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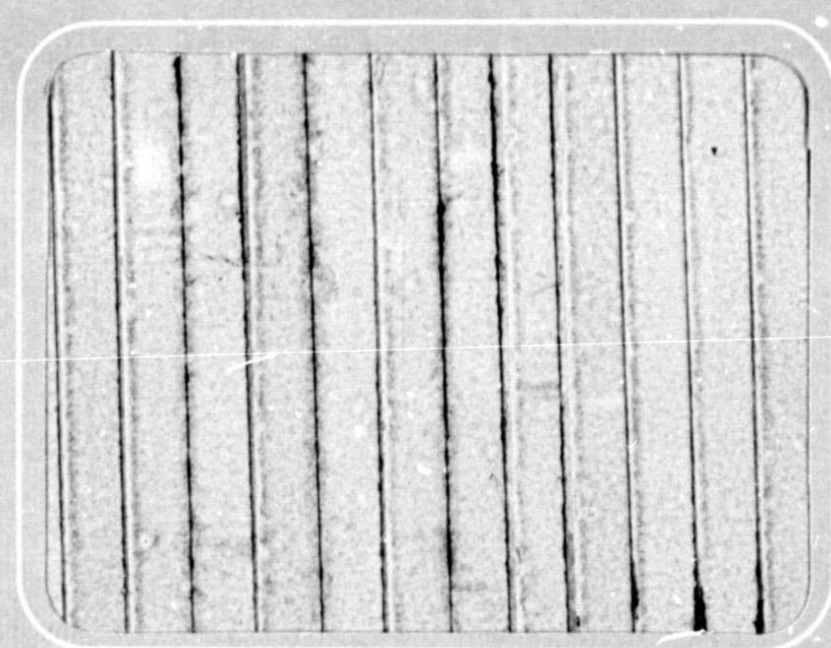

SUMMARY REPORT

on

ANALYSIS AND ASSESSMENT OF FILM MATERIALS AND ASSOCIATED MANUFACTURING PROCESSES FOR A SOLAR SAIL

to

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

February 23, 1978

by

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ANALYSIS AND ASSESSMENT OF FILM MATERIALS AND ASSOCIATED MANUFACTURING PROCESSES FOR A SOLAR SAIL

by

E. J. Bradbury, R. J. Jakobsen,
and F. A. Sliemers

INTRODUCTION

It is the goal of NASA's Jet Propulsion Laboratory to develop a solar sail for use in a rendezvous with Halley's Comet in 1985. Several configurations (square sail and heliogyro) are being considered for the application. These concepts relate primarily to production, operation, and deployment.

For successful implementation of the solar sail for the Halley Mission at a distance of 0.25 A.U. from the sun, polymeric film candidates must contain a special combination of properties (mechanical, thermal, etc.) and must maintain these properties during long-term exposure to the space environment. This environment may be characterized to a large extent through definition of its temperature, pressure, and spectral irradiance.

A survey and assessment of thin films and thin film technology was made by BCL as Phase I* of a Solar Sail Materials Development Program.

Polymeric materials which have thermal and mechanical properties suitable for consideration in this application are relatively few in number. Further, most are not available commercially as films and none in the ultra-thin gauge required for the sail application. Therefore, it is necessary that an assessment be made of the manufacturing capabilities of potential film producers for the various materials candidates.

In addition to the manufacturing-capabilities assessment, it will be necessary to establish certain properties (physical, mechanical, thermal, etc.) of candidate materials that presently are unavailable.

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* "Survey and Assessment of Monolithic Film Materials and Associated Manufacturing Processes for a Solar Sail", Summary Report, May 2, 1977.

Such data, much of which can only be meaningful if obtained on materials at the ultrathin application gauge, are vital to the selection of materials with optimum solar sail service potential.

SUMMARY

This report covers a limited amount of the work projected as Phase II effort in support of the JPL Solar Sail Development. Initially, this was to consist of two principal subtasks. The first subtask was to be a limited survey of candidate resin manufacturers and film producers to determine the availability of key materials and to establish the capabilities of fabricators to prepare ultrathin films of these materials within the capacity/cost/time constraints of the Halley program. The second subtask was to establish the relative serviceability of various materials through a characterization of critical properties. However, shortly after initiation of work on the first subtask, JPL was forced by financial constraints to request BCL to discontinue all research with the exception of FTIR (Fourier Transform Infrared) and ATR (Attenuated Total Reflectance) studies on samples selected by JPL. This report, therefore, covers only the preliminary organization of the film producer evaluation and the FTIR evaluations conducted in support of the JPL development.

