ADVANCED AROMATIC POLYMERS FOR SPACE APPLICATIONS AND THEIR ENVIRONMENTAL EFFECTS IN SPACE

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INTRODUCTION

Aromatic polyimides are known to have an excellent environmental stability in addition to thermal and mechanical properties due to their chemical structures and ordered-structures. When Apporo-II spacecraft successfully made a soft landing on the moon in 1968, it was observed that the golden, shinning polymeric film was covered on the surfaces of the lunar vehicle. It was a metalized polyimide film for thermal protection of spacecraft. A thermal control film which is so called a flexible multilayer thermal insulation(MLI) is now very popular for a passive thermal control systems of the spacecrafts.

A flexible solar array is an another attractive example of aromatic polyimide films for space application. Japan's first spacecraft SFU retrieved by the NASA Space Shuttle, during the STS-72 mission in this January deployed the two large polymeric wings in low earth orbit(LEO). Because of high Tg and outstanding mechanical properties even in very low temperature, aromatic polyimides are the most successful polymeric materials in space and are widely used for the materials in spacecrafts such as insulators of electric wires, tapes, dust covers, MLIs, light weight deployable solar arrays, and so on.

However, it was found that Kapton polyimide film seriously reduced the film thickness during the Space Shuttle mission in LEO. It is reported that the results originated from a surface degradation(recession) by impinging oxygen(atomic oxygen). SFU retrieved also exhibited signs of discoloration of MLIs, suggesting atomic oxygen erosion effects and complex environmental effects. This paper shows the typical examples of advanced aromatic polymers for space applications in Japan(1) and will discuss the space environmental effects of these polymers.

ADVANCED AROMATIC POLYMERS FOR SPACE APPLICATIONS

Spacecrafts and each instruments are usually covered with the various metalized polymer films to control the temperature of the spacecrafts. It is known that thermal control blanket can be applied to regulate surface temperature within the range desired to produce a hot or(cold) structure in a space environment. Surface temperature is a function of the ratios of solar absorptivity (α)to low temperature emissivity(ε). At equilibrium, low α / ε ratio provide a low surface temperature; high value provide a high surface temperature. Therefore, by choosing the proper film and the appropriate metal, it is possible to specify a thermal control surface within a wide range of α and ε values. A passive (nonactive) thermal control system very helps to maintain spacecraft systems and component at specified temperature limits. Kapton polyimide and Teflon films have long been accepted as the space stable insulating materials. Figure 1 shows chemical structures of aromatic polyimides for MLI. They can comprise over 90% outer layer covering of a spacecraft. Figure 2

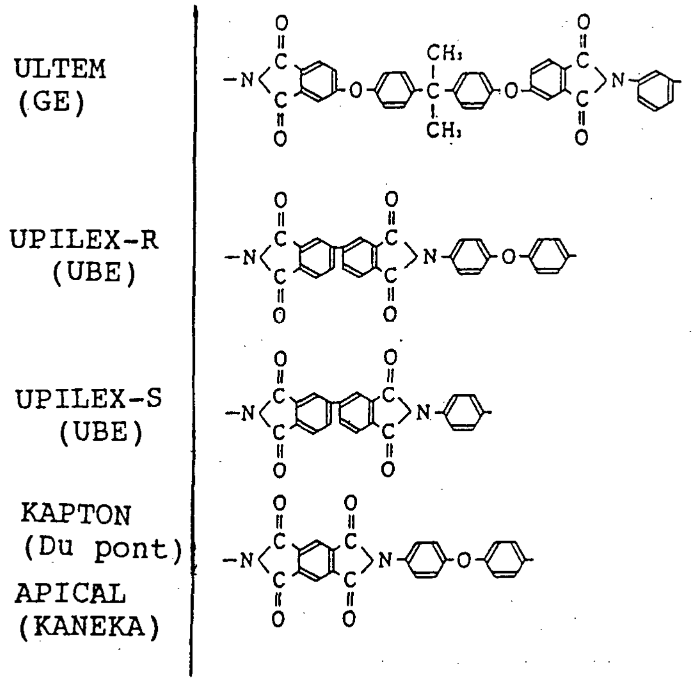

Figure 1. Chemical structures of aromatic polyimides.

