## Identification and Significance of the Problem or Opportunity

The ultimate goal of this program is to produce high-efficiency thin multijunction solar cells that can generate space-based specific power exceeding 1000 W/kg. The proposed project seeks a dramatic decrease in both the mass and stowage volume for a space-based solar array, relative to State-of-the-Art (SOA) configurations. Reduced solar array mass and stowage requirements obviously mean reduced launch costs, mitigated satellite dynamics/controls issues, enhanced orbital maneuvering capabilities, and so on. To achieve this goal, there is a need to develop innovative thin multijunction solar cell substrate concepts that take advantage of and are compatible with next-generation solar cell electrical interconnects systems for III-IV materials.

This proposal addresses the need for thin encapsulants that will not only increase the array-level specific power, but can also be optimized to maintain the structural integrity of ultra-thin crystalline solar cells, and retain the stiffness requirements for launch and on-orbit attitude control. It focuses on a concept that significantly improves SOA array level performance parameters (100 W/kg specific power and 13 W/m3 stowability).

The technical approach will ultimately lead to reduced overall operating costs and improved mission capabilities for high power platforms supporting higher bandwidth communications for space based applications. After the new materials have been characterized, the proposer will seek a collaborative arrangement with relevant Air Force Contractors with a view toward commercialization of the novel copolymers.

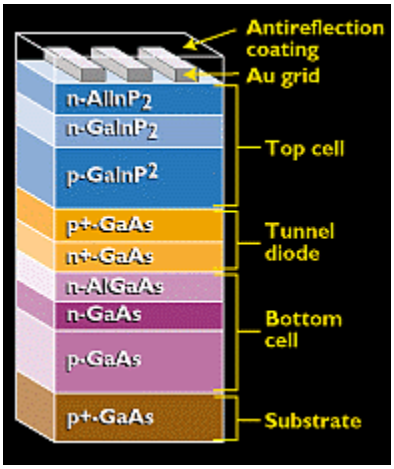



Figure 1. Schematic Representation of Multijunction Solar Cell

## Phase I Technical Objectives

The goal is to develop synthetic and processing techniques for a series of elastomeric copolymers of perfluorinated polyimides and silicones, and evaluate them for use as thin film encapsulants for photovoltaic arrays to be used in space.

Specific technical objectives for the Phase I effort are to:

1. Prepare and characterize block copolymers in a preliminary screening program, while developing a set of selection criteria for candidates for a detailed experimental study, including additional syntheses and characterizations.
2. Synthesize suitable block copolymers and characterize their key physical properties controlling performance, such as elastic moduli, thermal stability, optical absorption coefficient over the 400 – 2000 nm range, as well as briefly assess their charging and flammability characteristics, and their stability in the space environment, e.g., vacuum UV;
3. Optimize the synthetic procedure;
4. Evaluate a limited number of laminates comprising of (1) copolymer film/cell/elastomer/polyimide substrate to demonstrate feasibility, and for delivery to the Air Force;
5. Prepare the final report.

In pursuit of the primary goal of demonstrating feasibility of the concept, Phase I will answer the following questions:

A. What is the optimal composition for the lower layer of the encapsulant?
B. What is the optimal composition for the top layer of the encapsulant?
C. What is the extinction coefficient of the combined layers between 400 nm and 2000 nm?
D. What are the glass transition temperatures of both layers of the encapsulant?
E. What is the stress-strain relationship of the copolymer layers?
G. What is the peel adhesion of the bottom layer to the solar cell?
H. What is the peel adhesion of the top layer?
I. What is the percent transmissivity of the optimal copolymer over the 400 nm to 2,000 nm region of the electromagnetic spectrum?
J. What is the extinction coefficient of the optimal copolymer over the 400 nm to 2,000 nm region?

## Phase I Work Plan

Phase I Work Plan Outline

1) Scope

The work during Phase I involves: (a) synthesis, characterization, optimization and evaluation of several copolymers of perfluorinated polyimide-silicones for use as optical encapsulants for broad band solar cells and (b) the demonstration of the feasibility of the concept.

2) Task Outline

The work during Phase I is organized along four main tasks as delineated above in the Technical Objectives. These tasks are: Preliminary screening; synthesis and characterization; optimization; evaluation; and reporting.

3) Milestone Schedule

The relevant milestones are answers to the questions posed in the Technical Objective section of the proposal. It is not possible to give precise dates at the present time because of the iterative nature of the applied research plan. Table 1, however, is a tentative schedule for reaching significant milestones during Phase I.

