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EFFECT OF SPACE EXPOSURE ON PYROELECTRIC INFRARED DETECTORS

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INTRODUCTION

Pyroelectric detectors are one of the many different types of infrared radiation detectors. Pyroelectric detectors are of interest for long-term space use because they do not require cooling during operation. Also, they can detect at very long wavelengths and they have a relatively flat spectral response. A disadvantage is that the radiation must be chopped in order to be detected by a pyroelectric detector.

The objective of the experiment was to determine the effects of launch and space exposure on the performance of commercially available pyroelectric detectors.

The approach was to measure performance parameters of the detectors before and after flight on the Long-Duration Exposure Facility (LDEF) and determine the loss of detector performance. The experiment was passive; no data was taken during flight.

Experiment

A total of twenty pyroelectric detectors were flown on the LDEF and another nine were stored in unsealed containers on the ground as control samples. The detectors were chosen from what was commercially available in 1978. The detectors were mounted on tray E-5 of the LDEF, which was a slightly-trailing-side location. The tray was covered with a perforated aluminum plate for thermal control. The plate blocked 50% of incident radiation. Four of the twenty flight detectors were covered with a solid aluminum plate which shielded them from most of the space radiation but left them exposed to space vacuum.

The detectors used in the experiment represented three different pyroelectric materials, three different window materials and three different manufacturers (figure 1). The detector materials included lithium-tantalate (LT), strontium-barium-niobate (SBN) and triglycine-sulfate (TGS). The window materials included zinc-sulfide (ZnS), thalium-bromide-iodide (TlBrI), and polished germanium (Ge). Five of the flight detectors had no material in their windows. A list of the detectors with their material types, windows and location during flight is given in table 1.

The primary figure of merit for infrared detectors is the detectivity, D*. D* is calculated from the measured values of signal and noise voltage using the following equation:

$$D^* = \frac{S/N \sqrt{\Delta f}}{H \sqrt{A_d}} \quad (\text{cm} \sqrt{\text{Hz}} /\text{W})$$

where:
S = signal (volts)
N = noise (volts)
Δf = bandwidth (Hz)
H = radiant energy flux (watts/cm^2)

A_d = detector area (cm^2)

Signal and noise measurements were made using a 500 K blackbody, a light chopper, a preamplifier and a wave analyzer and were made at chopping frequencies of 5, 10, 20 and 50 Hz.

Eleven LT detectors were flown. Five of these detectors had windows made of ZnS, one had a window of TlBrI and five had no window material, which exposed the pyroelectric material of these detectors directly to the space environment.

Five SBN detectors were flown. All SBN detectors had windows of polished germanium.

Four TGS detectors were flown. Three of the TGS detectors had windows of TlBrI, and one had a window of polished germanium. The cases of all of the TGS detectors were hermetically sealed.

The LDEF was put into orbit in April 1984 and was brought back to earth in January,1990. Performance parameters of the flight detectors were measured after their return and compared to their pre-flight values. The same measurements were made on the control detectors. Results for flight detectors were compared to results for controls to separate the effects due to aging from the effects of space exposure.

POST-FLIGHT RESULTS

Visual Observations

There was a brown discoloration on the outer surfaces of the detectors similar to the "tobacco stain" that was found on much of the LDEF.

A much more noticeable effect was the existence of cloudy-white regions on the surface of the detector windows which were made of thallium-bromide-iodide (figure 2). This effect was seen only in the TlBrI of the exposed detectors and will be discussed in the Results section.

Detectivity

The results of the post-flight detectivity measurements are summarized in table 1. The table lists the detectors according to detector material, window material and location of the detector during the experiment (i.e. control sample, exposed flight sample or flight sample covered by the aluminum plate). Changes in noise measurement less than +/- 25% are not considered statistically significant.

LT Detectors

Among the LT detectors there were three "failures", i.e. no signal or erratic, unrepeatable signal. The erratic output signal suggests mechanical failure rather than radiation damage to pyroelectric material. The failure rate among the flight LT detectors (2 out of 9) was comparable to that for the control LT detectors (1 out of 4).