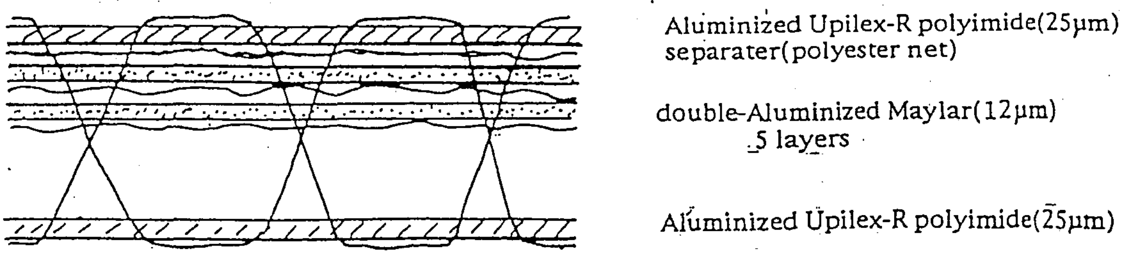

Figure 2. Multilayer thermal blanket for ASCA.

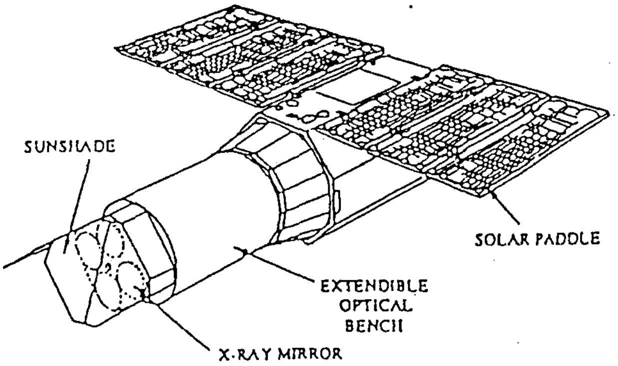

Figure 3. ASCA spacecraft

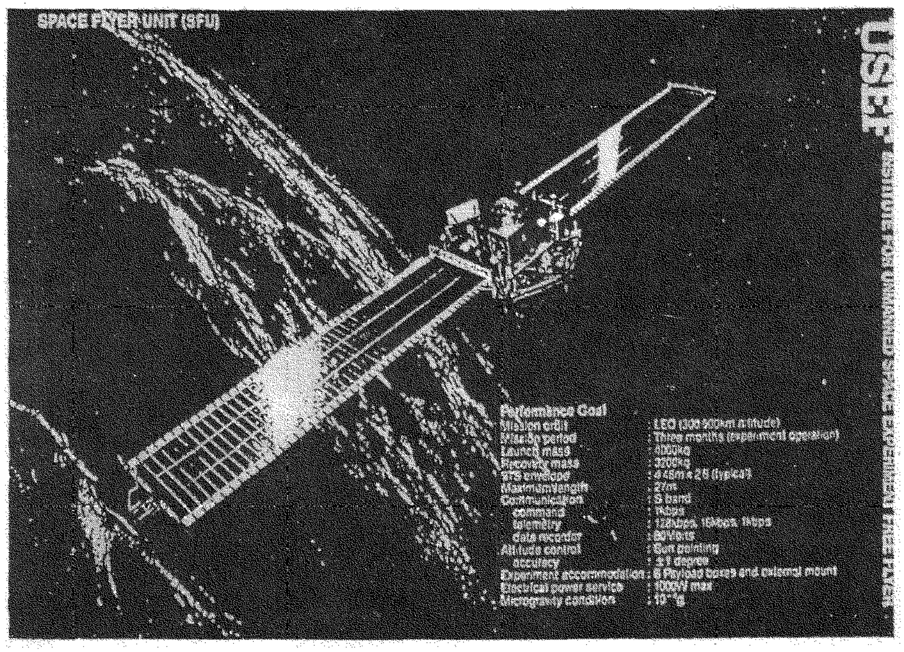

Figure 4. The SFU spacecraft with two extended flexible solar arrays.

