# 12.0 Materials for Missile, Space, and Launch Systems

## 12.1 Introduction

Affordability is the key criterion for assessing the value of a new technology and its potential incorporation into military applications. Although enhanced performance continues to be a high priority, performance improvements must be achieved with affordable technologies. Affordability must be considered in terms of the life cycle cost of the system. This means that revolutionary materials and processes, which in some cases are more expensive than those currently in use, may have a favorable impact on a system's overall life cycle cost, and may also provide performance advantages.

A major obstacle to fully exploiting space is the high cost of getting there. Secretary of the Air Force Sheila Widnall has said that the highest selection criteria for replacing our launch fleet are "affordability, affordability, affordability." Therefore, a prerequisite for any future materials development effort is its potential payoff in lowering the cost of existing and future weapons systems. Because propulsion systems account for approximately 50 percent of total launch costs, the potential exists to dramatically reduce the cost of space and missile operations by the application of improved materials. Some technology areas that offer the possibility of meeting these needs include new energetic materials for propulsion systems and improved, lighter weight materials with higher temperature capability that allow the thrust to weight ratio of the system to be increased or allow the system to be operated at a more efficient temperature.

Opportunities for developing new energetic materials, including propellants, is discussed in a separate chapter of this report. This chapter describes other materials needs and potential developments that are critical for improving the affordability and performance of advanced missile, space, and launch systems.

Along with affordability, the other overriding consideration in future materials development is environmental compatibility and reduced environmental impact. The continually increasing environmental regulations on disposal practices and the content and handling of waste streams will limit the processes and materials that will be acceptable for future systems. This is of course the case for all of the materials applications discussed in this report, not just for missile, space and launch system needs. It is therefore an issue that must be emphasized by the leadership within the Air Force and DoD, in order to ensure that technologists developing new materials and processes adequately address environmental compatibility.

## 12.2 Materials for Improved Performance

The areas of highest payoff for space and missile applications in terms of performance are 1) lowering the weight and 2) improving the high temperature capabilities of advanced materials. Composites have become the materials of choice for certain applications because of their significant potential weight savings compared to conventional metallic structural materials. However, although significant improvements have been made, improving the high temperature capability of composites and metallic alloys must remain a key objective of future development efforts.

There are numerous components in rocket motors that can benefit from improved materials. In all cases, the key issues in the development of new materials and processes are affordability and environmental compatibility. In the case of structural materials, lower weight with equal or better strength and stiffness is the main goal, while high-temperature capability and improved reliability are also prime objectives. In solid rocket motors, the structural components for which new, lighter-weight, high-temperature materials would provide the greatest payoff are cases, nozzles, and insulation. In liquid rocket motors, improved high-temperature capability offers the greatest performance payoff, with improved mechanical strength and lower weight also being important. Some of the components in liquid rocket engines for which advanced materials development should be pursued include tanks, turbines, injectors, nozzles, hot gas manifolds, and preburners. For space structures and space rocket motors, low weight is the driver. Significant cost savings can be realized by replacing metallic components with lighter weight composites.

There is a critical need for advanced materials with adequate structural and transmissive properties for windows and radomes for hypersonic (Mach 5 - 10) missiles and aerospace vehicles. These types of materials would also serve in other applications like sensors, space structures, and solar propulsion systems. Materials with improved optical properties at certain wavelengths, such as that of $CO_2$ lasers (8-12 nm), are also needed for supersonic applications (Mach 2 - 3). Advanced synthesis and processing of diamond films is one technical approach that may satisfy these needs. Improved methods of producing diamond-based structures could lower costs sufficiently to make diamond films or even diamond monoliths a viable option for future transparent materials applications.

Other needs unique to space systems are materials with improved resistance to radiation and atomic oxygen. Current efforts in this area are focusing on silicon- or aluminum-imbedded materials that form an oxide coating when attacked by atomic oxygen. Many other materials solutions may also become available.

There is considerable Air Force interest in running future liquid rocket engine oxidizer turbopumps oxygen-rich. Using them this way allows a lower turbine inlet temperature than fuel rich operation, and it eliminates a complex, heavy, multistage seal between the turbine and the impeller sections of the pump. The result is significant durability enhancement and thereby greater reliability. There is thus a need to identify and develop materials that are compatible with high-temperature, high-pressure gaseous oxygen in the turbopump and associated machinery. Likely candidates include metals, coated metals, and ceramics.