Table 1 Milestone Schedule

| Milestone | Months following SOW |
|---|---|
| Identification of the optimal composition of lower layer of encapsulant | 5 |
| Identification of the optimal composition of top layer | 6 |
| Identification of suitable ratio of F:Si | 5 |
| Successful preparation of an optical transparent perfluorinated polyimide siloxane with a transmissivity of 0.95 | 6 |
| Characterization of adhesive properties of the optimal copolymer | 6 |
| Characterization of stress-strain relationship of the encapsulant | 4 |

4) Deliverables
a. Kickoff meeting within 30 days of contract start.
b. Monthly progress reports.
c. Technical review within 6 months.
d. Final report with SF 298
e.. Prototypes of the most promising encapsulants.

TASK 1. PRELIMNARY SCREENING OF COPOLYMERS
During this task, we will prepare and characterize several copolymers in order to select and identify suitable candidates for further study. The principal objective is to prepare optically transparent copolymers using well established procedures for preparing siloxane polyimides (1-3). All substrates will be spin coated with the experimental copolymers in order to prepare films with uniform thickness. Radiation resistance testing will be performed on 25 μm thick films.

1.1 Development of Selection Criteria
The four major selection criteria are optical, mechanical, thermal, and charging characteristics of the candidate materials. As mentioned before, flammability and degassing characteristics will also have to be taken into account. In addition, vacuum UV radiation stability is a primary concern. These criteria were initially used to select the class of elastomers of the present proposal. The selection criteria will be further used to define the range of copolymer compositions and cross-linked densities, which will be evaluated in Phase I. A design of experiment approach will be used to predict the composition and cross-link density ranges within the targeted copolymer family in order to achieve the desired glass transition temperature (Tg) and optical absorption characteristics.

1.2 Preparation of Copolymers

The first polysiloxane copolymers will be prepared using essentially the same procedure described in the patent literature (1-3), except that perfluorinated dianhydrides, diamines, and an amine terminated polysiloxane will be the starting materials. The polysiloxane diamine with pendant vinyl groups is prepared using the following procedure:

1.2.1 *Preparation of polysiloxane*

A monofunctional silane, 1,3-bis(3-aminopropyl) 1,1,3,3,-tetramethyl disiloxane, is reacted with that amount of octamethyl cyclotetramethyl disiloxane, capable of yielding x moles of dimethyl siloxy groups and also with that amount of 1.3.5,7-tetravinylcyclotetrasiloxane capable of yielding y moles of methyl vinyl siloxy groups, where x + y = n.

