NASA CR-160039

FINAL REPORT ON FILTER DEVELOPMENT

FOR THE EXTREME ULTRAVIOLET EXPLORER

Contract NAS5-24189

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Prepared by:

Randy Kimble

Patrick Jelinsky

Approved by:

C. Stuart Bowyer
Professor of Astronomy

Space Sciences Laboratory
University of California, Berkeley

SUMMARY

We report below on the results of the filter development contract NAS5-24189 for the Extreme Ultraviolet Explorer (EUVE). The purposes of the study were to identify, develop, and evaluate thin film filters with EUV bandpasses unattainable with previously available filter materials.

In the early stages of the study, titanium and antimony were identified as the most promising materials for providing the scientifically important 350-500 Å bandpass heretofore unattainable with thin film filters. A subcontract was let to the Luxel Corporation, who succeeded, after overcoming a number of technical problems, in fabricating pure titanium foils and titanium-antimony sandwich foils of the required uniformity and durability. Transmission measurements and optimization studies performed at Berkeley indicate that the titanium-antimony combination provides an ideal bandpass for scientifically valuable, high-sensitivity observations with EUVE. Environmental testing of the mechanical strength, moisture sensitivity and aging characteristics of the newly developed filter materials demonstrate completely flightworthy performance. The titanium-antimony filter will be a valuable addition to the EUVE filter complement.

I. INTRODUCTION

Bandpass filters are essential to EUVE because of the sensitivity of the EUV detectors (microchannel plates) to far UV radiation (1000-3000 Å), a band in which the sky and most point sources are much brighter than in the EUV, and to charged particles. In addition, filter materials and thicknesses can be selected to minimize the background from the strong geocoronal and interplanetary EUV lines such as HeI 584 Å and HeII 304 Å, whose diffuse emissions would otherwise seriously impair the sensitivity of a photometric measurement. Furthermore, broadband EUV filters can perform the same scientific function as optical photometric filters, that of providing basic information about the temperature and chemical composition of a source, while maintaining high sensitivity.

EUV radiation does not pass through any thick crystal or stretched plastic sheets such as used in the far UV or soft X-ray respectively. The filter materials used in the EUV must be only a few thousand Å thick to be sufficiently transmitting for use on EUVE. Fortunately, vacuum deposition techniques have been developed over the years to allow the fabrication of large area, durable filters of metal and plastic as thin as 1000 Å or even less.

The baselined filter complement for EUVE was drawn from the commercially available and space-qualified materials used in various solar, atmospheric, and celestial experiments prior to the original EUVE proposal. That filter complement included:

1. Parylene. Parylene N is a plastic material which can be vacuum

deposited like a metal to form a filter as thin as 1000 Å. This provides a bandpass from 44-300 Å which is excellent in the study of sources in the transition region between the soft X-rays in the EUV. This is the EUV bandpass with the largest visibility through the intersteller medium. The turnon wavelength of the parylene - filtered telescope is determined by the design of the grazing incidence optics. The long wavelength cutoff is set by the thickness of the filter itself, selected for optimum sensitivity.

2. Aluminum. Aluminum has been the workhorse of EUV astronomy. It is sensitive from 180 to 600 Å, yet is opaque to the far ultaviolet. When used in combination with a thin layer of carbon to reduce the throughput of the bright 304 Å background line, it yields a 180-350 Å bandpass, making it the most important filter for purely EUV astronomy.

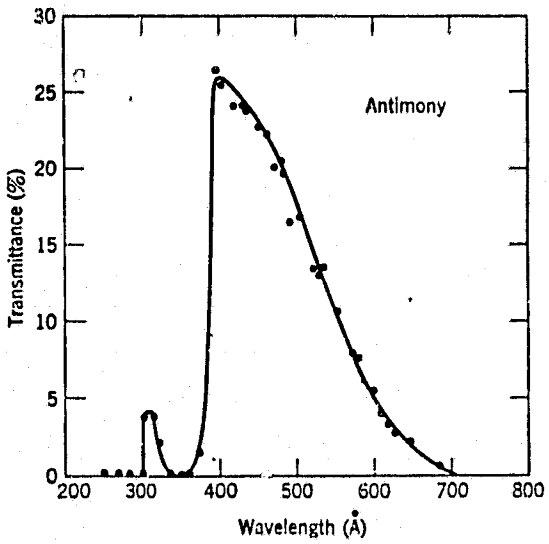
3. Tin. Tin has an excellent window from 500-750 Å. Its biggest drawback is the presence in the bandpass of the strong interplanetary 584 Å line.

4. Indium. Indium has a window reaching from 750 to greater than 1000 Å. If made sufficiently thick, its grasp can be restricted to lie below the 912 Å Lyman edge, making it a truly EUV filter. The strong absorption of the interstellar medium near the Lyman edge restricts observations through this filter to only the nearest stars.

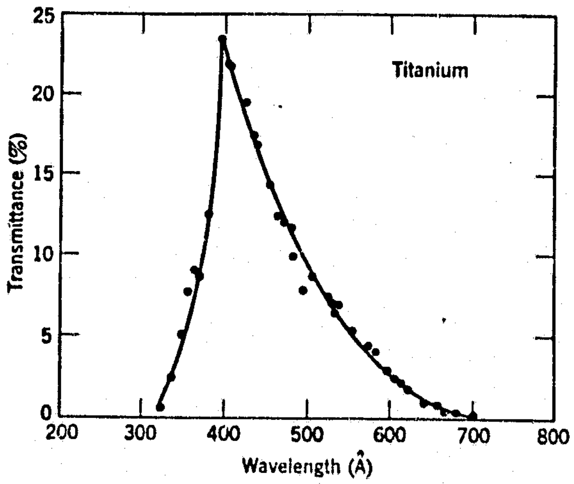
The most striking failing of the filter complement described above is the lack of a filter to cover the 350-500 Å band, between the bright 304 Å and 584 Å background lines. This central region of the EUV has great scientific potential. It lies at wavelengths sufficiently removed from the Lyman edge that visibility is still reasonably good through the ISM. However, this bandpass is the range in which the EUV flux from a number of sources such as hot white dwarfs will be turned over by interstellar absorption, so it can provide important information about the local ISM. In addition, the exclusion of the strong background lines from the bandpass allows great increases in sensitivity to be attained. For these reasons, the EUVE filter development study concentrated on materials with potentially useful bandpasses in the 350-500 Å range.

II. SELECTION AND FABRICATION OF NEW MATERIALS

The most promising materials for covering the 350-500 Å bandpass were identified through a search of the literature on the transmission properties of thin foils and through discussion with experts in the fabrication of such foils. The best compilation of transmission data is given in Samson's Techniques of Vacuum Ultraviolet Spectroscopy. The materials selected for fabrication after these investigations were antimony and titanium. The transmission properties of these materials as compiled by Samson are shown in Figure 1.



Transmittance of antimony 1000 ± 100 Å thick



Transmittance of titanium 525 ± 50 Å thick

The existence of transmission data such as this showing appropriate passbands does not guarantee the suitability of the material for the EUVE application for several reasons. First, the transmission characteristics are typically well known only in the peak transmission range of the material. The sensitivity of the EUVE detectors to a wide range of wavelengths makes it essential that there be no secondary window in addition to the basic astronomy window. Even residual transmission in the wings as low as 10^{-6} can be unsatisfactory because of the existence of the extremely strong hydrogen Lyman α 1216 Å diffuse background line. Hence a thorough investigation of the entire detector sensitivity range is essential for qualification of an EUVE filter.

Second, the transmission data for such materials are traditionally determined from extremely small foils and measured immediately after their fabrication. Hence it was never previously determined whether uniform, mechanically durable foils of sufficient size could be fabricated from these materials. Furthermore, no data existed on the longterm stability of the thin foils, which are in general susceptible to pinholing due to ambient moisture and to slow transmission decays with time from a variety of causes even in the absence of moisture (increasing oxidation of the surface, formation of intermetallic compounds in sandwich foils, etc.).

Hence, it was the purpose of this study to successfully fabricate large foils, verify the suitability of the overall transmission characteristics, and verify the mechanical and longterm transmission stability essential for space application.

