

Identification and Significance of the Problem or Opportunity

This proposal seeks flame retardant vinyl ester resins (VERs) that do not contain volatile organic compounds for application in the production of low cost, fiber reinforced composite structures. Currently, VERs are used in many structural composites because they are easily processed, producing durable finished products with excellent structural properties. However, commercially-available VERs contain between 30-50% styrene. During the curing of vinyl esters, the formation of styrene and acrylate ester copolymers produces the desirable matrix properties. However, the presence of the styrene is a serious problem because of environmental, occupational and flammability concerns.

The technical approach of this project involves the use of nonvolatile brominated compounds, organo- phosphates, borates, silicates, and aluminate monomers that are capable of copolymerizing with the acrylic groups of the bisphenol A epoxy acrylate. After characterization of the monomers and subsequent reaction with the epoxy acrylate, the cured products will be evaluated using the standard methods to evaluate the commercially available VERs, which typically contain 30-50% styrene. The driving force behind the approach is to eliminate styrene and to reduce flammability of the matrix materials.

The synthetic strategy underlying the proposed approach is to first utilize commercially available materials, rather than synthesizing the organometallic monomers. After feasibility has been established, the selected monomers will be synthesized in the proposer's laboratory in direct efforts to lower the cost of the VER.

Phase I Technical Objectives

The overall objective of Phase I is to demonstrate feasibility of the concept of a zero VOC and flame retardant VER, which can be produced and used in composite structures.

Specific technical objectives of Phase I are to:

1. Procure and select organo-metallic monomers to be used in a preliminary screening program.
2. Prepare and cure VERs
3. Evaluate postcured VER castings.
4. Prepare and evaluate glass laminates
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. Which organometallic monomers are suitable for replacing styrene and conferring flame resistance to VERs?
- B. What is the minimum concentration of each organometallic monomer necessary for acceptable flame resistance?
- C. What are the density, viscosity and shelf-life of the liquid VERs?
- D. What is the gel time at 25°C of the VERs using NOROX MEKP-925H and Cobalt Naphthenate-6%?

- E. What are the tensile strength, tensile modulus, flexural strength, flexural modulus, Barcol Hardness, and Heat Deflection Temperature of postcured VER castings?
- G. What are the mechanical properties preliminary ignition resistance of postcured glass laminates prepared from optimal VER compositions?

Phase I Work Plan

Phase I Work Plan Outline

1) Scope

The work during Phase I involves: (1) the development of a flame retardant VER that does not contain VOCs and (2) 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: Procure and select organo-metallic monomers to be used in a preliminary screening program; Prepare and cure VERs; Evaluate postcured VER castings; Prepare and evaluate glass laminates; 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

<u>Milestone</u>	<u>Months following SOW</u>
Identification of those organometallic monomers that are suitable for replacing styrene and conferring flame resistance to VERs	4
Identification of the minimum concentration of each organometallic monomer necessary for acceptable flame resistance	5
Successful determination of the density, viscosity and shelf-life of the liquid VERs?	2
Measurement of the gel time at 25°C of the VERs using NOROX MEKP-925H and Cobalt Naphthenate-6%?	3
Measurement of the mechanical properties of postcured VERS	4
Measurement of the mechanical properties of postcured VER glass Laminate	5

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 postcured glass laminate and liquid VER..

Phase I Work Plan

TASK 1. SELECTION OF ORGANO-METALLIC MONOMERS

During this task we will react bisphenol A epoxy acrylate resin, shown in Figure 1 below, with organometallic monomers at different levels in a preliminary screening program and select those that are suitable for further evaluation. In addition to flame resistance and low viscosity, we will be looking for the following features: versatility; low water absorption rate; high strength and toughness; tack free surface; improved profile; wets out reinforcements rapidly; high heat distortion temperature; thixotropic; stable gel time; and capable of being manufactured using statistical process and quality controls.

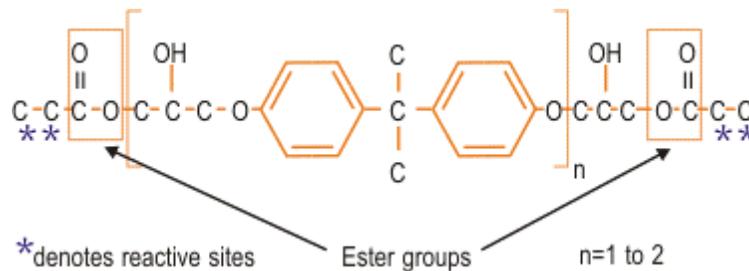


Figure 1. Bisphenol A Epoxy Acrylate

We have identified several monomers for screening and they are classified by inorganic element.

- 1.1 Aluminum
- 1.2 Antimony
- 1.3 Boron
- 1.4 Phosphorous
- 1.5 Silicon
- 1.6 Zinc
- 1.7 Zirconium
- 1.8 Bromine

1.1 Aluminum compounds

Aluminum triacrylate is a logical candidate for screening because of the presence of the aluminum, of course, and the multifunctional acrylic group. With a molecular weight of 240, however, a high concentration may be needed to produce a composite capable of meeting UL-94.