Another key area in which improvements to rocket propulsion are needed is turbopump engine bearings. Traditionally, vibrations experienced when the pump is cooled for liquid oxygen operation generate heat, leading to thermal runaway. Pump bearings are made of silicon nitride machined to a very fine finish with a low coefficient of friction in order to control temperatures during operation. There are two problems with this approach: 1) These bearings require high-quality silicon nitride produced only in Japan. 2) The precision production and machining required for the necessary surface finish are done in Germany due to the absence of a U.S. capability. There is no domestic source for these materials or components. Clearly, it is essential that our ceramics capabilities be markedly improved, not only for the production of high-performance materials but also in the high-level machining required to render these materials suitable for component application.

Developing approaches to combininghigh thermal conductivity, high modulus and low coefficient of expansion with improved strength in carbon-fiber composites is another important area Thermal management and dimensional stability are often limitations in space structures. Simultaneously achieving the thermal properties, structural loads, and displacement requirements will lead to decreased system weight.

## 12.3 Materials Technologies Critical for Space and Missile Systems

Other materials technologies with the potential to produce performance and cost improvements in propulsion systems include the development of advanced adhesives and coatings, thin films and diamond manufacturing, environmentally compatible insulation, molecular self-assembly and nanoassembly of structures, microelectronic machines, microtube technology, high power density, uncooled electronics, advanced IR sensor materials, nonlinear optical materials for high speed on board data processing and transmission, and miniaturization of rocket and space components. Based on current efforts, it appears that specially designed hybrids (combinations of organics, inorganics, metals, ceramics) will be the materials of choice to satisfy the requirements for many of these advanced applications. Hybrid materials may also offer other advantages besides improved performance, such as the ability to design for lower sensitivity to impact or hostile action.

*Adhesives and coatings.* Development of adhesives and coatings that are more environmentally acceptable is currently a high priority for both military and commercial applications. While the impact to the environment of adhesives and coatings used for space and missile systems is extremely small compared to other uses (such as aircraft, or, even more significantly, commercial industry), it is important to recognize the effect of environmental regulations on the availability of existing specialty adhesives and coatings required by military aerospace systems and on the development of new systems for future needs. Complying with new laws and regulations to protect the environment while preserving the capability of existing and future systems will require a considerable investment in new technologies. It will also require leadership and foresight by senior management, who collectively must take the initiative in sponsoring the development of new technologies that provide environmental compliance without an unacceptable deterioration in the performance or cost of weapons systems.

*Thin films and diamond technology.* Improved thin films and more affordable diamond synthesis and processing are enabling technologies for numerous applications. Some benefits for aerospace systems include the development of high thermal conductivity substrates for a number of uses (e.g., thermal management in electronics), smart coatings that act as sensors and protective materials, diamond windows, diamond-coated bearings, diamond micromechanisms, and diamond-based thermionic devices.

*Thermal insulation.* Replacement of current insulation, which contain asbestos, with new, environmentally benign formulations is certain to be a high priority over the next decade. Some promising approaches include insulation based on high performance polymers such as Kevlar or oxy-silicates, or TPE-based formulations.

*Molecular self-assembly and nanotechnology.* The achievement of micron precision in fabricating new devices revolutionized the electronics industry during the 1960s and 1970s, which in turn enabled development of a new generation of advanced weapons systems. Similar revolutionary advancements may be realized over the next decades through nanometer processing.

Nanostructured materials have significant promise for a number of applications, both military and commercial. For aerospace uses, nano-based processing could provide advanced electro-optic materials (discussed in Chapter 9.0), sensors (discussed in Chapter 13.0) and specialized structural materials, such as multispectral windows. Nano-assembly offers the possibility for creating multi-layer structures specifically designed on a molecular level. For example, current work is being conducted on multispectral windows such as shown in Figure 12.1 which consist of nanostructured silicon with specially designed dielectric properties imbedded in diamond or another high temperature substrate.