Fabrication

The fabrication efforts were subcontracted to the Luxel Corporation, whose president, Gordon Steele, has performed pioneering research in the fabrication of thin film filters. We review here the fabrication efforts that led to the final result of the filter study, a titanium-antimony combination foil which is strong, stable, and well-suited to high sensitivity observations with EUVE.

There are three conventionally used techniques in the deposition of metal films: evaportation from a tungsten filament, evaporation from a heated crucible, and electron bombardment. The fabrication difficulties presented by antimony required experimentation with all three techniques before a successful approach was found.

The tungsten filament deposition technique relies on wetting of the tungsten filament with the metal to be deposited. The metal evaporates from the hottest part of the filament while new metal is drawn to the evaporation point by capillary action. The properties of antimony render it unsuitable for this technique. The evaporation temperature of antimony is sufficiently close to its melting point that as soon as the metal is heated enough to flow, it flash evaporates, stopping the wicking action and preventing smooth deposition. It is sometimes possible to overcome this type of problem by alloying the unsatisfactory material with small percentages of another metal. Such alloying agents must not only be chemically suitable, i.e. must not form intermetallic compounds, but must not disturb the valence electron density so as to preserve the bandpass transmission. It was hoped that germanium would permit smooth deposition when alloyed with antimony, but such attempts were unsuccessful.

With the heated crucible technique, it is possible to produce a more constant deposition rate, and antimony foils can be produced by this process. However, pure antimony foils reveal two major problems. They are found to be extremely moisture sensitive, developing pinholes if there is any residual moisture in the organic solvent used to release the deposited foil from the ceramic substrate. Second, even foils successfully released from the substrate are found to be extremely non-uniform. The antimony atoms move along the surface of the ceramic substrate until nucleation centers form, leading to unacceptable irregularities in thickness and transmission.

Deposition by electron beam bombardment permits all of the above problems to be overcome. This technique is essential for the deposition of titanium, whose melting point is too high for the filament or crucible techniques. The electron beam technique permits deposition of uniform titanium foils, which are interesting in their own right for EUV astronomy applications, and which provide the solution to the antimony fabrication problems. Thin titanium films perform as an active nucleating surface and a protective overcoat layer when deposited before and after an antimony layer in rapid sequence in a single vacuum. Whereas 1500 Å thick pure antimony films exhibit a mottled transmission in the red, evidencing the non-uniformity, the same thickness deposited between two 100 Å thick films of titanium is uniformly opaque and demonstrates a low susceptibility to pinhole formation during processing.

These experimental considerations led to the eventual selection of films fabricated by Luxel and delivered to the Space Sciences Laboratory for testing and qualification: pure titanium filters of 500 Å and 1000 Å thickness, and titanium-antimony sandwich filters of 1100 Å antimony between 100 Å layers of titanium.

III. TRANSMISSION MEASUREMENTS

Transmission measurements of the Luxel filters were carried out in the EUV calibration facility here at the Space Sciences Laboratory. The data which must be determined are the absorption coefficients of pure antimony and titanium and the transmission characteristics of any oxide layer that forms on the foils. This data is necessary for determination of the optimum filter design for EUVE, given the optics design, detector performance, and available telemetry. The optimization procedure, which determines the filter thickness with highest sensitivity and greatest scientific return, is described in a later section. No pure antimony foils were made (for the fabrication reasons described in the last section). Nevertheless, the necessary separation of absorption coefficients can be made by measuring the transmissions of titanium films of different thicknesses and of the sandwich film, which provides enough independent data to solve for the three unknowns.

The transmission measurements were performed using a grazing incidence monochromator to select line radiation from a hollow cathode discharge source. The detector used was a calibrated one inch diameter channel electron multiplier (channeltron). The dynamic range of the detector was extended using calibrated meshes to attenuate the direct monochromator beam. All measured count rates were corrected for electronics deadtime, and off-line background measurements permitted the subtraction of spurious counts due to scattering in the monochromator.

Transmissions were measured at wavelengths from 130 Å to 2300 Å. For some wavelengths far into the wings of the filter bandpass, only upper limits could be found to the transmission. These upper limits are sufficiently low that the sensitivity of EUVE using the optimum thickness filter of these materials is independent of the actual value of the transmission for these far-off bandpass wavelengths.

The transmission curves for the two titanium thicknesses and titanium-antimony sandwich are shown in Figures 2-4. This is the raw data except for removal of the 80% transmission factor of the nickel support mesh on which the films are mounted. These transmission curves show several interesting features. The titanium transmissions confirm the existence of a second transmission window from 250 Å to X-ray wavelengths not shown by Samson, but reported by Sonntag et al. (Solid State Communications 7, 597, 1969). The overall behavior appears to be that of a broad transmission window beginning at ∿ 700 Å and containing a strong absorption line at ∿ 300 Å.

The predominantly antimony filter also showed the same overall transmission behavior as in previous studies. However, when actual antimony transmission was separated out, it was found that the pure antimony transmission was a factor of three higher than previously published results (Rustgi, JOSA 55, 630, 1965). We obtained a maximum of 85% transmission for an 1100 Å thick antimony foil, whereas Rustgi reported 25% maximum transmission for the same thickness.