EXPERIMENTAL WORK

Subtask (a)

In the first subtask (a) Battelle-Columbus projected research assistance to JPL in the assessment of the manufacturing capabilities of resin supplier and film fabricators of selected candidate polymeric materials for the solar sail application. The survey projected contacts with appropriate companies to develop materials information related to:

(1) Quality of product (uniformity and reproducibility of properties, size tolerance, etc.) and an assessment of existing or proposed quality assurance and/or inspection requirements.

(2) Potential production rates and availability of raw materials, personnel, etc.

(3) Status of existing facilities and equipment.

(4) Capital investment requirements for any new facilities and equipment needed to meet sail volume and schedule requirements.

(5) Potential manufacturing development costs for the producer where the material is not presently fabricated in film or in the desired film thickness.

(6) Ability to provide film material in the quantities required to support the solar sail schedule while maintaining reasonable costs.

(7) Plans for packaging and shipment of final product to its destination.

Prior to instructions to discontinue work on this subtask, emphasis was placed on commmunication with materials suppliers and plastic film fabricators. Based on telecon contacts, ten companies were identified and preliminary arrangements made for visits to each. These companies are listed below.

Company	Material
Carborundum Corporation	Polyarylsulfone
Celanese Company	Polybenzimidazole source
Ciba-Geigy Company	Thermoplastic polyimides
Drs. Altas/Mark	Consultants
Du Pont	Kapton films
Pallflex Product Corporation	Ultrathin plastic films
Rexham Corporation	Coating/PBI laminating (facility handles toxic solvents)
Schweitzer	Film casting facility
Union Carbide Corporation	Parylene film production
Upjohn Company	Thermoplastic polyimides.

Various site visits were projected to better establish the capabilities of these companies to meet JPL's sail production schedule. To this end, a number of survey questions were developed to determine capacities, controls, and possible constraints to production of both the base resin and the desired film. The general format for use in these discussions is summarized in Appendix A entitled "Survey Questions".

Subtask (b)

The second subtask (b) was projected to involve materials characterization testing on a selected basis on candidate film materials determined by JPL. The number and types of tests to be conducted in the process of evaluating candidate film physical, chemical, and mechanical properties was to be at the direction of JPL and within the time and funds available. Examples of the types of tests initially projected included ones that would:

(a) Determine chemical composition changes as a result of environmental exposure conditions, e.g., FT-IR analysis.

(b) Evaluate thermal changes in composite materials (effects of reinforcement fibers, filaments, etc. on films).

(c) Evaluate stresses (from blocking and electrostatic forces) involved in unfurling sections of the sail from its storage cannister.

However, due to the previously mentioned budgetary constraints, work on subtask (b) was limited to FT-IR analysis of the three samples provided by JPL. These analyses are summarized below.

Infrared spectra of the three samples were obtained as described in the following procedure. Each sample was pressed against an internal reflection (ATR) crystal with the polymer sandwiched between the crystal and the metal backing. The sample size was such that less than one-fourth of the surface of the internal reflection crystal was covered with sample. This resulted in weak spectra requiring about a six-fold scale expansion. Internal reflection spectra of the three samples were obtained using both a KRS-5 and a Ge internal reflection crystal.

The spectra of the three samples (using KRS-5) are shown in Figure 1 and the spectra obtained using a Ge crystal are shown in Figure 2. Note that for the KRS-5 spectra, the bands are broad, while the bands are sharp when using a Ge crystal. This apparently is caused by the effective penetration depth of the infrared light beam into the polymer sample. For Ge (45 degrees) the penetration depth is about 0.5 micron (average penetration depth over the wavelength range covered). For KRS-5 (45 degrees) the penetration depth is about 1 micron. Thus it appears as if the polymer film is between 0.5 and 1 micron in thickness. For Ge the infrared beam only penetrates into the polymer; but for KRS-5, the beam penetrates through the polymer and reflects off the metal backing causing band broadening (probably because of polarization effects).

