IN-33

13496

P8

NASA Technical Memorandum 104375

High Temperature Power Electronics for Space

Ahmad N. Hammoud
Sverdrup Technology, Inc.
Lewis Research Center Group
Brook Park, Ohio

and

Eric D. Baumann, Ira T. Myers, and Eric Overton
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio

Prepared for the
First International High Temperature Electronics Conference
cosponsored by Sandia National Labs, Wright Research Development Center,
and the University of New Mexico
Albuquerque, New Mexico, June 16-20, 1991

Ahmad N. Hammoud
Sverdrup Technology, Inc.
Lewis Research Center Group
Brook Park, Ohio 44142

Eric D. Baumann, Ira T. Myers, and Eric Overton
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

Abstract

Electrical components and systems are often required to operate reliably in harsh environments where stresses of different kinds and intensities are encountered. High temperature constitutes one of these stresses which exists in space-based as well as terrestrial environments. Space exploration missions (lunar base), nuclear-powered space vehicles, integrated engine electronics, satellite power conditioning, and SDI systems are examples of aerospace applications where high temperatures may be present. In addition, heat is generated by power processing devices during operation. This internally-developed thermal stress greatly influences the performance of the devices through gradual degradation which eventually leads to failure. Development of high temperature materials and components is therefore necessary to meet the challenges of advanced space power and electronic systems technology which places a great emphasis on reducing component size and weight, increasing packaging density, and improving performance and reliability.

A high temperature electronics program at NASA Lewis Research Center focuses on dielectric and insulating materials research, development and testing of high temperature power components, and integration of the developed components and devices into a demonstrable 200 °C power system, such as an inverter. An overview of the program and a description of the in-house high temperature test facilities along with experimental data obtained on high temperature materials will be presented.

INTRODUCTION

Dielectric and insulating materials are used extensively in many electrical systems and components such as high voltage capacitors, power cables, electronic switching and sensing devices, and energy storage and transport systems. These components and devices are often required to operate reliably in harsh environments where stresses of different kinds and intensities are encountered. High temperature constitutes one of these stresses which exists in space-based as well as terrestrial environments. Space exploration missions (lunar base), nuclear-powered space vehicles, integrated engine electronics, satellite power conditioning, and SDI systems are examples of aerospace applications where high temperatures may be present.

In addition to being an environmental factor, heat is generated continuously by power processing and conditioning devices during operation. The generation of heat and its build-up are believed to greatly influence the performance of many power devices as they cause gradual degradation which eventually leads to catastrophic failure. This internally-developed thermal stress is becoming more severe as the currently emerging demand for aerospace technology places a great emphasis on increasing the energy densities and raising the power levels of space-based power systems and components. For instance, future plans for many space exploration missions call for a tremendous increase in the power capability up to a magnitude of the order of megawatts [1]. These requirements will certainly result in raising the operating temperature of the device/system concerned [2]. The development of high temperature insulating and dielectric materials, and power components and devices is therefore necessary to meet the challenges of advanced space power and electronic systems technology with objectives to reduce component size and weight, increase packaging density, and improve performance and reliability.

A high temperature power electronics program at the NASA Lewis Research Center focuses on dielectric and insulating materials research, development and testing of high temperature power components, and integration of the developed components and devices into a demonstrable 200 °C power system, such as an inverter. A description of the in-house high temperature test facilities along with some experimental data obtained on high temperature materials are presented in this paper.

RESEARCH FACILITIES

A large number of insulation evaluation and electrical component testing facilities are available at the NASA Lewis Research Center. These facilities, which include thermal aging and conditioning, electrical breakdown and life testing, and dielectric characterization, have been set up to study the effect of electrical and/or thermal stressing upon the electrical and physical properties of dielectric materials and upon reliability and performance of components for use in high power energy storage and transport systems. A brief description of some of these facilities is described below:

Thermal Aging and Conditioning--This facility is comprised of a Hotpack Digimatec benchtop oven with chamber capacity of 5.1 cu.ft. The oven has a temperature range of 35 to 350 °C with electronic controller, digital readout, and oven temperature protection. Heated air is mechanically convected through the test chamber by a high velocity motor-driven blower to assure temperature uniformity within ±1.25 °C. Two adjustable ventilators on top of the unit control the flow of exhaust and intake air. The oven has two thru-wall ports for high voltage power cables and signal and control connections.