Examination of the Rustgi reference revealed that the antimony foil

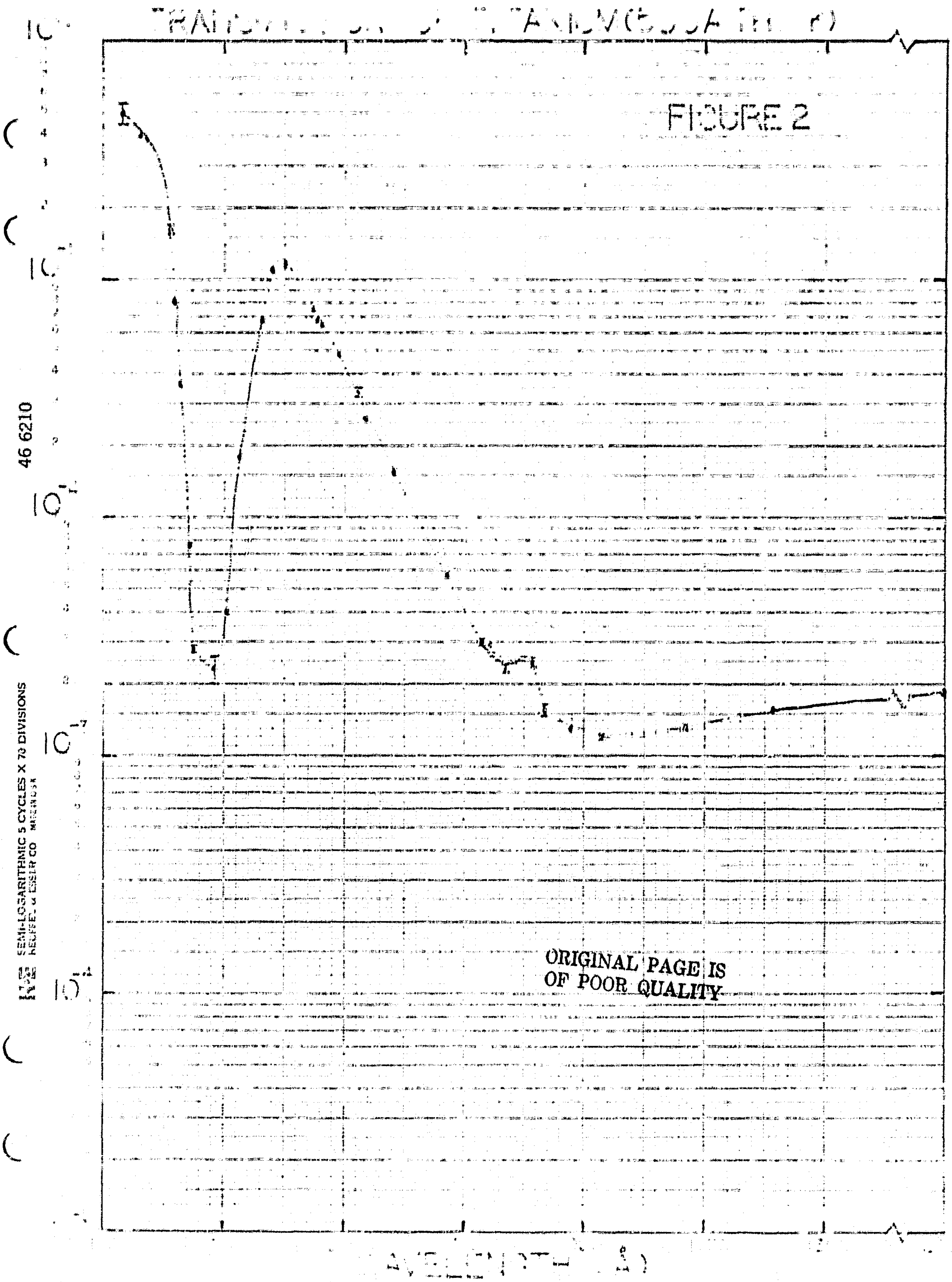


FIGURE 2

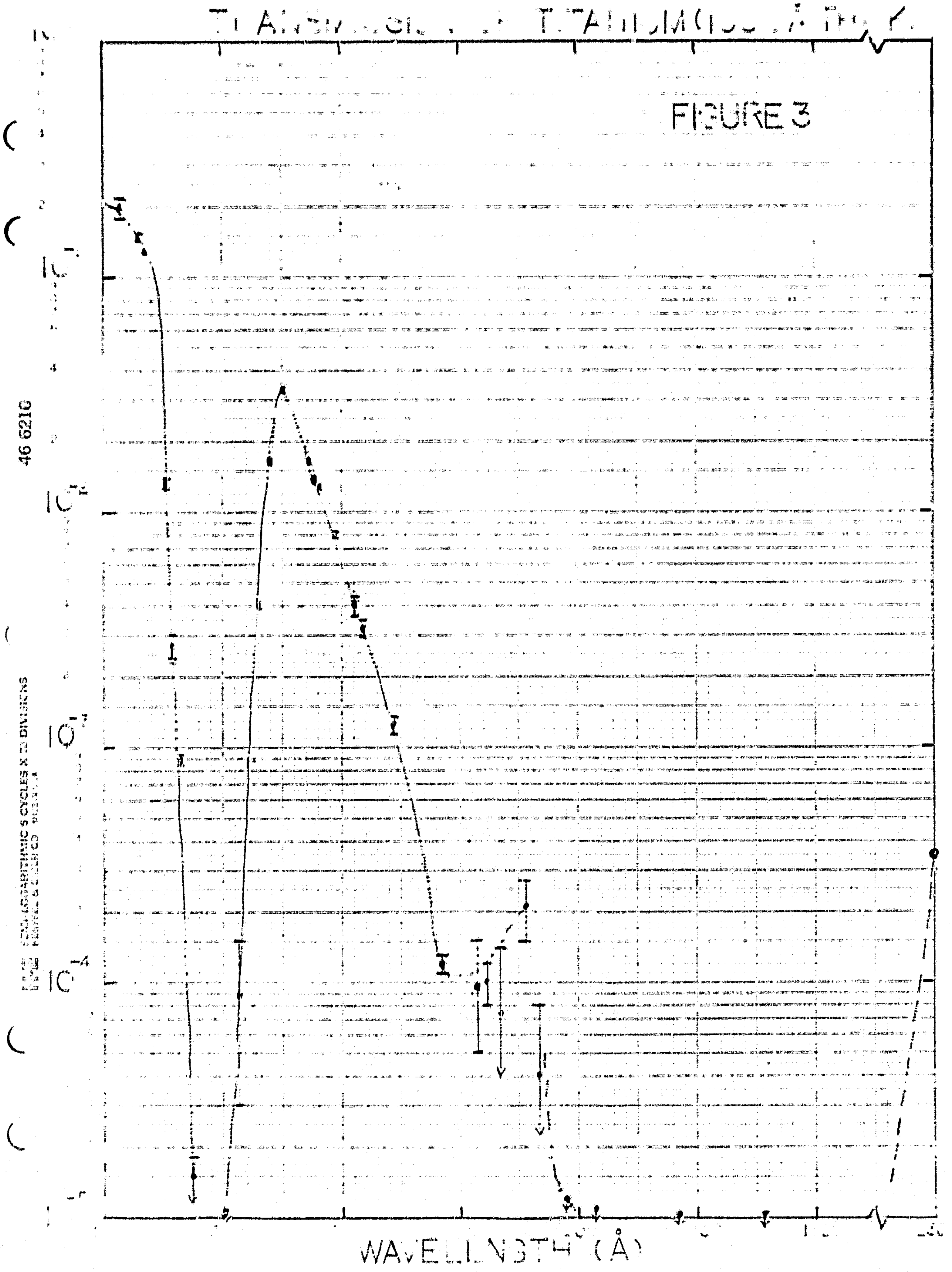
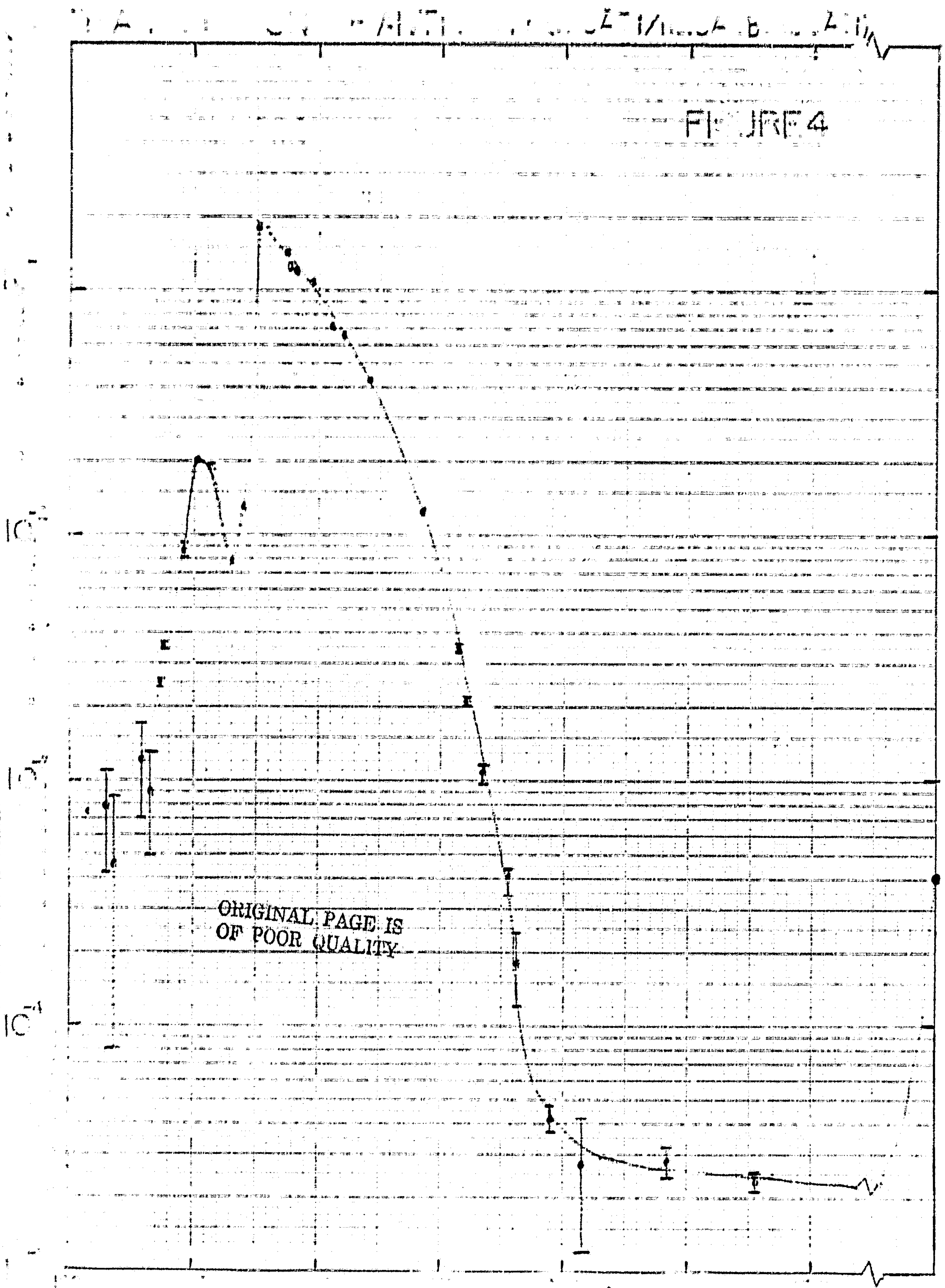


FIGURE 3
WAVELENGTH (Å)
46 6210



WAVELENGTH (Å)

used for that measurement had been deposited on aluminum, and then the composite foil was floated off the substrate in water. This cannot have given a valid measurement, since the intermetallic compound aluminum antimonide would have formed at the interface and the outer layer of the antimony would have been heavily oxidized by the direct exposure to water. The foils produced by Luxel however, are Ti/Sb/Ti sandwiches in which all three layers are vacuum deposited at the same time, removed from the substrate in an organic solvent, and kept in a dry atmosphere thereafter. Thus there is no intermetallic compound formed, nor any antimony oxide. Our measurements should therefore give the true absorption coefficient for antimony.