However, in either case (KRS-5 or Ge), the spectra are weak and accurate spectral subtractions are difficult (as will be discussed later). Thus an attempt was made to obtain an external reflection spectrum (single reflection) of the control sample (Figure 3). This spectrum is a low-angle (78 to 88 degrees from the normal) reflection spectrum (called reflection-absorption spectra). It is more intense than those obtained by internal reflection techniques. However, the spectrum is also quite different from the internal reflection spectra. These differences will be discussed later, but it can be seen that there are also some similarities. These similarities are closer to the KRS-5 spectra, which is another indication that in the KRS-5 internal reflection spectra the light beam penetrates through the polymer and reflects off the metal. However, the program ended before external reflection spectra could be obtained on the other two samples. Thus, we could not confirm the external reflection spectrum of the control sample nor did we have the other external reflection spectra to use for subtraction.

Results

Subtracted infrared spectra of the three samples are shown in Figure 4. These are subtractions involving the spectra obtained using a KRS-5 crystal. The subtraction between the straight leg sample and the control sample shows

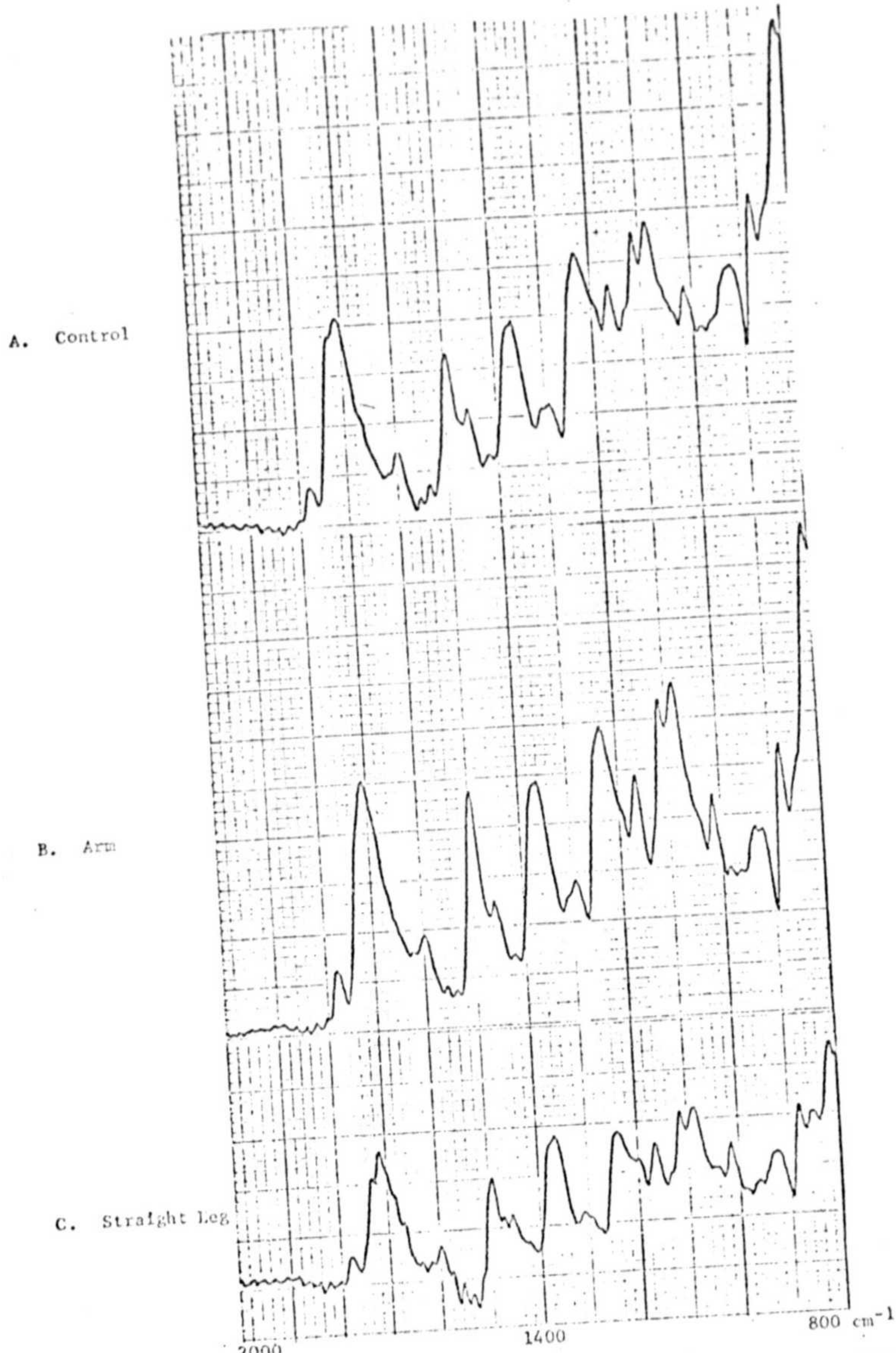

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FIGURE 1. INTERNAL REFLECTION SPECTRA (KRS-5 CRYSTAL)

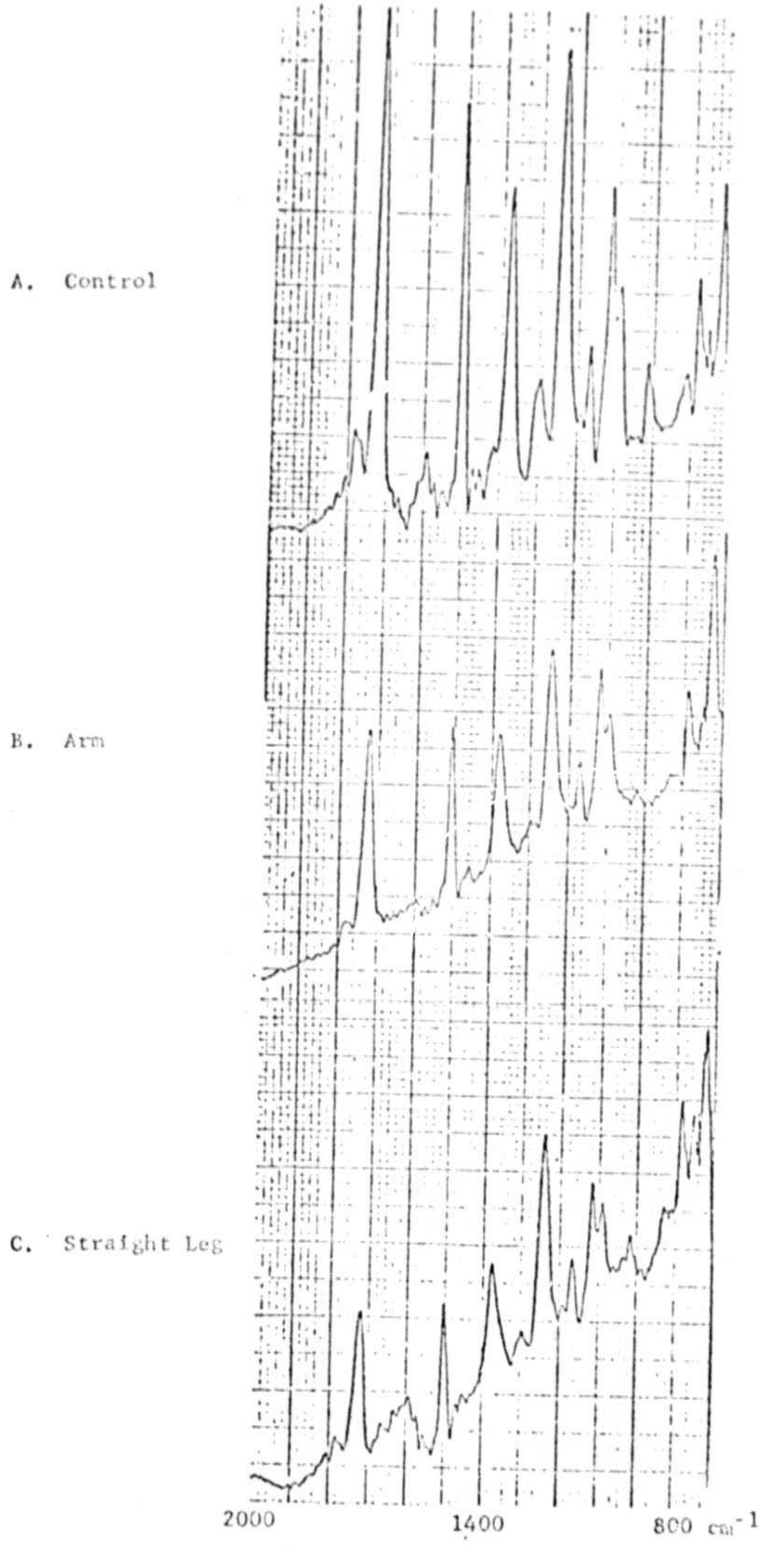

FIGURE 2. INTERNAL REFLECTION SPECTRA (Ge CRYSTAL)