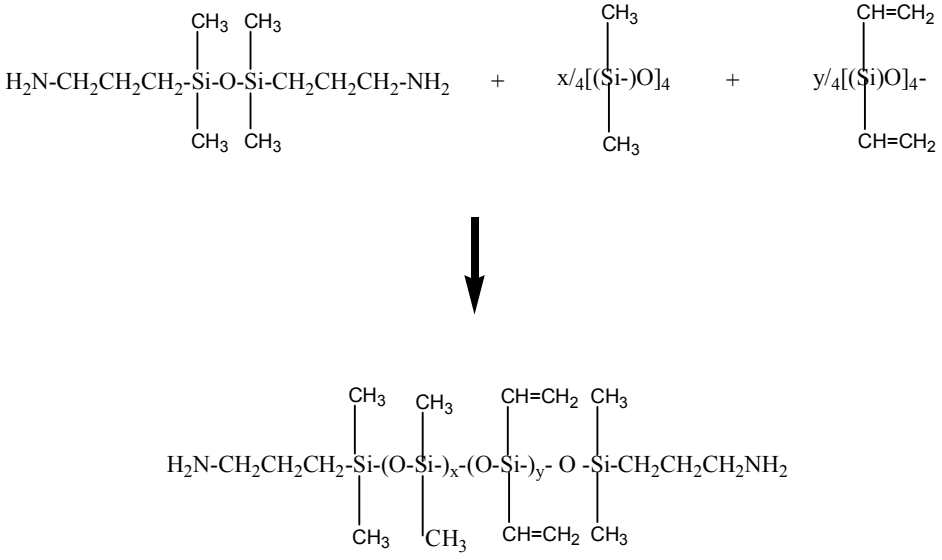


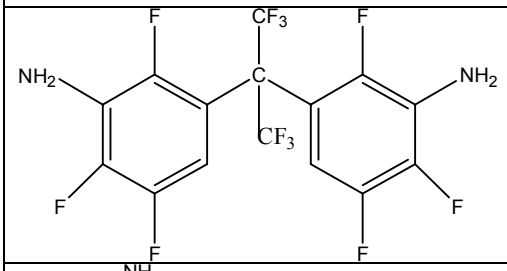
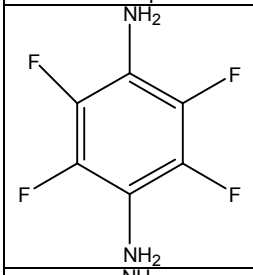
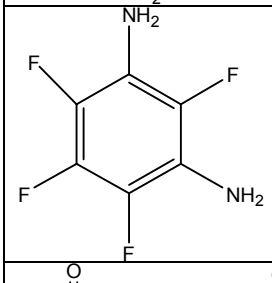
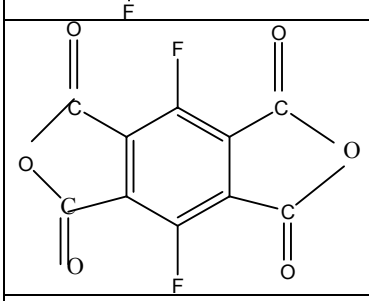
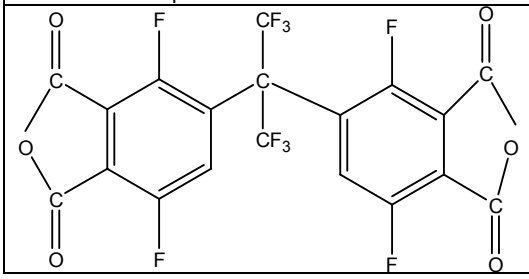
Figure 2. Chemical processes involved in the synthesis of amine terminated polysiloxane

A mixture of the disiloxane and tetramers is combined with a trace amount of potassium hydroxide in a four neck flask fitted with a reflux condenser, an argon inlet and a mechanical stirrer. The flask is immersed in a silicone oil bath at 85°C to heat the reaction mixture. The chemical reaction is complete when the viscosity of the reaction mixture reaches a constant level or when the solution changes from a multiphase mixture to a single phase solution. At the end of the reaction, the catalyst is neutralized and the mixture is cooled, filtered and percentage of functional groups determined by titration.

1.2.2 *Preparation of polysiloxane perfluoroimide*

The diamines and dianhydrides that will be employed in the synthesis are shown in Table 2.

Table 2. Chemical Structure of Monomers to be used in the Preliminary Screening Program

| Molecular Structure | Name |
|---|---|
|  | 14F Diamine |
|  | Para-4F Diamine |
|  | Ortho-4F Diamine |
|  | 2F Dianhydride |
|  | 10F Dianhydride |

Because the method of preparing the amino terminated polysiloxane is an equilibrium reaction, a Gaussian distribution of molecular weights results. Consequently, in the preparation of the polyimide siloxane, the lower molecular weight diamines will react first with the perfluorinated dianhydride. Hence, we propose to gradually add the dianhydride to

the solution of the polysiloxane diamine over an extended period of time at room temperature and then commence refluxing after all the dianhydride has reacted. At the end of the polycondensation reaction, we will add a small amount of the dianhydride and continue the refluxing until no unreacted polysiloxane diamine is present. Any unreacted dianhydride will be removed during the isolation and rigorous purification of the polymer. Oxidation of the unreacted polysiloxane diamine typically results in the formation of colored species. When the diamine is removed or fully reacted, the optical transparency of the cross-linked elastomeric siloxane polyimide is equivalent to that of DC-93500.

A four neck flask equipped with mechanical stirrer, nitrogen or argon inlet, thermometer, condenser coupled to a Dean Stark trap is charged with: a mixture of the disiloxane, methyl tetramers having (0.01 mole) of amine, zone refined or recrystallized 10 F (or 2F) dianhydride, and 450 grams monochlorobenzene. A catalytic amount of (0.15 gram) of para-toluenesulfonic acid is added and the entire reaction mixture is stirred and heated to reflux under nitrogen such that the water formed during cyclization is removed azeotropically with the solvent. The evolution of water ceases after two hours, but refluxing is allowed to continue for an additional three hours. After cooling, the polymer is isolated by precipitation in methanol and dried under reduced pressure in a vacuum oven.

This elastomeric copolymer is designed for application as the bottom layer of the encapsulating system in direct contact with the solar cell. And in our effort to increase the F:Si ratio, we will gradually replace some of the polysiloxane with each of the following:14 F diamine and 4 F diamines (para- and meta-), which are depicted in Table 2.

These are selected to further increase the toughness and radiation stability of the top layer .

