 44-54 (1996)
13. *C.* M. Castelli, private communication
14. Lawrence Livermore National Laboratory, *Inertial Confinement Fusion Quarterly Report,* Vol. 6-l (October-December 1995