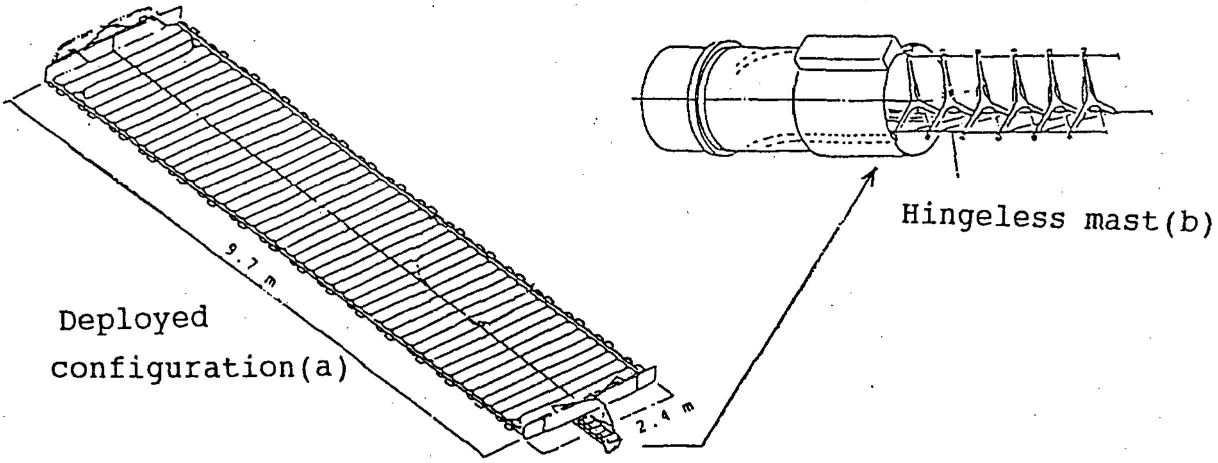

Figure 5a,b. Deployed configuration of the SFU solar array(a) and its hingeless mast(b)

shows the flexible multilayer thermal insulation(MLI) for ASCA shown in Figure 3. ASCA is an our new powerful X-ray observatory satellite launched in 1993. Because maximum allowable fluctuation of the focal point is 0,5 mm, the surface of 3,4 m long, high precision Extendible Optical Bench made of CFRP was covered UPILEX-R polyimide MLI. UPILEX-R consisting in biphenylimide with 4,4'-diphenyl ether posses a high optical transparency of the film as compared with that of pyromellitimide, Kapton. It is an advantage for the system due to low absorptivity. New MLI used for ASCA is composed by both 2 outer layers of aluminized 25 μ m UPILEX-R and 5 layers double-aluminized 12 μ m polyester films with separator net as shown in Figure 2. Until 1987, Kapton MLI is a only MLI for high temperature area of spacecraft and ASCA is the first satellite fully covered by an another polyimide MLI. On the other hand, outer layer were used for 50 μ m thick Aluminized KAPTON with 11 layers of double aluminized thin KAPTON films.

As you see in Figure 3, until ten years ago, a spacecraft usually has a rigid type power generator(solar paddle). When a spacecraft becomes larger, it requires much more electric power. It seems that a flexible solar array will be the most attractive way for the power generation in space. It was designed and experimented in Space Shuttle mission by NASA based on the beautiful application on an