Breakdown and Life Testing--A Hipotronics, Model HD 140, power supply allows high voltage stressing and breakdown measurements of film specimens and components. The unit can provide an output voltage of up to 40 kV DC or 15 kV AC with an output current of 5 mA. The high voltage supply has many features which include zero start, external interlock, adjustable voltage control, and overload protection. Grounding and shielding measures were also installed to ensure personnel safety and equipment protection.

Low to medium voltage AC testing can be performed using a Powertron Series 250-HF power supply. It consists basically of an oscillator and an amplifier with output power of 250 VA at 130 V in a frequency range from 45 Hz to 50 kHz. An output voltage of 2 kV at 20 kHz can be obtained by utilizing a step-up transformer which was built in-house. The power supply provides stable, low distortion power and has short-circuit as well as thermal overload protection.

Partial discharge signatures and discharge inception and extinction voltages of materials and components can be obtained using a Biddle Instrument, Model 75-795, Partial Discharge Analyzer. The unit is capable of providing voltages up to 36 kV AC or 40 kV DC at output currents up to 3 mA. An AC and DC superimposed output voltage up to 40 kV can be applied to the test specimen. In addition, the DC output can be provided in either polarity with 70 V resolution. Voltage control, over-current protection, and interlock mechanism are built into the unit.

Dielectric Characterization--Dielectric constant, electrical loss tangent, and capacitance of test specimen can be obtained in a frequency range from 12 Hz to 100 kHz using a GenRad 1689 RLC Digibridge. Component parameters such as capacitance, dissipation factor, inductance, quality factor, and insulation resistance can also be characterized using this instrument. The RLC bridge is microprocessor controlled, IEEE-488 programmable with an accuracy of 0.02 % and is capable of providing an internal bias of 2 V to the device under test. A bias of up to 60 V DC may also be applied with an external power supply. Current must be limited to 200 mA in this mode of operation.

Surface and volume resistivities of dielectric films can be determined through the use of a Keithley 6105 Resistivity chamber in conjunction with a high voltage power supply and an electrometer. The chamber is a guarded test fixture with good electrostatic shielding and high insulation resistance and is designed in accordance with ASTM standards for measuring electrical resistance of dielectric and insulating materials. Volume resistivity up to 10^{19} Ω.cm and surface resistivity up to 10^{18} Ω can be measured and excitation voltages of up to 1000 V can be applied.

A Keithley Source-Measure Unit SMU 237, capable of simultaneously sourcing and measuring DC voltage or current, can be used in a wide variety of measurement applications. These include characterization of semiconductor devices, leakage currents and resistivity measurements, and dielectric absorption and withstand voltage testing. The unit is capable of sourcing and measuring voltages from 100 μV to 1100 V, and currents from 100 fA to 100 mA with an accuracy of 0.03 %. The inputs and outputs are fully guarded, and the unit is configured to allow four-terminal measurements. Other features include simplified programability, memory storage of data up to 1000 points, and selectable input sweep capability.

Others--In addition to those mentioned above, equipment exists for data acquisition, measurement, and manipulation. These devices include various storage oscilloscopes, computer workstations, and IEEE-488 interfaceable instruments. Numerous standard and custom-built test fixtures allow the characterization of dielectric films and insulating fluids at room as well as at high temperatures. The effects of electric field uniformity, for example, on the breakdown behavior of many insulating systems can be determined by utilizing test electrodes with different sizes and shapes. The influence of electrode material and geometry can also be investigated.

Other on-site supporting research facilities include physical, chemical, mechanical, and optical test chambers and diagnosis stations. Characterization of materials and evaluation of systems and components under space-like environment, such as vacuum, plasma, and atomic oxygen, can be achieved in multi-stress aging test rigs and facilities.

EXPERIMENTAL PROCEDURES

Ongoing materials research includes the characterization of currently available dielectrics as well as the development of new materials for potential use as wire insulation and capacitor dielectrics in high temperature environments. A description of some of the current investigations follows.