Differences between the pre-flight and post-flight detectivities were within the error bounds of the measurement with one exception. The exception was a LT detector with a TlBrI window whose post-flight signal was 38% less than its pre-flight signal. This loss is attributed to a decrease in transmissivity of the window material which is discussed in a later paragraph.

This decrease in signal combined with a 57% increase in noise produced a 61% decrease in D*.

SBN Detectors

All of the SBN detectors survived the storage and flight. Differences between post-flight and pre-flight detectivities were within the error bounds of the measurement.

TGS Detectors

The detectors made of TGS did not fare well, either during flight or storage. Three of the four TGS flight detectors had zero signal response after flight. The fourth flight detector maintained its signal strength but had a 40% increase in noise. All of the TGS control detectors (4 out of 4) suffered complete loss of signal during storage on the ground. The failure of the TGS detectors during flight cannot be ascribed to space exposure since all of the control detectors failed during the same period of time.

Detector Windows

Some of the detector housings had infrared-transmitting materials in their windows; some had no material in their windows. Three different window materials were used: germanium (Ge), thallium bromide iodide (TlBrI) and zinc sulfide (ZnS). There was no visible damage in the germanium or zinc sulfide windows. Also, there was no significant loss in signal strength of the flight detectors having these window materials as compared to control detectors of the same type.

The TlBrI windows which were exposed during flight sustained noticeable damage. The damage was in the form of non-uniform white areas on the front surface of the windows (figure 2). This effect was not present in the TlBrI windows of the covered flight detector or in the control detectors. Similar damage was noted in two other LDEF experiments which exposed TlBrI during flight (experiment A0134, W. Slemp and experiment A0056, J.Seely et al.)

Transmission measurements were made on two of the damaged TlBrI windows and on a TlBrI window from one of the control detectors. The windows were removed from the detector cases in order to make the measurements. A 500 K blackbody was used as the radiation source, and the radiation flux was measured with a broad-band IR detector. The transmissivity was taken to be the ratio of detector signal with the window in the beam to the detector signal with no window in the beam. The exit aperature of the blackbody was smaller than the TlBrI windows allowing transmission measurements through several different areas of the same window. Transmission through the damaged TlBrI windows was compared to transmission through the control window. Loss of transmission through the damaged windows ranged from 17% to 50% depending upon the window and the location on each window; greater transmission loss corresponded to regions of greater visible damage.

Only one detector containing a TlBrI window was operable after flight. This detector was made of lithium-tantalate. All of the other TlBrI-windowed detectors were made of TGS. The decrease in signal strength from this detector after flight was 38%. This is consistent with the amount of IR transmission loss in the TlBrI windows.

Electron Spectroscopy for Chemical Analysis (ESCA) was performed on the same windows on which transmission measurements were made. Measurements were made at several locations on each window surface. The depth of this analysis was approximately 5 nanometers. The analysis showed the presence of silicon, in the form of silicates, on the surface of the exposed windows. The Si concentration was higher in the regions of lesser damage and lower in regions of greater damage. Another significant result of the analysis was the change in the ratio of thalium to bromine, Tl:Br, in the surface of the exposed windows. In the control window, the Tl:Br ratio is approximately 1:1. In the low-damage areas of the exposed windows the Tl:Br ratio was 4.6:1, and in the high-damage areas the Tl:Br ratio was >26:1 (see table 2).

CONCLUSIONS

Detectivity

This experiment has shown that pyroelectric detectors made of lithium-tantalate or strontium-barium-niobate are suitable for long-term space use. The LT and SBN detectors survived six years of storage plus almost six years of exposure to space with little or no loss of performance.

Based on the results from detectors from one manufacturer, the detectors made of TGS, however, cannot be recommended because of their apparent short shelf life. Seven of the eight TGS detectors failed to respond after storage and/or flight. The exact cause of their failure has not yet been determined.