Further, a tetramer with trifluoromethyl groups will be used to prepare other polysiloxane diamines which will be reacted with purified perfluorinated dianhydrides (10 F and 4 F) and subsequently with appropriate concentrations of purified 14 F and 4 F diamines. Purification is necessary to increase the optical transparency of the adhesive. A transmissivity of 0.95 is the goal.

The chemical structures of the dianhydride raw materials are also shown in Table 2.

The chemical reactions leading to the synthesis of the experimental polyimide siloxane are given in Figure 3.

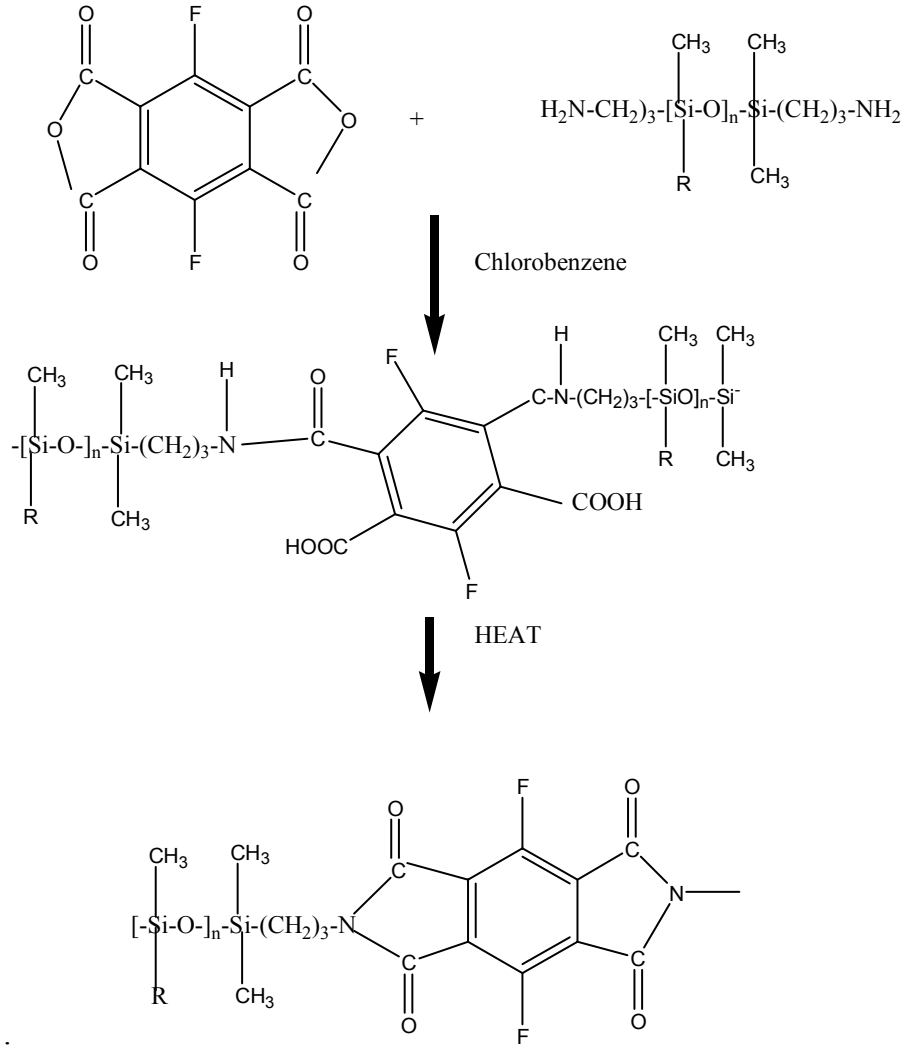



Figure 3. Chemical reactions involved in the synthesis of perfluorinated polyimide siloxane

1.3 Characterization of Copolymers

The objective of this sub-task is to identify and select those copolymers that are suitable for further experimental study in subsequent tasks. Accordingly, we will determine the following:

1.3.1 *UV-Visible spectra*

The extinction coefficients between 400 nm and 900 nm will be determined here on optically transparent candidates in the proposer's laboratory.

1.3.2 *Elemental analyses*

Small samples will be sent to Galbraith Laboratories for determination of %C, %H, %Si, %F. The results will be used in a database so that we can identify the optimal ratio of F:Si.

1.3.3 *FTIR*

The infrared spectra of thin films on sodium chloride cells will be recorded in the proposer's laboratory.

1.3.4 *Molecular weight*
Selected samples will be sent to DuPont Analytical Solutions for gel permeation chromatography of dilute solutions in THF.

1.3.5 *Thermal Analysis*
DSC and TGA analyses of promising samples will be conducted by DuPont Analytical Solutions.