Four candidate materials were evaluated for use as high temperature capacitor dielectrics. These were polybenzimidazole-PBI (Hoechst Celanese), Voltex 450 (Lydall, Inc.), and Nomex 410 and 418 (DuPont). The thicknesses of these samples were 2, 10, 2, and 3 mils, respectively. PBI is a linear thermoplastic polymer which has excellent thermal stability and strength retention over a wide range of temperatures [3]. It is chemically stable and is used as a reinforcement in high performance composites, filament winding and structural applications. Voltex 450, which is composed of aramid fiber and neoprene binder, has low water absorption and high dielectric strength [4]. It is commonly used as high temperature insulation in motors, generators, and transformers. Nomex 410 and 418 are aramid papers made from synthetic aromatic polyamide polymer. They are chemically stable and radiation resistant and are commonly employed as layer and barrier insulation in rotating machines and transformers. The 418 grade paper contains 50 % inorganic mica platelets and is designed for high voltage applications. The addition of mica makes the properties of the insulation more stable with temperature [5]. Some properties of the materials tested are given in Table I [3-5].

TABLE I. Properties of Dielectrics Tested [3-5].

Property	PBI	Voltex 450	Nomex 410	Nomex 418
Service Temperature (°C)	>300	>200	>220	>220
Shrinkage (%)	3 @ 315 °C	0.3 @ 180 °C	1.6 @ 300 °C	0.4 @ 300 °C
Density (g/c.c)	1.2 - 1.4	1.6	*	*
Elongation-at-Break (%)	*	*	11	2.3
Dielectric Constant	4.4 - 16.2	3.1	1.6	2.3 - 2.9
Dissipation Factor (x 10^{-2})	2.4 - 57	1.61	0.4	0.6 - 13
Dielectric Strength (kV/mil)	4 - 7	0.45	0.48	0.77
Volume Resistivity (Ω.cm)	10^{14} - 10^{16}	*	10^{14} - 10^{16}	10^{13} - 10^{16}
Surface Resistivity (Ω/sq.)	5 x 10^{10}	*	10^{14} - 10^{15}	10^{11} - 10^{14}

* Data Unavailable

The materials were characterized in terms of their dielectric constant and dissipation factor in a temperature range of 20 to 250 °C with an applied electrical stress of 50 V/mil at 60 Hz using Tettex Instruments, Type 2821 Capacitance System and Type 2914 Dielectric Test Cell. The PBI film was further characterized in terms of its AC and DC breakdown voltages as a function of temperature, up to 300 °C. A Hipotronics AC Dielectric Test Set and a Universal Voltronics DC power supply were employed in making these measurements. Dow Corning 210 H silicone fluid served as the impregnant. A temperature controller was utilized to maintain the test temperature within ±2 °C. During testing, the specimen was held between two cylindrical stainless steel electrodes of 0.25 inch diameter (ASTM D-149) and the voltage was raised at a rate of 500 V/s until breakdown occurred. The values reported are the average of at least seven measurements.

RESULTS AND DISCUSSIONS

The dielectric constant and the dissipation factor of the tested materials as a function of temperature with an applied electrical stress of 50 V/mil at 60 Hz are shown in Figures 1 and 2, respectively. It is evident that while the dielectric constant and the dissipation factor of both Nomex papers did not change with temperature, these properties for the other two materials increased at elevated temperatures. These changes became prominent when the temperature reached 150 °C for Voltex paper and 250 °C for PBI film. It is important to note that while Voltex started to char when the temperature exceeded 200 °C, the PBI polymer maintained its physical integrity at temperatures as high as 300 °C. The increase in the dielectric constant and the dissipation factor with temperature might be attributed to some thermally-induced molecular agitation phenomena or other processes such as material softening and degradation as the temperature approaches that of the material's thermal stability limit.