Window Material

The damage to the TlBrI windows was an interesting result. The damage was not uniform and was limited to the detector windows which had direct exposure to space. The presence of silicon in the form of silicates on the window surfaces is similar to reports from many LDEF experiments. The reason for the non-uniformity of the silicon concentration is not known. However, the inverse relationship between the silicon concentration and the amount of Br loss from the surface suggests that the silicate acted as a shield which lessened the loss of Br and I.

This experiment shows that the choice of window and lens material are of major importance. When used in space, a detector will be part of a system and will be located behind a lens or window of some sort. Damage to the lens or windows will most likely play a larger role in loss of system performance than will damage to the detector material.

Table 1
Changes in Detector Parameters

Detector Type (No. of Samples)	Window Material	Location During Flight	% Change Signal (avg)	% Change Noise (avg)	% Change D* (avg)
LT (1)	none	control	+ 2.5	- 9	+ 5.8
LT (1)	none	control	- 100		
LT (1)	none	covered	+ 1.0	- 10	+ 5
LT (1)	none	exposed	erratic		
LT (3)	none	exposed	- 5.3	+ 1	- 10
LT (2)	ZnS	control	- 4.0	+ 23	- 23
LT (1)	ZnS	covered	- 3.5	+ 4	- 5.5
LT (1)	ZnS	exposed	erratic		
LT (3)	ZnS	exposed	- 6.7	+ 24	- 25
LT (1)	TlBrI	exposed	- 38	+ 57	- 61
SBN (1)	Ge	control	+ 0.5	+ 1	0
SBN (1)	Ge	covered	- 1.4	+ 1	+ 2
SBN (4)	Ge	exposed	- 2.0	- 22	+ 28
TGS (4)	TlBrI	control	- 100		
TGS (1)	TlBrI	covered	- 100		
TGS (2)	TlBrI	exposed	- 100		
TGS (1)	Ge	exposed	0	+ 40	- 30

Table 2.

ESCA Analysis of TlBrI Windows

Sample	Si conc. (atomic %)	Tl:Br ratio
control	0	1:1
exposed low damage	17%	4.6:1
exposed high damage	6%	> 26:1