The separation of the absorption coefficients is performed using the following relationships:

$$T(500) = \exp[(\mu_{Ti} - \mu_{TiO})X_{TiO}] \exp[-\mu_{Ti}(.05)]$$

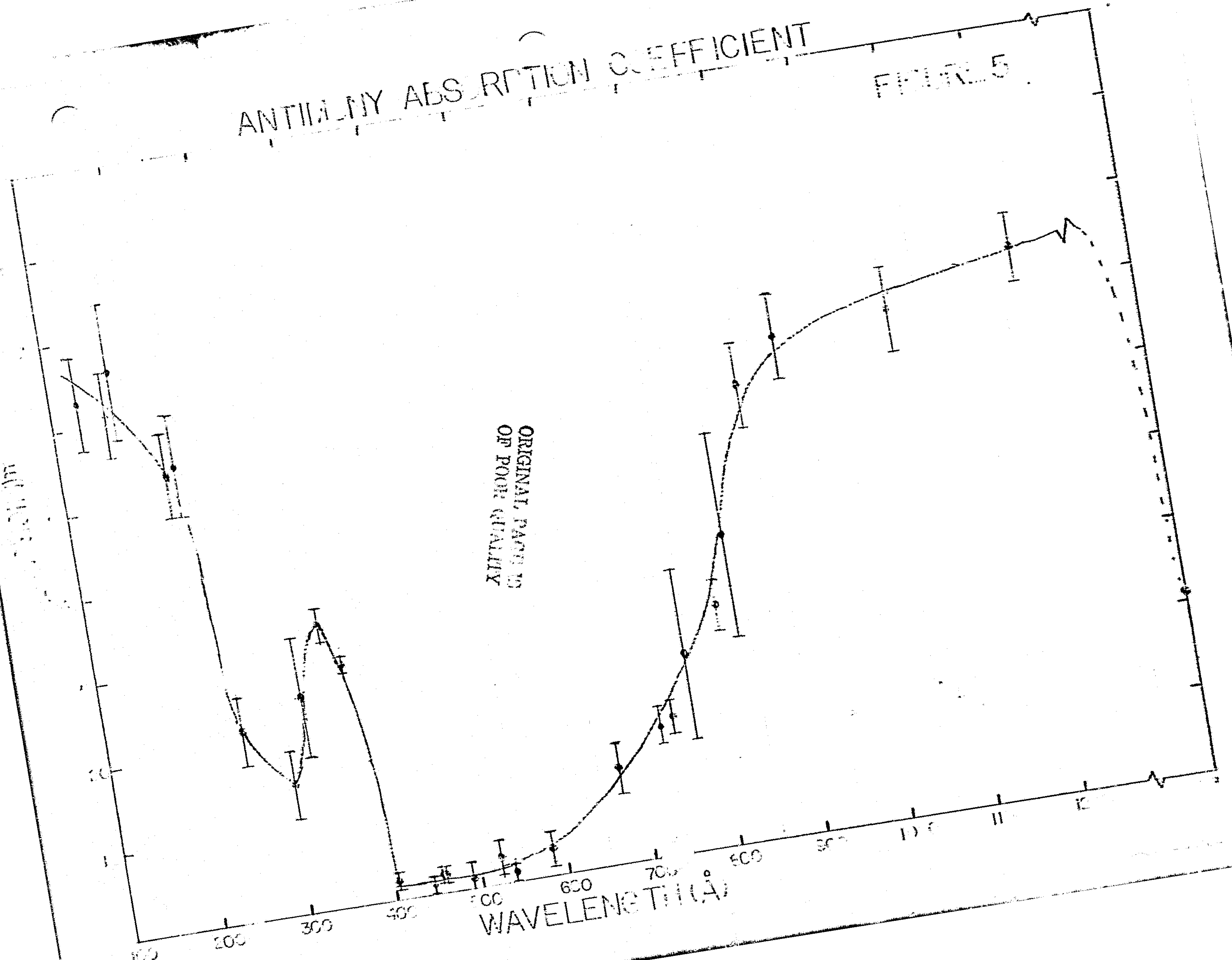
$$T(1080) = \exp[(\mu_{Ti} - \mu_{TiO})X_{TiO}] \exp[-\mu_{Ti}(.108)]$$

$$T(Sb) = \exp[(\mu_{Ti} - \mu_{TiO})X_{TiO}] \exp[-\mu_{Ti}(.020)] \exp[-\mu_{Sb}(.112)]$$

T(500) and T(1080) are the transmissions of the 500 and 1080 Å thick titanium foils, T(Sb) is the transmission of the sandwich foil, X_{TiO} is the thickness of the oxide layer formed, and μ_{Ti}, μ_{Sb}, μ_{TiO} are the absorption coefficients of titanium, antimony, and the oxide layer, measured in microns^{-1}. One can solve for μ_{Ti}, μ_{Sb}, and $\exp[(\mu_{Ti} - \mu_{TiO})X_{TiO}]$, yielding the absorption data necessary to predict the transmissions of filters of different thickness and hence optimize the EUVE design. The derived coefficients are shown in Figures 5-7.