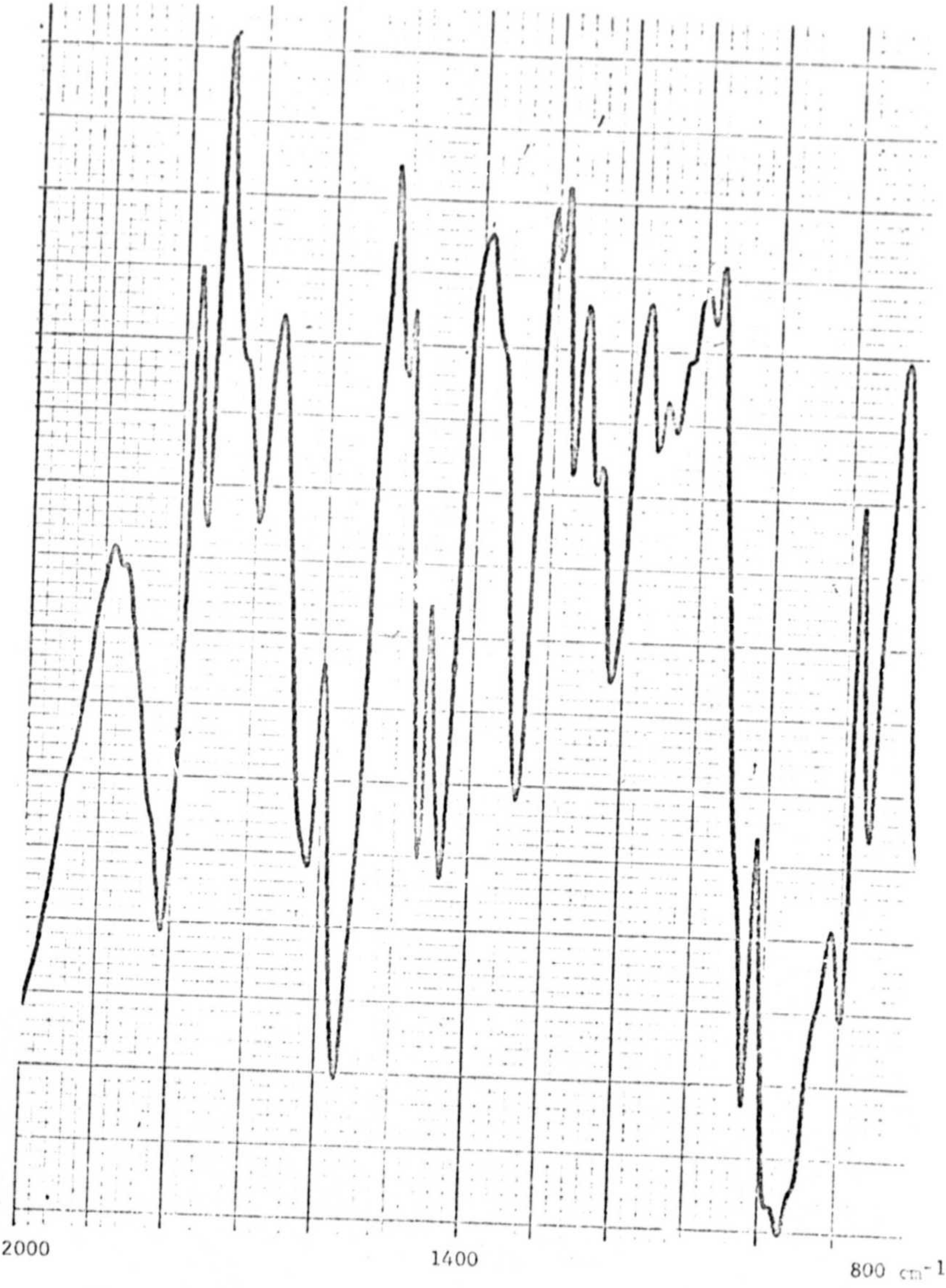

FIGURE 3. EXTERNAL REFLECTION SPECTRUM OF CONTROL SAMPLE

FIGURE 4. SUBTRACTED INTERNAL REFLECTION SPECTRA (KRS-5 CRYSTAL)