1.2 Antimony compounds

Methacryloxy diphenyl antimony (34% Sb) will be evaluated first individually and the brominated monomers, seen below in 1.8, in efforts to find a synergistic relationship. This is necessary to achieve the desired fire resistance with minimal smoke. Convenient Class I FR Compliance from current VERs is obtained by using a brominated vinyl ester premixed with antimony pentoxide (3-5%) or by formulating with standard antimony synergists.

1.3 Boron compounds

1.3.1 Boron allyl oxide (5.9% B)

The allylic groups of this monomer will be reacted with the epoxy acrylate at different ratios and the products will be tested for flame resistance. Once the minimum concentration of boron necessary for self-extinguishing is determined, the boron acrylates will be prepared by reacting boron hydroxide with acrylyl chloride or with acrylic acid anhydride in our laboratory.

1.4 Phosphorous compounds

1.4.1 Bis (2-methacryloxyethyl) phosphate with a molecular weight of 322.2 will be evaluated during this task at different levels to determine the minimum concentration needed for self-extinguishing properties.

1.5 Silicon compounds

1.5.1 3-acryloxypropyl trimethoxy silane

1.5.2 3-methacryloxypropyl trimethoxy silane

1.5.3 Methacryloxypropyltris(trimethylsiloxy)silane

1.5.4 Methacryl disilanol isobutylPOSS

These monomers are interesting because they are also coupling agents which are capable of chemical bonding to the glass fiber. Silane coupling agents have the ability to form a durable bond between organic and inorganic materials. Encounters between dissimilar materials often involve at least one member that is siliceous or has a surface chemistry with siliceous properties: silicates, aluminates, borates, etc. This is important because it facilitates the incorporation of other inorganic elements into the VER. Consider the following:

The general formula for a silane coupling agent typically shows two classes of functionality.

$\mathbf{R-(CH_2)_n - Si - X_3}$, R is of course the organofunctional group, such as the acrylic moiety, and X is a hydrolysable group typically alkoxy, acyloxy, halogen or amine. Following hydrolysis, a reactive silanol group is formed and it can condense with other silanol groups, those on the surface of siliceous fillers, to produce siloxane linkages. Stable condensation products are also formed with other oxides such as those of aluminum, zirconium, tin, and titanium. Less stable bonds are formed with the oxides of boron.

Included in this group is polyhedral oligomeric silsesquioxane (POSS) with a monofunctional methacrylic group. This oligomer is based on POSS nanostructured chemical technology which has two features: (1) the chemical composition is a hybrid, intermediate ($\text{RSiO}_{1.5}$) between that

of silica (SiO_2) and silicones (R_2SiO); (2) POSS molecules are physically large ranging from approximately 1-3 nm. (MA0713).

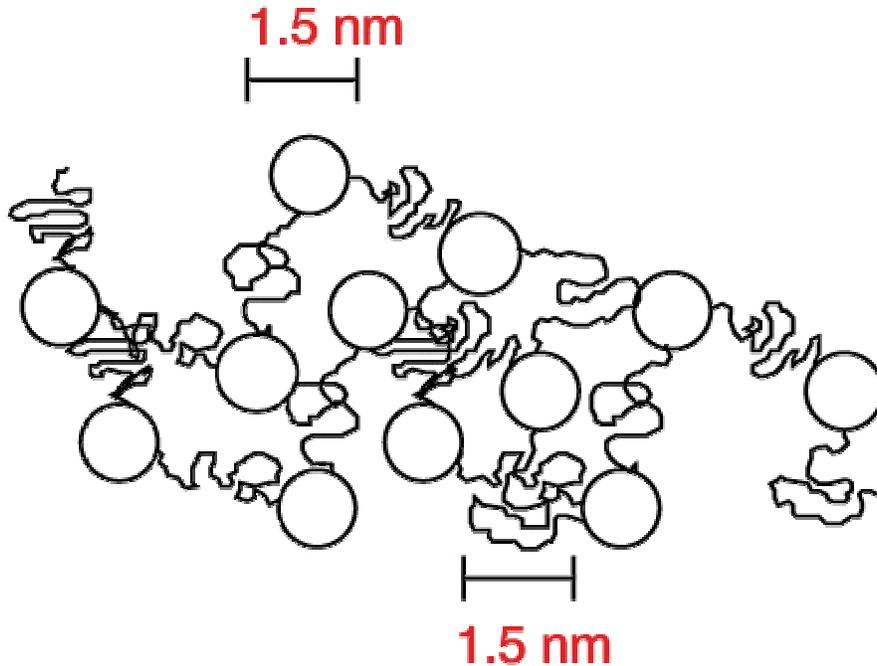


Figure 2. Idealized representation of a nanostructured POSS methacrylate.

Compared to common fire retarded plastics, polymers containing POSS show delayed combustion and major reductions in heat evolution.

1.6 Zinc Compounds

1.6.1 Zinc diacrylate (32% Zn) is included here because, in combination with other organometallics, it may produce a synergistic effect in flame retardance and smoke reduction.