ANTIMONY ABSORPTION COEFFICIENT

FIGURE 5



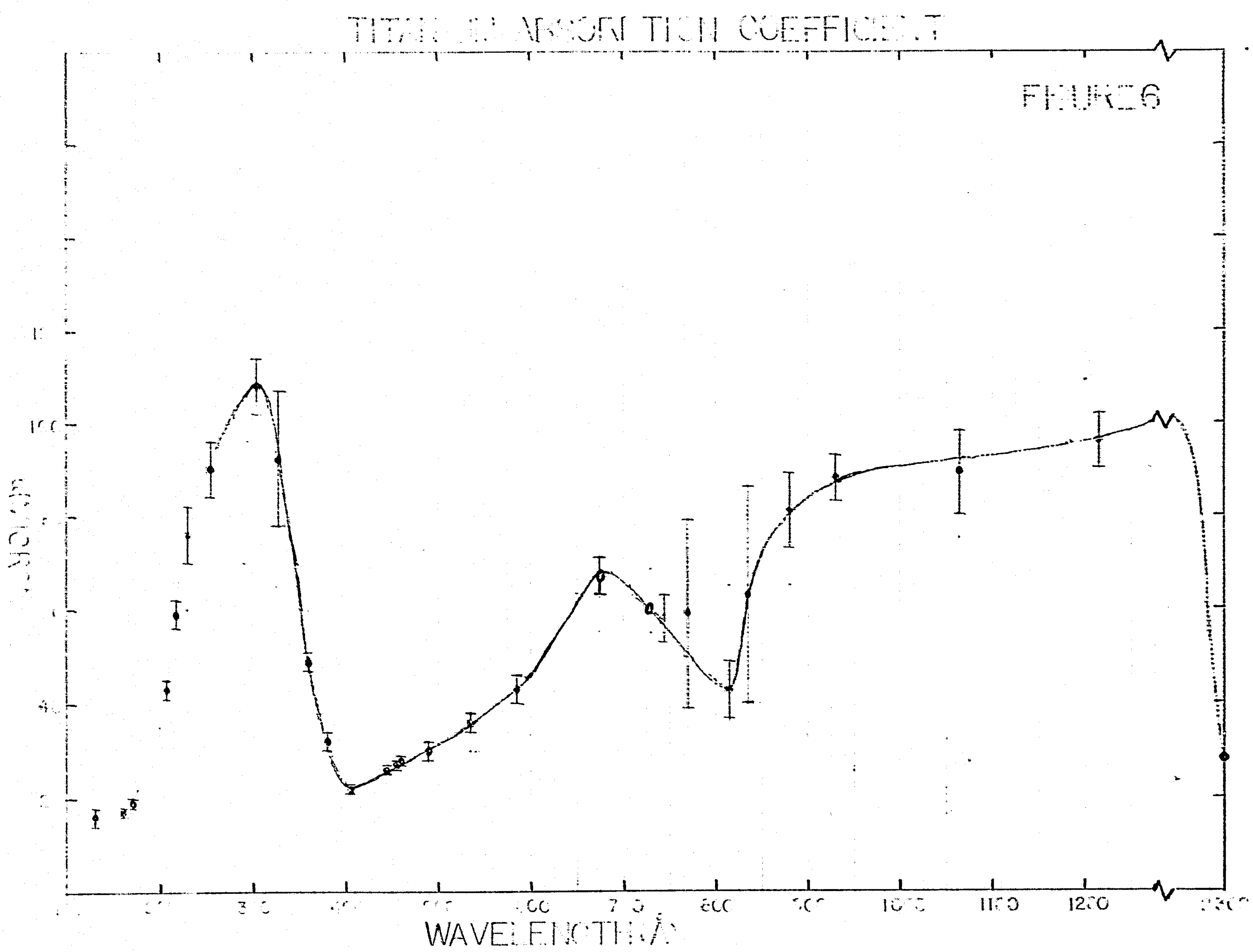
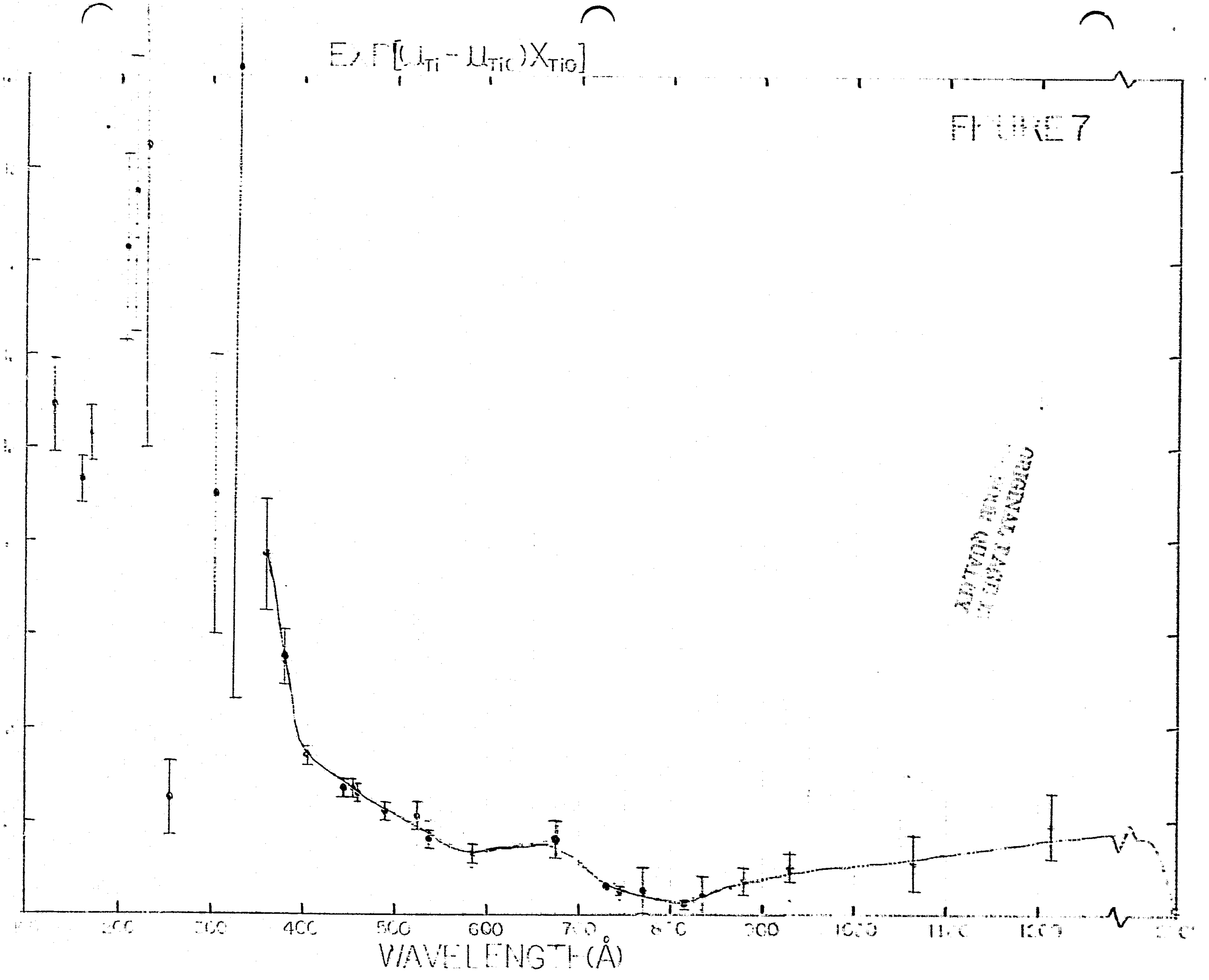


FIGURE 6
WAVELENGTH Å
1200

FIGURE 7



$EXP[(\mu_{Ti} - \mu_{TiO}) X_{TiO}]$
ORIGINAL PAGE IS
OF POOR QUALITY
400
500
600
WAVELENGTH (Å)

IV. SCIENTIFIC POTENTIAL ON EUVE

The achievable sensitivity of the EUVE using the newly developed filter materials has been determined using the filter optimization procedures developed for EUV astronomy here at the Space Sciences Laboratory. The overall sensitivity of EUVE of course depends on a wide range of instrument parameters: telescope size, field of view and angular resolution; detector quantum efficiency and spatial resolution; observation time and telemetry rate; filter transmission properties. All are subject to various constraints. Given a baselined instrument design, observing time, and telemetry capability, filter optimization consists of determining the filter thickness which yields the smallest detectable flux. For a sandwich filter thicknesses of the two filter materials are varied independently in the search. The resulting minimum detectable flux defines the instrument sensitivity. We briefly summarize here the optimization procedure.

A. Theory of Filter Optimization

A source has been detected with 99.9% confidence if the number of counts due to the source (in the source pixel) is at least three times the square root of the average number of counts in adjacent (background) pixels. This requirement leads to an expression for the minimum detectable flux, F, in photons s^{-1} cm^{-2} $Å^{-1}$ assuming that the source spectrum is flat within the bandpass.

$$F = 3\sqrt{\frac{\overline{\omega}}{T}}\ \frac{\sqrt{R_o f^2 + A \int t(\lambda)B(\lambda)d\lambda}}{[A \int t(\lambda)d\lambda]\ (1 - e^{-tm/R})^{\frac{1}{2}}} \qquad (1)$$

where

T = total observing time

ω = solid angle observed by one pixel

A = effective area of telescope x quantum efficiency (QE) of detector (assumed to be constant throughout bandpass)

$t(\lambda)$= filter transmission at wavelength λ

$B(\lambda)$= background flux density at λ

R_D = detector backgound per unit area $s^{-1}cm^{-2}$

f = telescope focal length

tm = telemetry limit (cts s^{-1})

R = total count rate of detector (cts s^{-1})

The computer routine utilized to optimize the filters for EUVE incorporates all of the data necessary for evaluating the minimum detectable flux F. It calculates an instrument throughput for every 10 Å interval, accounting for variations in telescope resonse, detector quantum efficiency, and filter transmission with wavelength. It includes all known sources of diffuse radiation background from 10-2000 Å, as well as theoretical estimates in poorly measured regions of the spectrum. It calculates the minimum detectable flux for a given filter thickness or pair of thicknesses. In addition, it computes the mean wavelength, the total grasp and the grasp shortward of a chosen wavelength, which permits a determination of the approximate bandpass of the filter. (Grasp is defined as $\int t(\lambda)d\lambda$.)