TASK 2. SYNTHESIS AND CHARACTERIZATION
The primary objective of this task is to synthesize and characterize the most optically transparent copolymers identified in the preliminary screening program. The synthetic procedure will be fine tuned further, including more intensive purification of starting materials, including solvents. The purpose is to further increase the optical transparency of the copolymers. After the results of the synthesis can be duplicated, the most suitable copolymers will be characterized and evaluated.

Following synthesis, the adhesive films will be evaluated for application in MEO and GEO. Performance characteristics, such as optical transmission over the wavelength range 400 nm to 2000 nm will be measured by DuPont Analytical Solutions. Tensile stress-strain response up to break will be measured over a selected temperature range by Plastic Testing Laboratories. Dynamic response will be measured on a TMA apparatus by DuPont. Polydimethyl silicones are known to have a crystal transition at or near room temperature. It is our intent to suppress this phase transition in the experimental copolymers, if it exists. The adhesive bond strength will be determined through peel tests, which will be performed as a function of temperature. Laminates will be subjected to a selected number of thermal cycles, followed by a peel test, in order to determine if the adhesive bond strength is significantly altered by thermal cycling. No attempt will made to deduce long term performance from these data; the sole use of these data will be to determine feasibility of the concept.

Thermal properties will be estimated from TGA and DSC measurements conducted by DuPont. But charging, flammability and degassing characteristics will be deferred till Phase II.

It is perhaps instructive to state that we ultimately want to determine if the optical and mechanical properties of the best copolymers can be retained after exposure to vacuum ultraviolet (1 sun air-mass-zero equivalent) for 1000 hours between 30-40$^{\circ}$C under a vacuum of $10^{-6}$ torr. And that thermal cycling in the space environment involves the temperature range of -150$^{\circ}$C to 150$^{\circ}$C.

We have allocated sufficient funds for the determination of radiation resistance so that if the resistance to protons is acceptable to demonstrate feasibility, we will consult with the technical monitor concerning additional testing. If there is a need for further testing, we will seek permission form the SBA to approve testing for vacuum UV resistance at a NASA or

Air Force facility. Then, too, if time and resources permit, we will try to arrange testing in an Oxygen Plasma Reactor capable of 3 x $10^{-2}$ torr in order to measure the resistance of a free standing film of the optimal copolymer late in the program. We propose this with a view toward low earth orbit applications. But the first requirement is an optically transparent copolymer. Hence, we will only evaluate optically clear reaction products. Those copolymers which exhibit optical clarity in the visible region will be sent to DuPont Analytical Solutions for determination of a plot of extinction coefficient versus wavelength between 400 nm and 2000 nm.

TASK 3. OPTIMIZATION

During this task, the synthetic procedure that yields an optically transparent polyimide silicone will be refined to improve the optical clarity of thin 25 μm films reproducibly. This will entail using the optimal ratio of Fluorine to Silicon and other parameters identified in the preliminary screening program.

TASK 4. EVALUATION

Those systems which possess the necessary transmissivity will be rigorously evaluated here. The crucial tests are the determination of radiation resistance, which will be performed at the Proton Irradiation Facility at Auburn University. The initial tests will be on the effect of low energy protons.

The irradiations will be carried out in vacuum, 5 x $10^{-7}$ to 1 x $10^{-6}$ torr at room temperature at a constant dose rate of $10^{12}$ protons/$cm^2$. After each irradiation, samples will be inspected visually for damage and the spectral transmission will be measured. Subsequently, the following dose schedules will be followed:

:

| | |
|---|---|
| Second irradiation: | $10^{13}$ protons/$cm^2$; |
| Third irradiation: | $10^{14}$ protons/$cm^2$; |
| Fourth irradiation: | $10^{15}$ protons/$cm^2$. |

Two samples 3.5 cm x 2.5 cm samples on cover glass or free standing films will be irradiated using the accelerator. Controls with DC 93-500 will be run simultaneously.

If the results are promising, the effect of electrons and vacuum UV on thin films on glass will be evaluated, if time and resources permit. Control samples with DC-93-500 and RTV-S 695 will be included. Transmittance measurements will also be performed at Auburn University at the same time because spectral transmission curves are an integral part of the reporting. Accordingly, the following will be determined during this task:

4.1 Optical Properties
4.2 Adhesion
4.3 Humidity Cycling
4.4 Thermal Cycling
4.5 Thermal Stability under a vacuum
4.6 Radiation Resistance: a. effect of electrons; b. effect of low energy protons; and c. effect of vacuum UV

TASK 5. PREPARATION OF FINAL REPORT
At the conclusion of the experimental work, we will prepare a final report with a discussion of all results and test data, including estimates of technical feasibility.