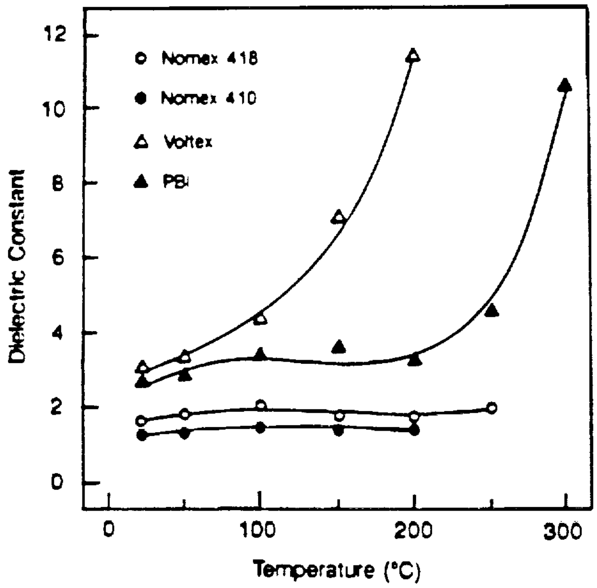

FIGURE 1. Dielectric Constant versus Temperature.

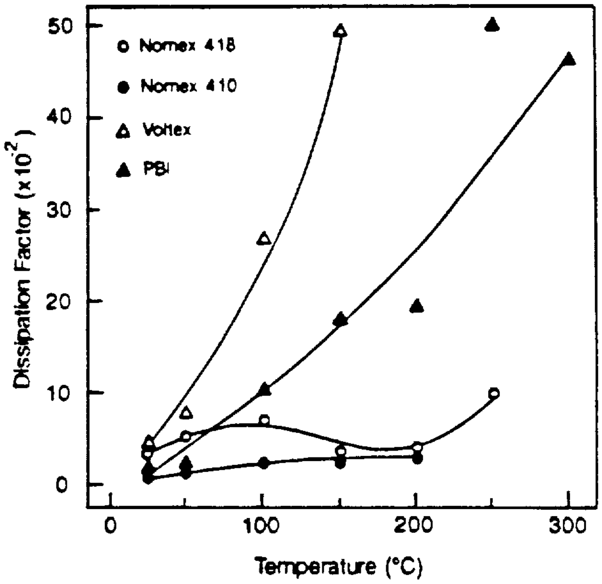

FIGURE 2. Dissipation Factor versus Temperature.

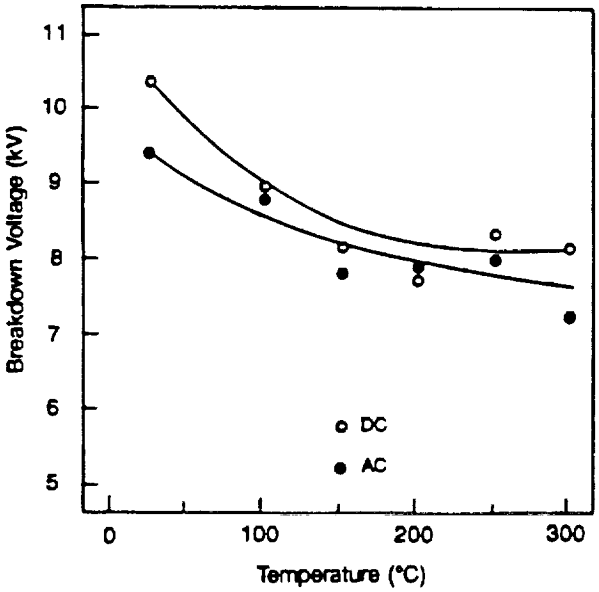

FIGURE 3. Dependence of Dielectric Strengths of Impregnated PBI Film on Temperature.

A comparison of the AC (peak) and DC breakdown voltages of the silicone oil-impregnated PBI polymer film as a function of temperature is shown in Figure 3. It can be seen that for either case, AC or DC, the dielectric strength decreased slightly with increasing temperature. This reduction in the breakdown voltage can be attributed to the softening of the polymer film when exposed to high temperature. In addition, the heat build-up occurring in the specimen due to increased loss with temperature as well as a possible decomposition of the oil at high temperatures might have contributed to the breakdown behavior.

CONCLUSION

An overview of the high temperature electronics program at NASA Lewis Research Center was given. The research efforts currently underway include dielectric and insulating materials research and evaluation, development and testing of high temperature power components, and system integration and demonstration. Other supporting research activities include the development of high temperature silicon carbide materials and devices, the characterization of magnetic materials at high temperatures, radiation effects, power management and control, and system studies, to name a few.