only very weak bands, indicating that there is little difference between these two samples. However, the subtraction between the arm sample and the control sample shows both positive and negative bands. Positive bands at 1510 cm^{-1} and 790 cm^{-1} represent an excess of a component in the arm sample which is likely to be aromatic and quite similar to the original polymer. Negative bands at 1740, 1190, and 1140 cm^{-1} indicate an excess of an ester-like component in the control sample. This ester-like component gives bands similar to those found in fingerprint grease and may represent an impurity introduced into the sample during processing or handling.

A subtracted spectrum between the straight leg sample and the control sample using a Ge crystal is shown in Figure 5. Here the carbonyl absorption band is at 1720 cm^{-1} and not at 1740 cm^{-1} as seen in the subtraction involving the spectra obtained with a KRS-5 crystal. Also, for the Ge spectra, there are no bands at 1190 and 1140 cm^{-1}. Thus, if the 1740, 1190, and 1140 cm^{-1} bands represent fingerprint grease, the grease must be near the surface facing the metal and not near the surface away from the metal. The problem of small amounts of grease on metals frequently has been experienced in other Battelle studies and, surprisingly, removal of the grease is very difficult.

In Figure 5 the bands observed represent bands of the original polymer which do not cancel out due to the baseline differences in the spectra involved in the subtraction (see Figure 2). Such baseline slopes occur when the sample does not cover the entire crystal and, therefore, uneven pressure on the sample often results.

The differences between the external reflection spectrum of the control sample (Figure 3) and the Ge internal reflection spectrum of the same sample (Figure 2) definitely show that the polymer facing the metal is different than the polymer away from the metal. This is indicated by the 1670 cm^{-1} band and the splittings and intensities of bands in the external reflection spectrum which is not seen in the internal reflection spectrum.

Thus, it is apparent that much better results and smaller differences could be obtained by (1) using larger samples to obtain stronger internal reflection spectra, thus giving better subtracted spectra, and (2) obtaining