**Related Work**

The only research that we are aware of is the development of POSS coatings and adhesives for solar cells (6). The approach is to develop an encapsulants rather than an adhesive for bonding the cover glass to the solar cell. Highly relevant and related work follows:

1. Vacuum Ultraviolet Radiation Effects on DC93-500 Silicone Film are illustrated below in Figure 4.

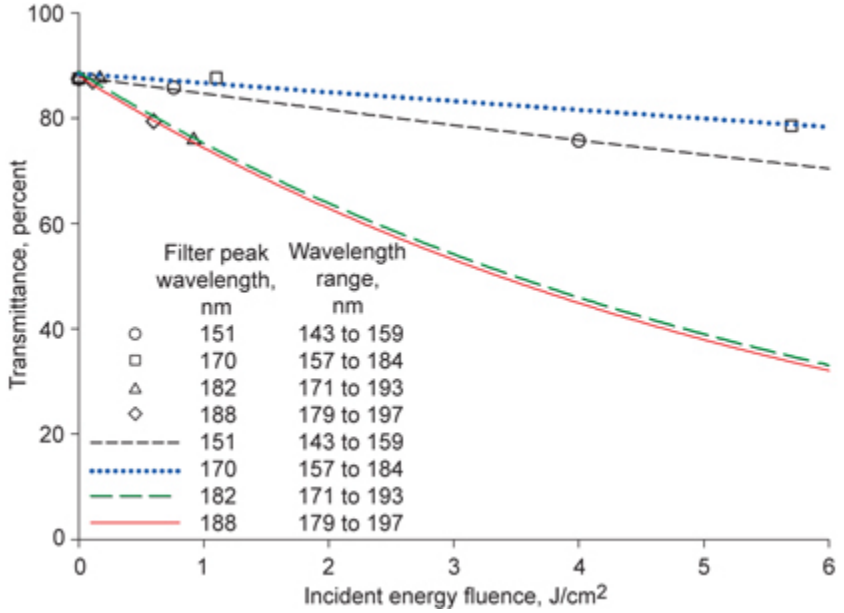



Figure 4. Transmittance of 152-µm DC93–500 silicone film at 250 nm as a function of incident VUV energy fluence provided by exposure to various wavelength ranges through narrow band pass filters. (Data reproduced from work performed by Joyce A. Dever, Bruce A. Banks, and Li Yan of the NASA Glenn Research Center)

2. Atomic oxygen resistance

Organo silicone polymers such DC-93500 possess significant advantages over their organic analogs in high thermal stability and resistance to environmental factors such as ultraviolet and atomic oxygen in space. All the same, it is known that contaminating films on space craft surfaces in many cases consisted primarily of products resulting from the interaction of atomic oxygen with silicones, according to data obtained from a published "Analysis of Materials Flown on the Long Duration Exposure Facility: Summary of Results of the Materials Special Investigation Group," by the Space Agency in May, 1995 (7). In addition, there was extensive cracking of silicone surfaces returned from space missions or after ground-based oxygen-plasma testing.

The adhesive and adhesive-like materials flown on LDEF included silicones (including lap shear specimens), conformal coatings, potting compounds, and several tapes and transfer

films. Typically, adhesives were not exposed to solar radiation or atomic oxygen. FEP and Kapton films attached with RTV de-bonded. However, this failure may have been due to lack of primer and not the adhesive. Silicone adhesives also provided many localized sources of out-gassed material. This is evidenced by the presence of Si on many analyzed specimens taken from near identified locations of silicone adhesive.

With respect to the synthesis and properties of perfluorinated polyimides, it is essential to cite a most comprehensive body of work (8), which will be used in the present work. In Chapter 14 of the Second Volume of Fluoropolymer, there are detailed accounts of: the optical transparency of fluorinated polyimides at near IR wavelengths; the effect of perfluorination on optical transparency; characterization and synthesis of materials for perfluorinated polyimides; synthesis of a novel perfluourinated dianhydride; synthesis of perfluorinated polyimide (10FEDA/4FMPD; estimation of the imidization process from NMR and IR spectra; optical transparency at near IR and Visible wavelengths; optical, mechanical, thermal and electrical properties of perfluorinated polyimides.