A description of the in-house high temperature research facilities for materials testing and characterization, and component and system evaluation along with some preliminary experimental data obtained on high temperature dielectrics were also represented. Coordination of the various research efforts as well as the utilization of test facilities with the proper diagnostics and analytical tools will certainly contribute to meeting the needs of future space power and other electrical systems.

Acknowledgments

This work was supported by NASA Lewis Research Center, Contract #NAS3-25266, Task Order #5423-01, "High Temperature Dielectrics."

References

1. R. W. Bercaw, "Toward an Electrical Power Utility for Space Exploration," Proceedings of the European Space Power Conference, Madrid, Spain, October 2-6, 1989.

2. E. Sugimoto, "Applications of Polyimide Films to the Electrical and Electronic Industries in Japan," IEEE Electrical Insulation Magazine, Vol. 5, No. 1, 1989.

3. E. J. Powers and G. A. Serad, "History and Development of Polybenzimidazoles," in High Performance Polymers: Their Origin and Development, R. B. Seymour and G. S. Krishenbaum, editors, Elsevier Pub., 1986.

4. Lydall Inc., Voltex 450 Product Bulletin, 9/88.

5. DuPont Co., Nomex Aramid Technical Bulletins E-91807 and E-91809.

NASA
National Aeronautics and
Space Administration

Report Documentation Page

1. Report No.
NASA TM - 104375

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
High Temperature Power Electronics for Space

5. Report Date

6. Performing Organization Code

7. Author(s)
Ahmad N. Hammoud, Eric D. Baumann, Ira T. Myers, and Eric Overton

8. Performing Organization Report No.
E -6181

10. Work Unit No.
506-41-41

9. Performing Organization Name and Address
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135 - 3191

11. Contract or Grant No.

13. Type of Report and Period Covered
Technical Memorandum

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, D.C. 20546 - 0001

14. Sponsoring Agency Code

15. Supplementary Notes
Prepared for the First International High Temperature Electronics Conference cosponsored by Sandia National Labs, Wright Research Development Center, and the University of New Mexico, Albuquerque, New Mexico, June 16-20, 1991. Ahmad N. Hammoud, Sverdrup Technology, Inc., Lewis Research Center Group, 2001 Aerospace Parkway, Brook Park, Ohio 44142 (work funded by NASA Contract NAS3-25266). Eric D. Baumann, Ira T. Myers, and Eric Overton, NASA Lewis Research Center. Responsible person, Ahmad N. Hammoud, (216) 433-8511.

16. Abstract
Electrical components and systems are often required to operate reliably in harsh environments where stresses of different kinds and intensities are encountered. High temperature constitutes one of these stresses which exists in space-based as well as terrestrial environments. Space exploration missions (lunar base), nuclear-powered space vehicles, integrated engine electronics, satellite power conditioning, and SDI systems are examples of aerospace applications where high temperatures may be present. In addition, heat is generated by power processing devices during operation. This internally-developed thermal stress greatly influences the performance of the devices through gradual degradation which eventually leads to failure. Development of high temperature materials and components is therefore necessary to meet the challenges of advanced space power and electronic systems technology which places a great emphasis on reducing component size and weight, increasing packaging density, and improving performance and reliability. A high temperature electronics program at NASA Lewis Research Center focuses on dielectric and insulating materials research, development and testing of high temperature power components, and integration of the developed components and devices into a demonstrable 200 °C power system, such as an inverter. An overview of the program and a description of the in-house high temperature test facilities along with experimental data obtained on high temperature materials will be presented.

17. Key Words (Suggested by Author(s))
High temperature; Dielectrics; Insulation; Components; Electric power; Electronics

18. Distribution Statement
Unclassified - Unlimited
Subject Category 33

19. Security Classif. (of the report)	20. Security Classif. (of this page)	21. No. of pages	22. Price*
Unclassified	Unclassified	8	A02

NASA FORM 1626 OCT 86

*For sale by the National Technical Information Service, Springfield, Virginia 22161

[illegible] 7 INTENTIONALLY BLANK PRECEDING PAGE BLANK NOT FILMED