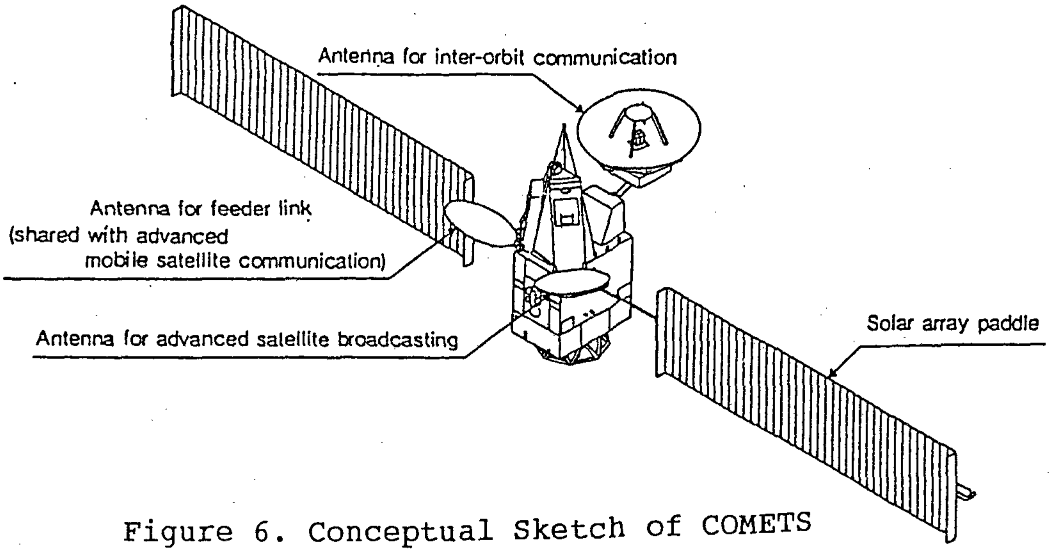

Figure 6. Conceptual Sketch of COMETS

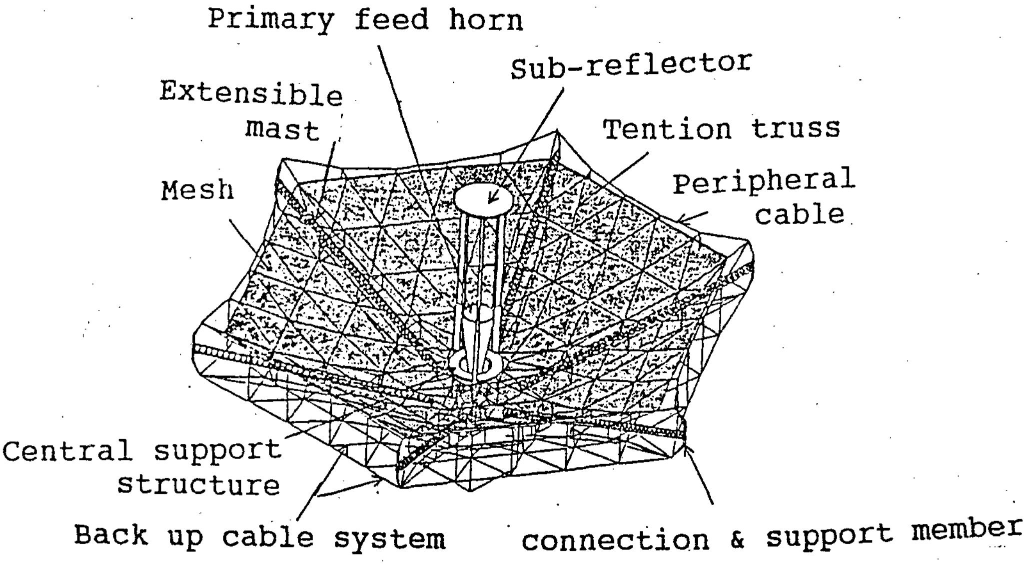

Figure 7a MUSES-B Antenna

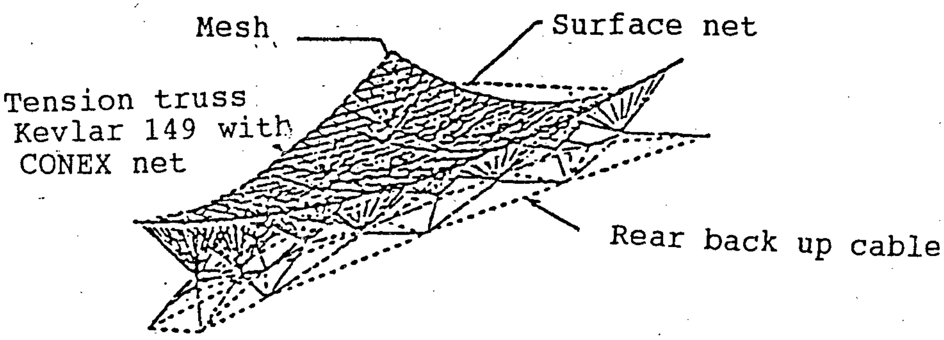

Figure 7b. Cable Structures and Mesh Configuration

idea of releasing the strain energy of fiber reinforced polymeric rods. It consists of a single extendible mast and flexible fold-out high performance film. Figure 4 illustrates SFU spacecraft with two extendible flexible solar arrays. It is the multi-purpose, Shuttle retrievable unmanned space experimental facility, and was launched in last year by H-II rocket, retrieved in this January.

Figure 5a and 5b describe the array configuration and the extendible mast, respectively. A size of the deployed wing is 2,4 mm wide and 9,7 m long. The array is composed of two boards assembly and the mast canister. The extendible/retractable mast is the continual coilable mast which is composed of three GFRP spring rods and radial spacers. The main source of its spring force is generated by bending strain energy of the FRP rods. The radial spacers were made of UPILEX-R molded. Therefore, no mechanical bachlash exists, because of no pin-joint hinges, resulting in the high dimensional stability. Each array blanket consists of 48 hinged polyimide panels(films) whose size is 202 mm wide and 2,400 mm long. About 27,000 solar cells are mounted on two array blankets and generate 3,0 kW power. 100 micrometer thickness silicon cell with 100 micrometer cover glass are adhered by S-691-RTV silicon type adhesive on the polyimide panels. It is known that UPILEX-S shown in Figure 1 is the most highly thermal and environmentally stable polyimide in space. 125 micrometer thickness of this film with SiO2 sputtered for protection against the atomic oxygen ion LEO was successfully used for the array blanket substrate. In 1997, National Space Development Agency of Japan(NASDA) which is in charge of development of application satellites and launchers also will launch the powerful Communications and Broadcasting Satellite(COMETS) with two large flexible solar array paddles shown in Figure 6. A array paddle also made of polyimide films is approximately 30 m long.