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**Relationship with Future Research or Research and Development**

The objective of Phase I is to demonstrate the feasibility of producing an advanced solar array structure and module technologies optimized for 20 micron thick multijunction solar cells. An important milestone is the successful preparation of an optically transparent polyimide silicone copolymer with adequate fluorine groups. This will lead to or generate more intensive tests during Phase II with respect to radiation resistance. During Phase II, we will apply results from Phase I to design, fabricate and test a prototype solar array structure that validates the design approach for significantly increasing an array’s specific power and stowability..

Additional resources will enable more comprehensive determinations of the following:

a. effect of electrons; b. effect of low energy protons; and c. effect of vacuum UV versus that of the DC-93-500 and RTV-S 695.

Vacuum ultraviolet (VUV) radiation of wavelengths between 115 and 200 nm produced by the Sun in the space environment can degrade polymer films, producing changes in their optical, mechanical, and chemical properties. These effects are particularly important for thin polymer films being considered for ultra lightweight space structures, because, for most polymers, VUV radiation is absorbed in a thin surface layer. VUV exposure using ground-based test chambers can also be used as part of combined or sequential simulated space environmental exposures to determine combined damaging effects with other aspects of the space environment, which include solar ultraviolet radiation, solar flare x-rays, electron and proton radiation, atomic oxygen (for low-Earth-orbit missions), and temperature effects.

## Commercialization Strategy

It is highly significant that all military spacecraft use multijunction space solar cells for electrical power generation. This means that if the proposed encapsulant can be qualified with the assistance of a DOD contractor, the probability of a successful commercialization will be quite high. It is obvious that the availability of solar arrays with improved specific power will increase the capability of military spacecraft. Commercial spacecraft and ground-based solar generators will also benefit from improved specific power and the other benefits associated with thin multijunction solar cells.

The commercialization strategy is a simple one. It is based on synthesizing an optically transparent adhesive and sending thin films and laminates for the determination of radiation resistance and other pertinent properties by outside laboratories. After seeking patent protection, we plan to publish the results in order to attract the interest of Lockheed and other contractors who supply photovoltaic cells for space applications. It assumes that the performance of the proposed materials is acceptable to both the US (Lockheed Martin and Boeing) and EU (EADS) contractors. Because of the small volume of material used, the proposer intends to manufacture the adhesive at the present location and supply it to its customers. Optically transparent perfluorinated polyimide-silicones are commercially attractive polymers.

We plan to secure a commitment for Phase III that is of the same order of magnitude as the Phase II funding. We expect that this will be adequate to commercialize the proposed product after it is placed on the Qualified Products List.

## Key Personnel

Dr. Ronald W. Gumbs will serve as principal investigator on the project. He has the requisite experience and training to synthesize the proposed materials using raw materials that are commercially available. He will be assisted by Dr. Chenchang Chen, a polymer chemist with over 15 years of combined academic and industrial experience. The resume of Dr. Gumbs is shown below:

**RONALD W. GUMBS**

**Education** *Ph.D.*, Chemistry, 1969, SUNY College of Environmental Science and Forestry.; Dissertation on "Cationic Polymerization of N-vinylcarbazole" Research Professor: Michael Szwarc

*M.S.,* Chemistry, 1965, Polytechnic University; Thesis on "Cyclopolymerization" Research Professor: Herman F. Mark

*B.S.*, Chemistry, 1962, Brooklyn College, City University of New York

**Experience** RWG Corporation 6/2003 to Present CEO & Chief Scientist
Conceived and founded an intellectual property development company with the sole purpose of selling or licensing new technologies.

Gumbs Associates 2/73 to 6/2007 President
Developed: dental and medical polymers; heat resistant plastics; coatings and adhesives; encapsulants for silicon solar cells; thin film laminates for solar energy applications; thermoplastic composites for primary structures; and conductive polymers for radar and thermal signature suppression.

Yulex Corp. 11/2001 to Present Consultant

NJIT Enterprise Development Center 6/87 to 12/1997 Advisory Board Member

Summer Institute in Polymer Science and Technology at SUNY New Palz, 5/79 to 6/79 Instructor

Medgar Evers University, CUNY 2/73 to 6/73 Adjunct Assistant Professor of Chemistry

Borden Chemical 4/69 to 2/73 Group Leader
Supervised synthesis of wet and dry strength resins for paper; non-aqueous dispersions; conductive polymers; and solventless coatings and inks.
4/70 to 2/73 Safety Coordinator

Resin Research Laboratories 6/62 to 9/65 Chemist
Conducted R&D on various polymeric materials and composites.

**Memberships**: American Chemical Society; Division of Polymer Chemistry; Division of Polymeric Materials;
ASTM Committee C09 on Concrete and Concrete Aggregates.