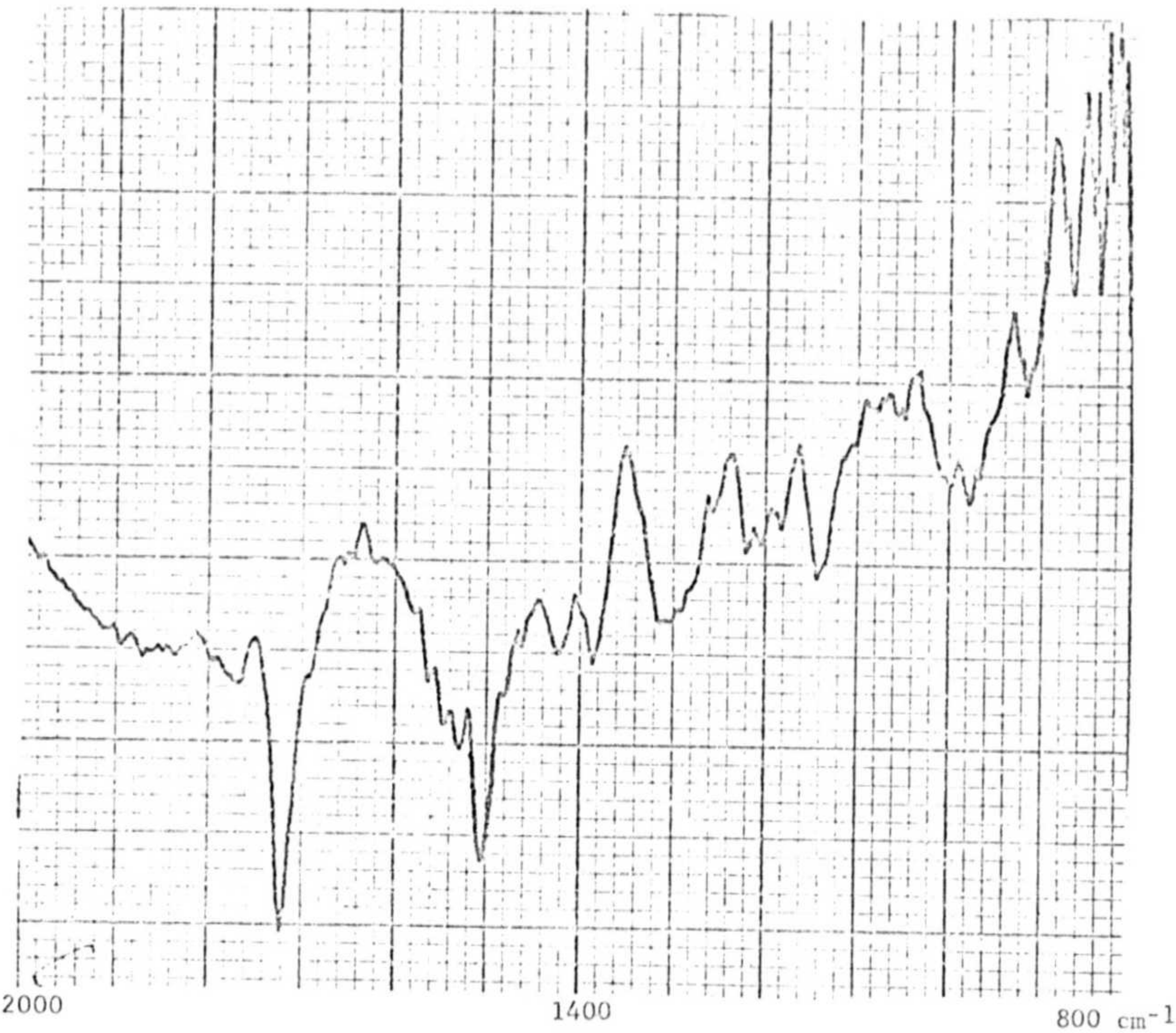

FIGURE 5. SUBTRACTED INTERNAL REFLECTION SPECTRA (Ge CRYSTAL)
(Control minus Straight Leg)

external reflection spectra on all samples which would assure that differences in the polymer at the metal-polymer interface are identifiable.

RECOMMENDATIONS

In view of the extremely critical materials requirements of the solar sail mission, it seems imperative that further studies be carried out to insure satisfactory performance in a number of materials- and performance-related areas. These would include:

- Materials Availability--From the standpoint of both quantity and quality
- Fabrication/Deployment Factors--Handling, fastening, deploying the exceedingly thin-film material
- Assured Service Reliability--Rate of property degradation as a function of service environment.

The success of the mission certainly will be dependent on the completeness with which relevant information pertaining to each of these research areas is identified and utilized.

APPENDIX A

SURVEY QUESTIONS

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SURVEY QUESTIONS

1. Raw Materials (for resin and film formation)

   (a) Solvents, chemicals, etc., used in resin production

   - Are sources of these to resin producer limited? (Establish adequacy of raw materials)

   - Are qualities of raw materials likely to change if resin production schedule is stepped up? (Applies probably only to small producer)

2. Normal Production

   - How is resin prepared? Is it a batch operation? Is it a continuous process?

   - What about QC instrumentation?

   - What about environmental considerations? If production rate is increased dramatically or if, for example, a different solvent is required, will pollution and/or toxicity problems arise?

   - What is normal output rate?

   - What is normal QC?

   - Is resin prepared routinely? Is there likely to be competition for machine time or other production facilities that could influence scheduling?

   - What are normal delivery schedules? What kind of lead time is normally required?

   - What are normal shipping procedures? packaging? handling?

3. Potential Production Needed for Sail Materials

   - Will existing facilities suffice? If not, how can additional production be handled?

   - Will larger volumes of raw materials, larger manpower requirements, larger capital needs, etc., create problems?

- Will there be specific development requirements for the product to be made for JPL?

- What quality assurance methods will be used associated with production of JPL material?

- What projected lead time?

- What projected shipping procedures?

4. Properties Assessment

- Are there potential shortcomings to the use of the specific material of interest that need clarification? (We will review for manufacturer what we consider to be major requirements of material.)

- (Obtain all available pertinent company literature.)