The computation of the mean wavelength and grasp below a specified wavelength allows additional scientific judgment to be applied to the filter optimization. It is not necessarily true, for example, that the optimum design of a sandwich foil is that combination of thicknesses which yields the lowest minimum detectable flux. Maximum scientific return from EUVE requires that bandpasses of the various filters remain distinct. Hence while an aluminum/carbon achieves the maximum sensitivity as the aluminum thickness goes to zero, such a design would not be chosen since the resulting bandpass would be identical to parylene. Hence an external constraint on the bandpass properties is sometimes imposed on the filter design and optimization takes place within that constraint.

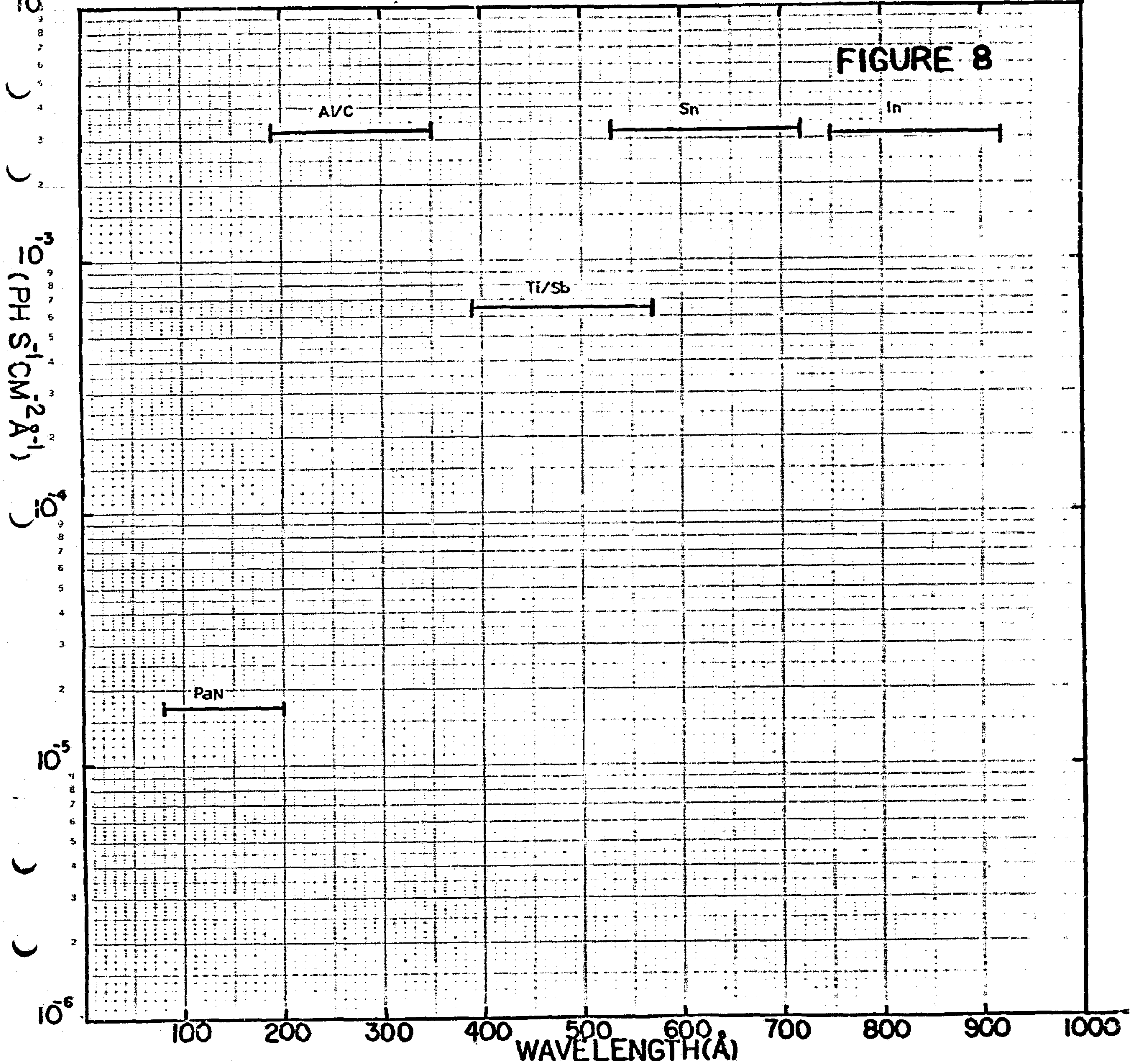
B. Sensitivity results for titanium and antimony

Both titanium and antimony transmit well in the range from 400-500 Å. Optimum sensitivity results when the materials are used together. Pure titanium is inappropriate for covering the 400-500 Å bandpass because of the transmission window below 250 Å. Pure antimony can be improved by the addition of titanium because the titanium transmission falls rapidly above 500 Å, while that of antimony falls more slowly. Hence the addition of titanium attenuates the strong 584 Å background flux while preserving the primary bandpass.

The minimum detectable flux has been minimized with the requirement that less than 1% of the grasp lies shortward of 350 Å. Relaxing this requirement to 10% does not improve the sensitivity by more than 20%. With the 1% constraint the optimum combination is 1400 Å of titanium sandwiching 1000 Å of antimony. Such a combination presents no fabrication problems.

The resulting sensitivity of EUVE with the titantium/antimony sandwich filter and the previously qualified filters is shown in Figure 8. These sensitivities are derived assuming the baselined instrument parameters and