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## Facilities/Equipment

RWG Corporation has a modern research facility in East Brunswick, NJ with 1,400 square feet of laboratory space and the option to lease more space as the need arises. The firm

maintains a library, machine shop and a glass-blowing capability at this location. Equipment includes all standard equipment, including two custom-built 6' fume hoods, for chemical synthesis and characterization.

This facility meets all environmental laws and regulations of federal, New Jersey, and local Governments for the following groupings: airborne emissions, waterborne effluents, external radiation levels, outdoor noise, solid and bulk waste disposal practices, and handling and storage of toxic and hazardous materials.

The firm has a Master Services Agreement with DuPont Analytical Solutions providing access to a comprehensive analytical laboratory when the need arises. Typically, a request for quotation is made and samples are subsequently submitted. The laboratory offers a full range of services from routine testing to complex analytical problem-solving. It is an organization of experienced professionals with a strong support staff and world-class capabilities presently being used by the proposer. A request for a quote is followed with an estimate. If funds are available, the sample is forwarded to DuPont with a purchase order.

The firm also has working and informal arrangements with the Materials Testing Laboratory of NJIT, Plastic Testing Laboratories, and Galbraith Laboratories for the past 35 years.

Additional specific major pieces of equipment owned by the proposing firm and located in its laboratory in East. Brunswick, include:

1. A complete electrochemical research system based on an EG & G Princeton Applied Research (PARC) Model 273 Potentiostat/Galvanostat and Houston Instruments Model 2200GW X-Y recorder.
2. Spectra-Physics Model GCR-11-3 Nd:YAG ns pulsed laser with 2nd, 3rd harmonic generation and pulse compression, associated optics, positioners, two Scientech Model 36-5002 digital power meters, an Antel Optronics Model AR-S1-C custom large-area picosecond photodetector, mounted on a Newport precision optical table. A 2.5 - 7.0 ns, 200 mJ (@ 532 nm) laser pulse repeating at 1 - 15 Hz is available.
3. Instron Model 4201 Universal Testing Machine; a state-of-the-art instrument for measuring mechanical properties of polymeric materials.
4. Perkin-Elmer Model Lambda 3B automated UV-Vis. Spectrophotometer; also used in conjunction with PARC 273 for spectro-electrochemistry.
5. Perkin-Elmer Model 1615 FT-IR.
6. Tektronix oscilloscopes: Model 2210, digital storage, Model DCA 602, pico-second digital storage.
7. Optical train and laser/optic instruments incl. Newport Model C-2001-65ML 65 mW Ar ion laser with acousto-optic (Isomet) modulation, Newport Model M-877 200 ps photodetector, Oriel Model 66165 150 W Xe source, Model 77250 monochromators, associated wavelength controllers, drives, optics, 3-axis positioners. Used for spectroelectrochemical, polymer studies.
8. Denton Vacuum Model 502A high vacuum thermal evaporation system (for thin film semiconductor, metal and other depositions.

9. Resistivity/conductivity and electrical test instrumentation: Signatone Model S301-4 4-point resistivity probe interfaced to Keithley Model 617 electrometer, Keithley Model 220 current source; Keithley Model 197A digital multimeter.
10. Integrated Technologies, Inc. Model P6204 Spin Coater.
11. Power supplies for Electropolymerization: Micronta Dual Tracking and Vector-Viz WP-773A, associated bulk (1 L) synthesis cells.
12. Precision Instruments vacuum pumps and high-vacuum line system.
13. Ovens/Furnaces: Labline IV and Thermolyne F21100 tube furnace (to 1200$^{o}$C).
14. Large capacity LabLine Imperial controlled-temperature system.
15. Ultraviolet light sources for polymerization initiation, related functions.
16. U.S. Stoneware Ball and Jar Mill, Model No. 753 RM/V.
17. Brookfield Viscometer
18. Dymax Model 1200 Focused Beam UV-curing system

**Subcontractors/Consultants**

No formal subcontracting or consulting will be used in Phase I.

**Prior, Current, or Pending Support of Similar Proposals or Awards**

Two prior pending proposals containing essentially the same work have been submitted to two other Federal Agencies. Details are as follows:

(a) Air Force
(b) 09/19/2007
(c) Perfluorinated Polyimide-fluorosilicone Copolymer Adhesives for Solar Cell Coverglass
(d) Ronald W. Gumbs, Chief Scientist
(e) AF073-095

(a) Department of Energy
(b) 11/27/2007
(c) Encapsulant for Broadband Multijunction Solar Cells
(d) Ronald W. Gumbs, Chief Scientist
(e) Topic 24c

Budget Justification

The required details are given in the budget.