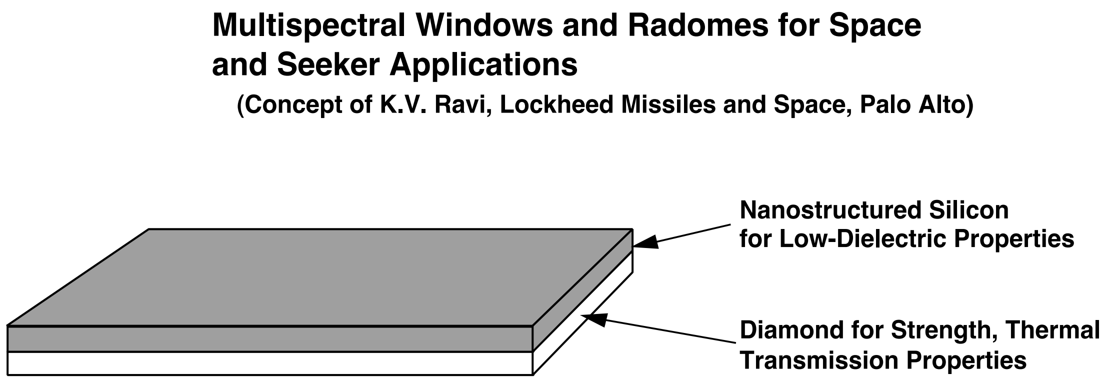



*Figure 12.1 Nano-structured Multispectral Windows*

*Micro-electronic machines (MEMS)/miniaturization.* MEMS promises to create a revolution in the capabilities of aerospace systems by combining the benefits of very small size, high performance, reliability and very low cost into one package. In space and missile applications, where size, cost, and intelligence are dominant considerations, the first MEMS systems are already finding application in the form of tiny, cheap inertial guidance units for smart munitions and micro-instruments for satellites. The ability to put on a single chip such devices as accelerometers, compasses, gyroscopes, pumps, fluid mixing systems, gas analyzers, cameras, and adaptive optical systems promise revolutionary improvements in every kind of complex technological system. The integration of hundreds, even thousands of microdevices into larger systems and structures offers still unexplored possibilities for self-monitoring, adaptability, and autonomous control. Figure 12.2 shows a microscale motor developed by Eckart Jansen of the MIT Microsystems Technology Laboratory.

Recent developments such as microtubes offer broad possibilities for micro-machine applications as well as potential uses in processing unique components, such as self-cooled nozzles or self-monitoring smart devices and structures. Some other potential propulsion applications

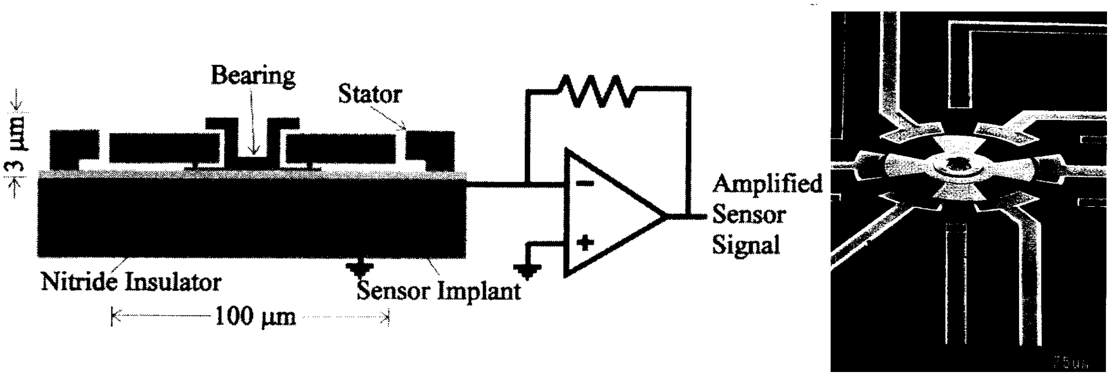



*Figure 12.2 A microscale electric motor produced at the MIT Microsystems Technology Laboratory: a) diagrammatic b) imaged*

for microtube composites include encapsulation, bondline venting of off-gases, microthin injectors, microcombustion chambers, and solar absorbing heat exchangers. Figure 12.3 shows a potential use of microtubes in high temperature insulation.