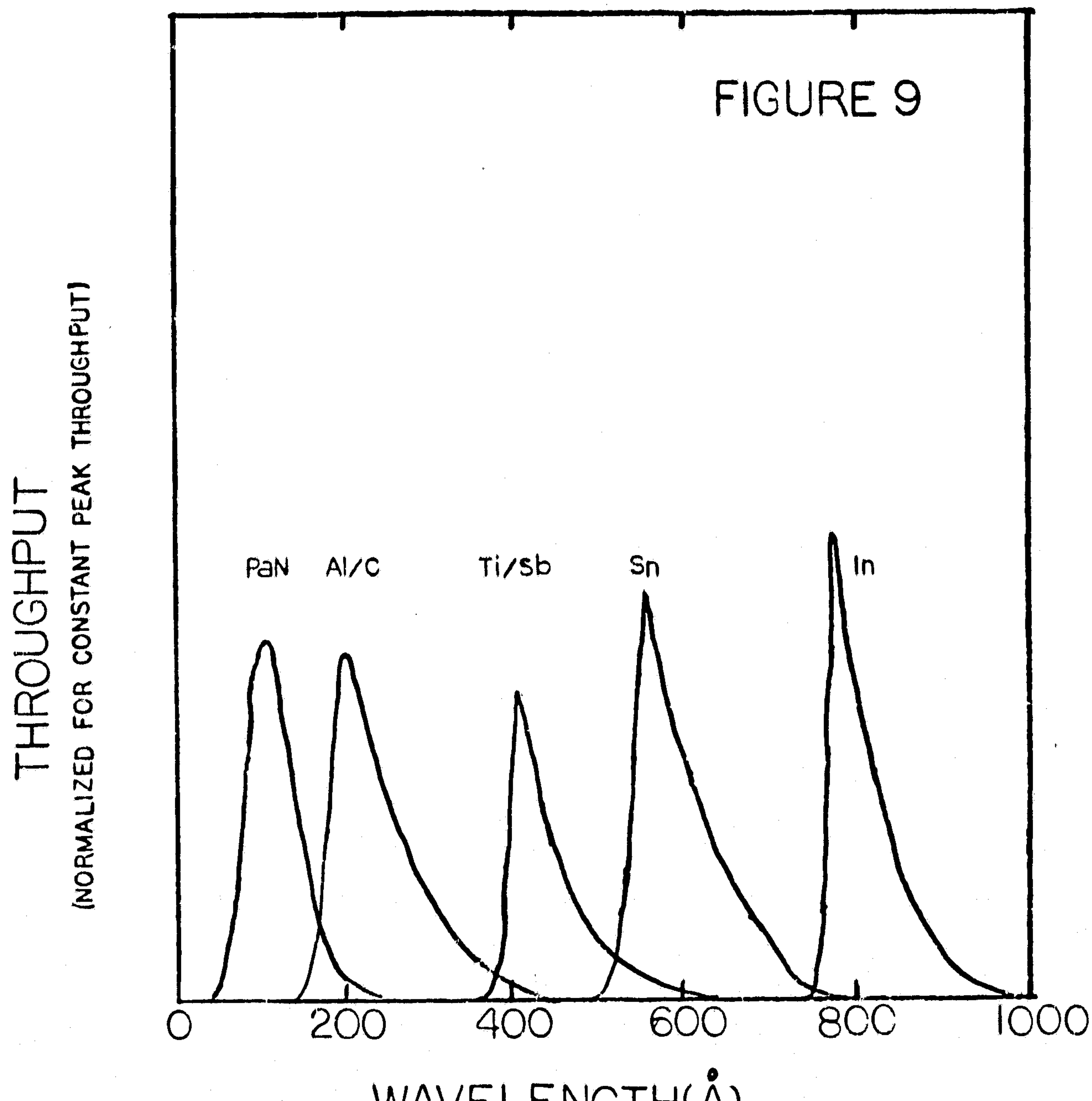
EUVE MINIMUM DETECTABLE FLUX VS. WAVELENGTH



the baselined telemetry rate of 800 bits per second per telescope. The bandpasses shown are defined as the full width to 10% of maximum instrument throughput. A better representation of the spectral coverage of the filters now available is given by Figure 9, which presents the transmission curves for the optimized filter of each material or combination.

These figures dramatically illustrate the scientific potential of the newly developed filter combination. The titanium/antimony filter combination fills in the missing wavelength range in the baseline EUVE coverage and does so with a factor of five greater sensitivity than the other EUVE bandpasses.

EUVE BANDPASSES



V. QUALIFICATION

The excellent transmission characteristics and potential EUVE sensitivities described in the previous sections are of course useless unless the titanium-antimony sandwich foil demonstrates acceptable longterm stability and mechanical strength sufficient for spaceflight qualification. The Ti/Sb/Ti filters have therefore been subjected to extensive testing of these characteristics. We describe here the tests of moisture-sensitivity, longterm transmission stability, and mechanical strength passed by the new filter.

A. Moisture-Sensitivity

We present here excerpts from the report of the development subcontractor, Luxel, of the humidity testing of the titanium-antimony sandwich filter. This test is crucial to the qualification of a flight filter. Though the EUVE filters will be launched in vacuum, they will of necessity be exposed to the standard laboratory environment during testing and calibration unless extraordinatry measures are taken.

"Aging Characteristic of Antimony Type XUV Filter Foil"
Gordon Steele/Luxel Corporation

Introduction

Submicron thick metal foils, employed as filters or windows for instruments functioning in the extreme ultraviolet and soft x-ray region of the spectrum, present special problems in common with their fabrication. Perhaps foremost among these is their proneness to develop 'pinholes'. Such pinhole defects may leak white radiation or may vacuum leak gas from a cell. The particular proneness of these foils toward this end is due their chemical reactivity in the presence of atmospheric moisture and their extremely thin nature. Many metals which are noted for their durability in the earths atmosphere in 'massive' form are unstable in submicron thick foil form. The reason for this is that the protective oxide layer formed on metals in their massive form usually exceeds the total thickness of submicron foils. Determining the durability and practicality of new materials, of interest for their special optical properties, is achieved by exposing the foil material to a standard degrading environment and measuring the visible light leakage as a function of time. Such is the subject of this report wherein the desired material is a metal foil of antimony and titanium.

Discussion

Pinholes resulting from chemical action between a metal foil and the gaseous environment form with point attack such that a certain amount of time is required to penetrate the foil and thereafter the oxidation proceeds laterally in a 'burning grass' type of growth. Increased transmission with aging is due to enlargement of initial pinholes with very few new ones forming. Typically the initial stage shows very little pinhole transmission, but after this phase the transmission increases rapidly to some apparent plateau with a drift increase thereafter.

Two types of pinholes result from this action; virtual and real. Virtual pinholes, point leaks of visible light a few hundreds of nanometers in diameter, are determined by SEM to be oxidized metal structurally retained within the foil. Stoicimetric oxidation does not occur initially and thus visible transmission is primarily in the red. Subsequently, stresses developed through volume change in conversion to the oxide breaks the oxide out of the foil and a hole or real pinhole, a few thousands of nanometers in diameter, results.

Pinhole formation in submicron foils seems to occur at selected sites. It is believed that these are associated with a screw dislocation growth of the foil during formation. The principal factor contributing to pinholes is relative humidity. Trace amounts of acid forming gases such as carbon, sulphur and nitrogen oxide gases and particulates like salt have an accelerating effect in the presence of moisture, but none when dry. Therefore test aging of foils for pinholes development is done with an exposure to air adjusted to some constant relative humidity by a constant R.H. solution. Care must be exercised in selection of a R.H. solution since most of the handbook recommendations represent a particular concentration of salts which buffer the R.H. at some desired level. Our work finds that significant and variable amounts of acid gases exist in equilibruim with these solutions (i.e. CO_2 over K_2CO_3 solution) which unreliably accelerates the results. Therefore this laboratory employs a 'clean' constant R.H. aqueous solution of sodium hydroxide recognizing that it not only adjusts the water vapor content but removes any acid gas traces that may be present in a laboratory enviornment (and also, one might add, the natural CO_2 in air). Extensive testing has shown most submicron foil materials do not develop significant pinholes as less than 20% R.H. over an exposure of three months. At 60% R.H., chosen as a probable value for most field environments, the initial or 'induction' stage for aluminum lasts about one week after which a three decade increase occurs. Indium and tin on the otherhand have induction phases of about three days with subsequent rapid deterioration over a four decade increase. Initial pinhole transmissions are generally about 10^{-8} of incident light. After six weeks, pinhole transmissions are typically 10^{-6} to 10^{-5}.

Tests and Results

It was decided from experimental considerations that a filter comprised of 200Ti/1500Sb/200Ti foil would be optically suitable. Such a foil and filters thereof were fabricated and tested. Representative filters were stored in R.H. buffered closures at 60%, and ~1% (desicated) environments. From time to time, over a period of six weeks, the filters were removed for measurement of white light transmission in a PM photometer having a dynamic range of four decades. Initial transmission ofeach of the filters was 4.0×10^{-9} of incident light. The data, shown in Figure 1, demonstrates that the XUV foil material 200Ti/1500Sb/200Ti is very durable toward pinhole aging due to moisture. Over the period of the test no degredation was observed within the sensitivity range of the photometer (1×10^{-9}). For comparative purposes Figure 1 also includes the degredation which would be typical for a 1500Al:Si XUV foil similarly exposed to 60% R.H.

Conclusion:

1. Pure antimony foils are unsuitable as XUV filters from two practical points of view. First the evaporative techniques used to prepare submicron foils results in foils of mottled red transmission when 1500 Å thick. Second, pinhole-free antimony films are difficult to fabricate due to their high sensitivity to atmospheric moisture.

2. Providing 200 Å thick films of titanium as a nucleating surface and as an overcoat results in a sandwich foil of antimony 1500 Å thick which is very opaque to visible light and unusually resistant to pinhole formation when exposed to a 60% R.H. environment. This titanium-antimony laminant foil demonstrates aging characteristics which are superior to aluminum type XUV filters.

B. Transmission Stability

The transmissions of the filters were measured again one year after the initial measurements described above to ascertain the longterm stability of the titanium and sandwich filters. During that period the filters were exposed to the laboratory environment for a few weeks and stored in dry nitrogen for the rest of the time.