Examples of Pyroelectric Detectors

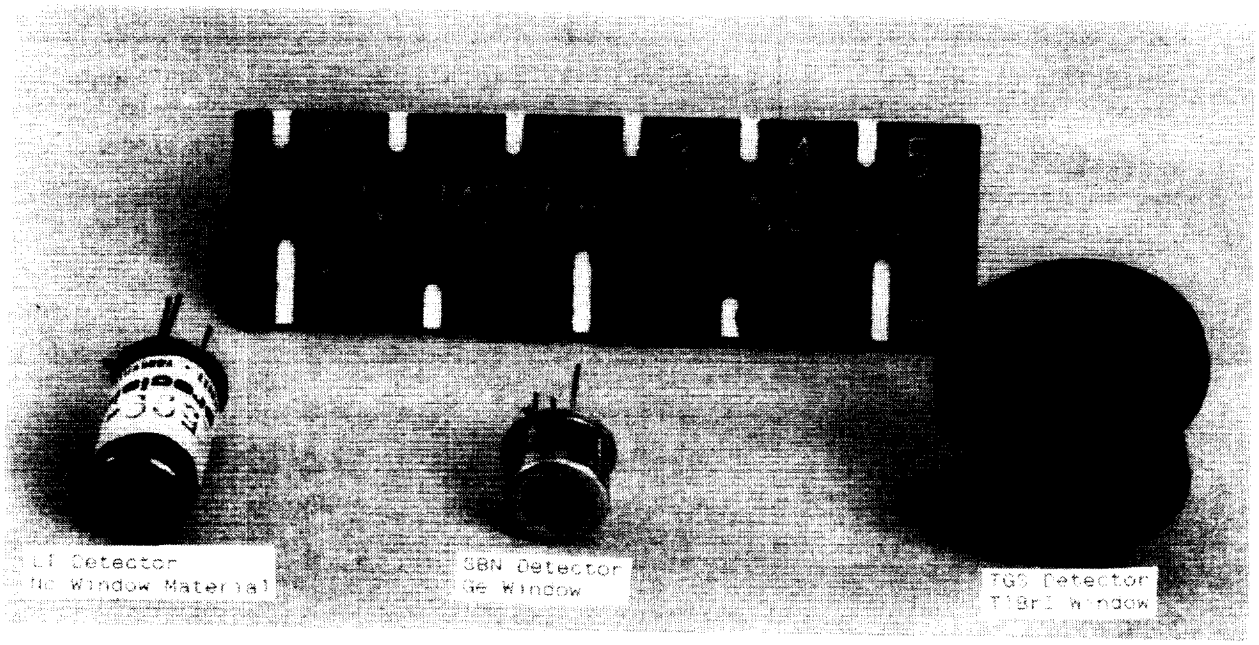

Figure 1

T1BrI Windows Showing Damage in Exposed Samples

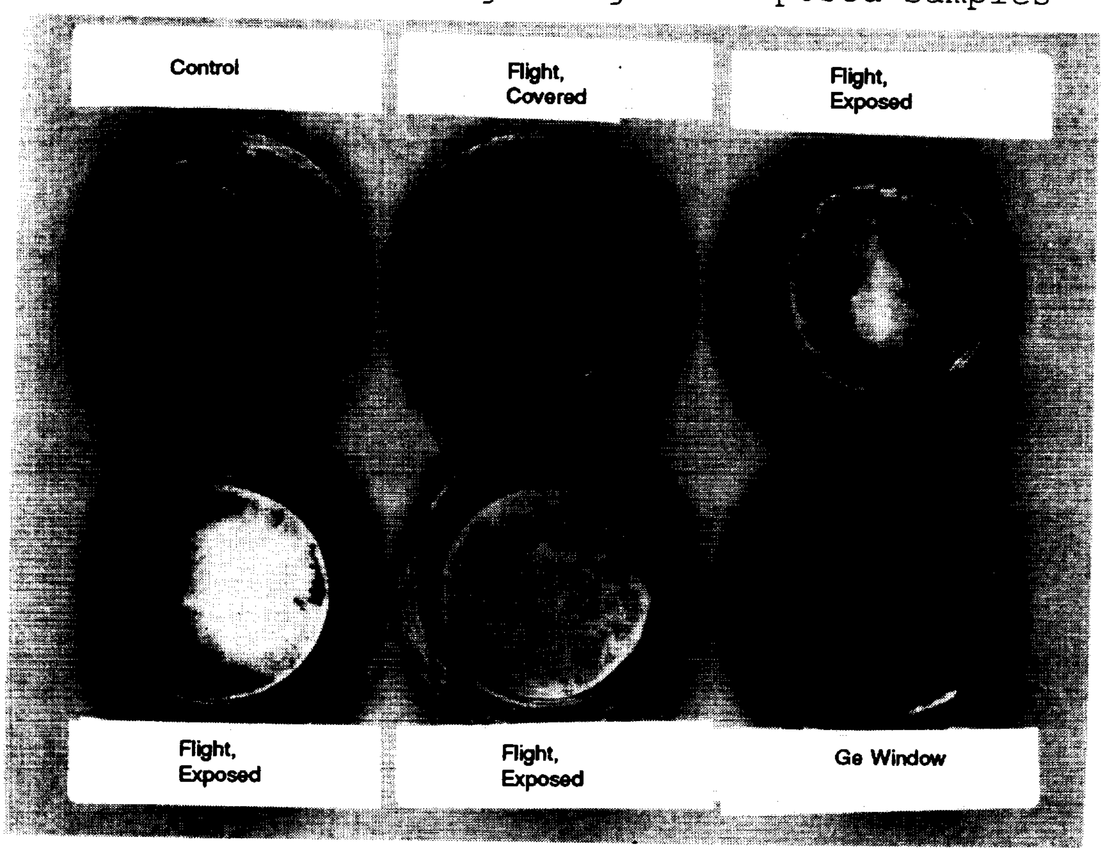

Figure 2