In near future, development of a large deployable antenna is an another important technology in space. Figure 7 illustrates Muses-B antenna which is planned to be used aboard the satellite for Space-VLBI(Very Long Baseline Interferometry). 10 m diameter parabolic antenna with mesh surface will be expected to deploy with

Table 1. Atomic oxygen reaction efficiencies for polymeric materials in USA.

Material	Reaction Efficiency ($\times 10^{-24}$ cm^3/atom)
Kapton	3.0
Tedlar	3.2
Mylar	3.4
Polyethylene	3.7
FEP Teflon (EOIM)	<0.05
FEP Teflon (LDEF)	0.25
Silicones:	
RTV-560	0.02*
DC6-1104	0.02*

* Units of mg/cm^2, loss assumed to occur in early part of exposure on STS-8 mission

P.R.Young, NASA CP 3275, 1993

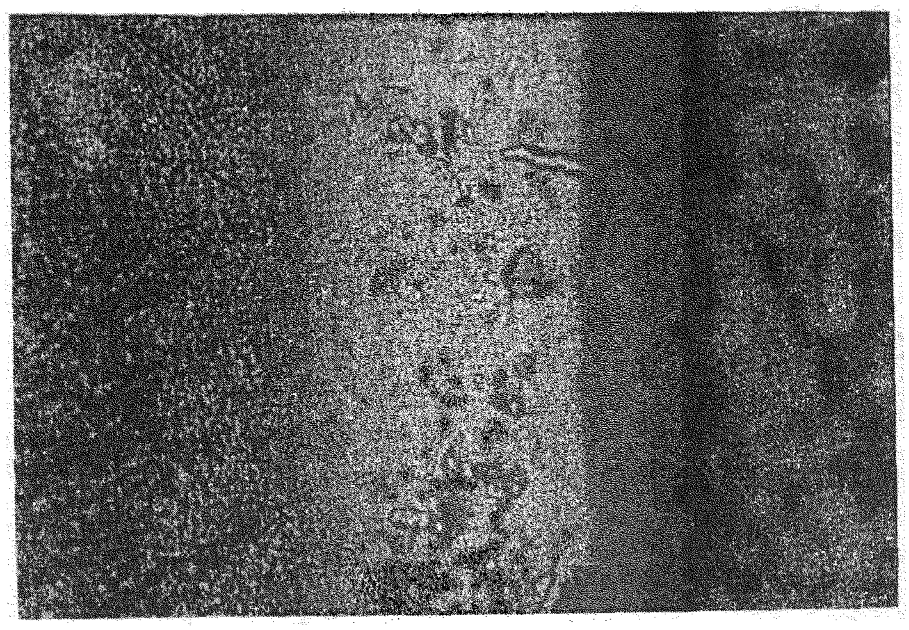

Figure 8. Optical photograph of exposed SFU-MLI.

step extending the six extendible masts gradually in space. This incredibly complicate system composed by about 6,000 fine cables of high modulus Kevlar 149 aramid covered by CONEX aramid net. Because of requirement of high surface accuracy, a cable must keep precisely its length without creep under a tension field in space. It is known that a high strength Kevlar 149 cable exhibits a very little elongation as stressed and has minus C.T.E. during wide range temperature. It is the first application of high performance organic fibers for a large deployable parabolic antenna surface in space.

SPACE ENVIRONMENTAL EFFECTS OF ADVANCED AROMATIC POLYMERS

When the SFU spacecraft was retrieved, and returned to Japan in early spring in 1996, it was observed that many surfaces of polyimide MLI lost its golden shining color and had undergone changes from pre-flight condition. It was reported that KAPTON polyimide film seriously reduced film thickness during exposure in LEO. Table 1 summarized atomic oxygen reaction efficiencies for several materials in USA The discrepancy in reaction efficiencies of the FEP in LDEF and EOEM exposures seems to be attributed to the synergistic interaction of the solar vacuum ultraviolet radiation. Silicones are known to form a self-protective SiOx glass-like film which resists AO attack. The surfaces of post-fright MLI on the SFU spacecraft became rugged and opaque as compared with unexposed film. Figure 8 shows a preliminary photo of outer layer polyimide MLI.

1) China-Japan ABC Seminar in Shanghai, 1995, p100