The results demonstrate remarkable stability, particularly for the

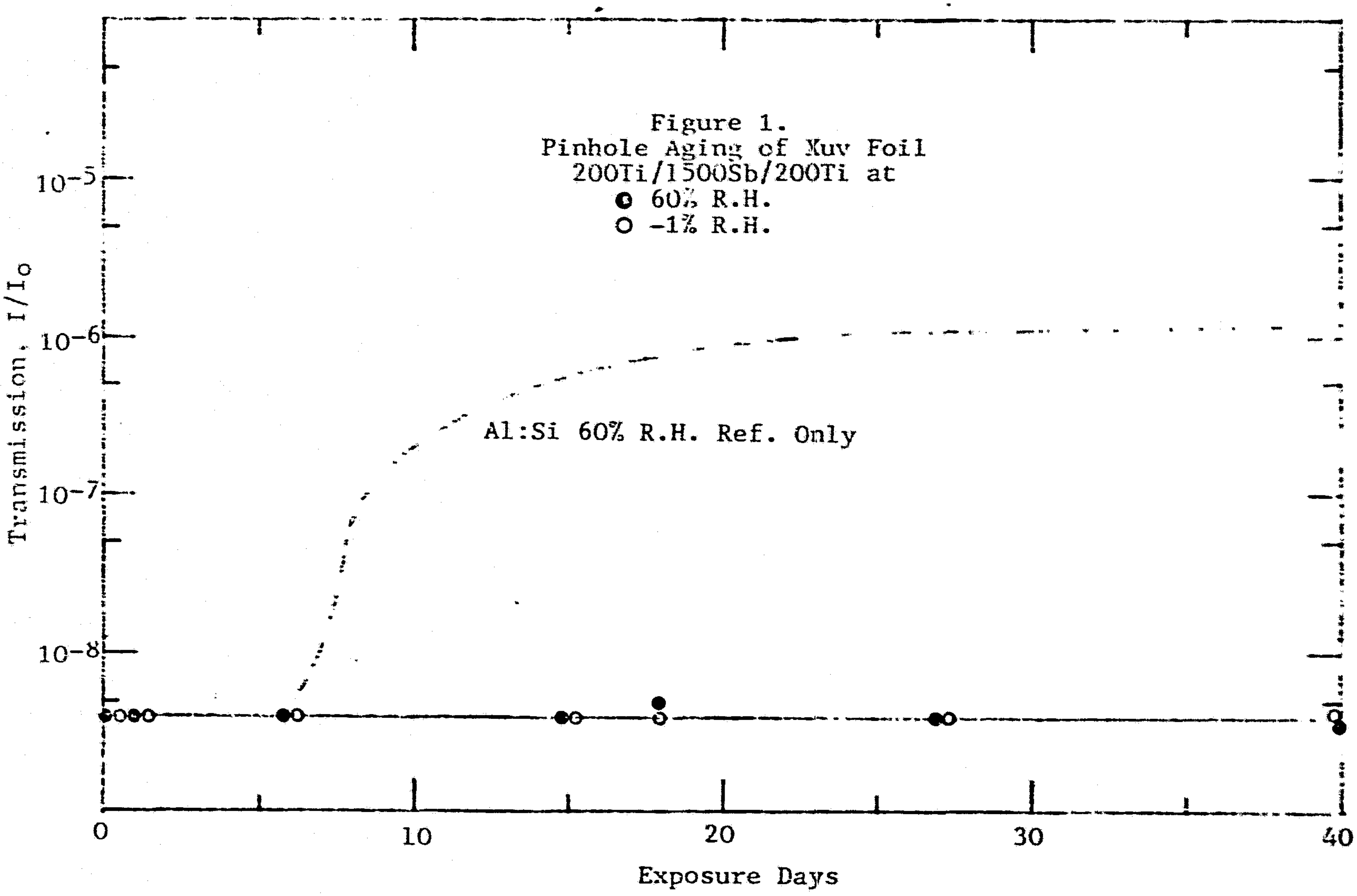


Figure 1.
Pinhole Aging of Xuv Foil
200Ti/1500Sb/200Ti at
● 60% R.H.
○ −1% R.H.

titanium-antimony combination. In the bandpass of the sandwich filter the transmission decreased by a maximum amount of 13%, while in the wings the transmission decreased by a maximum of 25%. The corresponding maximum decreases for the 1000 Å titanium filter are 12% in the bandpass and 70% in the wings. For the 500 Å titanium filter the results are 30% in the bandpass and 18% in the wings. Of particular interest is that at no wavelength did the wing transmission open up to indicate the development of pinholes. Rather the general behavior is for the ratio of bandpass to wing transmission to grow even higher.

This stability is excellent when compared with previously used EUV filters. Standard filters such as aluminum, tin, and indium show transmission drops in the bandpass of 20% in only three months. Hence it is conventional to procure flight filters as late as possible before launch or before they can be stored in vacuum. The titanium-antimony sandwich, with its superior longterm stability, therefore has no deleterious impact on the EUVE filter storage requirements or delivery schedule.

C. Mechanical Strength

To determine the mechanical acceptability of the newly developed filter, the filters were vibration tested at NASA Ames Research Center. The filters tested had been mounted by Luxel in the standard manner they have developed for thin film filters. The foils are glued to an 80% transparent finely spaced nickel mesh glued around the edges to a rigid frame. Often for filters used in space research a bead of compliant epoxy is placed around the edge of the filter and filter frame. This procedure (called margining) greatly reduces the stress on the filter by distributing the loads at the interface to the frame.

The filters at launch are subjected to two types of stress, vibrational and acoustic. The extremely high strength-to-weight ratio of the foils and meshes enables them to withstand extremely high levels of vibrational loading. The acoustic stress tends to be much more severe. The EUVE filters will be launched in vacuum boxes with the detectors, eliminating the acoustic loading.

The vibration testing at Ames was performed with the 16 mm diameter filters used for the transmission measurements. These are probably smaller than the EUVE flight filters, which may be as large as 40-50 mm in diameter. However, the test was extremely conservative in two regards: the filters tested were not margined and the test was performed in air, rather than in a vacuum box. The large factor of increased stress from the presence of the acoustic loading more than compensates for the increased stress resulting from using larger filters. Hence we consider the test as a whole to be conservative with regard to the requirements of the EUVE flight filters.

Vibration testing was performed to the qualification levels of random vibration and sine sweep for the space shuttle. In addition, the filters were subjected a large amplitude sinusoidal vibration at a constant low frequency. This test has been used on some previous launch programs as a simulation of DC accelerations. Specifications for all three tests are given in Table 1.

TABLE 1

Random Vibration	(3 minutes, each axis)
20 Hz	.006 g^2/Hz
20-100 Hz	+6 db/octave
100-1000 Hz	.15 g^2/Hz
1000-2000 Hz	-6 db/octave
2000 Hz	.0375 g^2/Hz

14.7 grms overall

Sine Sweep (each axis)

1 g at 1.5 minutes/octave from 20-2000 Hz.

DC Simulation (5 minutes, each axis)

20g at 40 Hz.

All filters tested (500 Å Ti, 1000 Å Ti, and the 100 Å Ti/1100 Å Sb/100 Å Ti sandwich) survived the random vibration and sine sweep with no damage. The sandwich filter and the 1000 Å titanium filter survived the DC simulation with no damage. The 500 Å titanium filter developed pinholes during the DC simulation test. Hence, further testing under evacuated conditions would be necessary to qualify a filter this thin for launch. However, the 500 Å titanium filter is not useful for EUVE because of the large wing transmissions. The most important new filter developed, the titanium-antimony sandwich, shows excellent mechanical strength and will have no problem with EUVE launch.

VI. CONCLUSIONS

1. Both pure titanium and titanium/antimony combination filters have been fabricated. The fabrication process is now well understood and filters of different thicknesses should present no problem.

2. The transmission properties of the two materials in combination and separately have been determined. With this data, the optimum filter design for EUV instruments using these materials can be determined.

3. The optimum titanium/antimony EUVE filter has been designed. With current design parameters and telemetry availability the optimum combination consists of 700 Å Ti/1000 Å Sb/700 Å Ti. In combination with previously developed filters, the resulting sensitivity and spectral coverage offer dramatic improvement over the original EUVE design. The optimum EUVE filter complement now consists of parylene N, aluminum/carbon, titanium/antimony, tin and indium filters.

4. The titanium/antimony combination filter has undergone extensive testing of moisture sensitivity, longterm transmission stability, and mechanical strength. In all areas, the new filter demonstrates qualities equal to or superior to those of previously qualified EUV filters.

5. The new filter material has no impact on EUVE cost and schedule. Price and delivery of titanium/antimony filters will be similar to those of the other EUV filters.