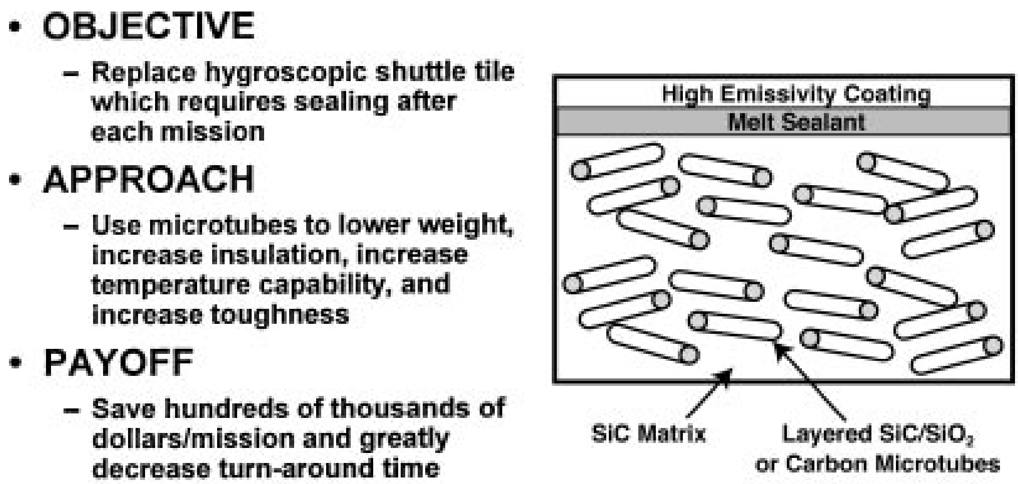



*Figure 12.3 Microtubes in High Temperature Insulation (Photo courtesy of Phillips Laboratory*

*High Power Density Uncooled Electronics, Advanced IR Sensor Materials, Nonlinear Optical Materials for Data Processing and Transmission.* High power density electronics based on wide-bandgap semiconductors have the potential for great payload weight savings because they can handle much more power than similar sized conventional semiconductors, or can deliver the same power in a much smaller and lighter package. They also have significant potential advantages in radiation hardness and reliability. Advanced IR sensor materials will increase the performance of surveillance payloads while reducing weight due to reduced cooling requirements. Nonlinear optical materials are the key to high speed on-board optical data processing and optical communication between satellites or between satellites and Earth. Millimeter-wave crosslink communication is also a high payoff, but potentially nearer term capability.

A consistent long-term investment in the fields of nanotechnology and miniaturization is strongly recommended. These fields offer great potential for enabling the development of new components and devices for aerospace systems and also have potentially broad commercial significance.

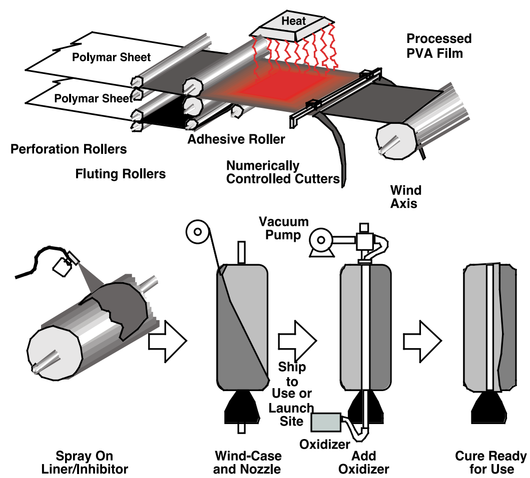
## 12.4 Far-Term Objectives

Far-term objectives for low-cost solid propulsion systems include development of functionally graded motors and integrated manufacturing techniques that allow rockets to be fabricated with a minimum of steps. Such methods may include fabrication of more than one rocket component (e.g., rocket propellant, insulation, case) concurrently, or with a single piece of equipment. Figure 12.4 shows a potential concept for low-cost manufacture of rocket motors. Functionally graded motors would provide a means for controlling the thrust of the rocket by changes in the internal composition of the propellant within the motor. Thermoplastic-based rocket propellants and rocket components would be inexpensive to produce and would allow the motor to be recycled rather than disposed of at the end of its service life.

Another far-term propulsion concept would require light weight, strong materials for use in cryogenic tanks. These tanks may contain liquid helium with energetic materials slurried in, or they may contain solid hydrogen or solid oxygen with energetic fuels or oxidizers embedded in the matrix. In conjectural designs for reusable launch vehicles (RLVs), there may be a large temperature delta of approximately 3000 K between external, leading-edge structures and the cryogenic tank. This will place tremendous loads on the materials.

**TECHNOLOGY CHALLENGE:**

**Develop Revolutionary Approach For Manufacturing Rocket Motors in More Reliable, Safe, Cost Efficient and Environmentally Acceptable Manner**




**PAYOFF:**

- **Significant Improvement Over Conventional Solid Motor Manufacture**

  **9 Steps vs 23**
- **Environmentally Benign Solution Propellant**
- **Safer Manufacture**
- **Improved Performance (greater than 5%)**

*Figure 12.4 Concept for Concurrent Manufacture of Rocket Motor Components (Photo courtesy of Phillips Laboratory)*