1.7 Zirconium Compounds

1.7.1 Zirconium tetramethacrylate (21% Zr)

1.8 Bromine compounds

The objective of investigating monomers containing bromine is to determine whether superior flame resistance can be achieved with the inclusion of these monomers in the VER. Accordingly, we will prepare VERs with the following:

1.8.1 Pentabromophenyl acrylate (74% Br)

1.8.2 Pentabromophenyl methacrylate (72% Br)

1.8.3 Tribromophenyl methacrylate (60% Br)

The bromine compounds are significant because of the low bond energy of the C-Br bond. And it is worth repeating that Convenient Class I FR Compliance from current VERs is obtained by using a brominated vinyl ester premixed with antimony pentoxide (3-5%) or (2.19-3.65% Sb) or by formulating with standard antimony synergists. The amount of bromine in the formulation is therefore estimated to be about 20%, while the amount of styrene is 35%. Incidentally, this can be confirmed by measuring the amount of Sb and Br on a small sample of Derakane 510C-350 FR Epoxy Vinyl Ester Resin.

In flame retarding polymers, the synergistic action between brominated compounds and antimony trioxide and antimony pentoxide is well known. Among the brominated compounds in use are: tetrabromobisphenol-A (TBAA), 58.8% Br; 1,2-bis(2,4,6-tribromophenoxy)ethane (TBPE), 70.0% Br; octabromodiphenyl oxide (OBDPO), 79.8% Br; and a proprietary brominated aromatic compound (BAC), 66% Br. With antimony pentoxide, it is customary to formulate at mole ratios of 3:1 and 4:1, bromine to antimony metal, respectively.

Flame retardance is more dependent on the structure of the brominated compound, rather than amount of bromine. For instance, a proprietary brominated aromatic compound (66% Br) works very well with Sb_2O_5 , but brominated polystyrene with the same amount of bromine is ineffective. So, assuming 20% Br, 3% Sb and 35% styrene, the concentration of different brominated compounds and Sb_2O_5 in a current state-of-the-art formulation is shown in Table 2.

Table 2. Composition of VERs with different brominated fire retardant compounds

INGREDIENT	A	B	C	D
Styrene	35	35	35	35
Acrylic Ester of Bisphenol A Epoxy + Cat. + Acc.	27	32	36	31
Antimony Pentoxide	4	4	4	4
Tetrabromobisphenol-A (TBAA)	34			
1,2-bis(2,4,6-tribromophenoxy)ethane (TBPE)		29		
Octabromodiphenyl oxide (OBDPO)			25	
Proprietary brominated aromatic compound BAC				30
TOTAL	100	100	100	100

The low concentration of epoxy acrylate is obvious and therefore this must be accompanied with a lowering of mechanical and other properties.

Now, with the proposed technology, let us also assume 20% Br and 3% Sb. Table 3 shows a higher concentration of acrylic epoxy ester can be used in formulations with both organometallic and brominated monomers.

Table 3. Composition of flame retardant compounds based on proposed technology

INGREDIENT	E	F	G
Acrylic Ester of Bisphenol A + Cat. + Acc.	64	65	58
Methacryloxy diphenyl antimony	9	9	9
Pentabromophenyl acrylate	27		
Pentabromophenyl methacrylate		28	
Tribromophenyl methacrylate			33
TOTAL	100	100	100

But since the fire retardant properties of neat epoxy resins and bisphenol A polycarbonates are superior to those of polystyrene and polypropylene, a lower concentration of synergist is expected. This is because a rating of V-2 in the UL-94 vertical flame test is possible with 1.0% of a mixture of BAC and Sb₂O₅ in virgin polypropylene; after flame times range from 0 to 3.8 seconds. Hence, Table 4 presents revised formulations in light of this fact and analysis.

Table 4. Composition of VERs with lower of concentration of flame retardants.

INGREDIENT	H	I	J
Acrylic Ester of Bisphenol A + Cat. + Acc.	99	99	99
Methacryloxy diphenyl antimony	0.25	0.24	0.21
Pentabromophenyl acrylate	0.75		
Pentabromophenyl methacrylate		0.76	
Tribromophenyl methacrylate			0.79
TOTAL	100	100	100

Increasing the concentration of flame retardant monomers will produce a higher UL-94 and the epoxy acrylate can be diluted to the required viscosity with many reactive diluents, hexanediol diacrylate, for example, and still maintain the zero VOC specification.

Antimony triacrylate or a mixture of mono- or di-acrylate can be prepared by adding hydroxy ethyl acrylate (or a mixture of HEA and ethyl alcohol in the appropriate ratio) to antimony trichloride under dry conditions in the proposer's laboratory; sodium carbonate is included in the reaction as slurry to neutralize the HCl. The proposer has the requisite experience and capability to prepare all experimental organometallic monomers in its laboratory.

TASK 2. PREPARATION AND CURING OF VERS

During this task, the concern is on the cure and therefore we will add an accelerator to one component of the system and a catalyst to the other prior to mixing. A VER typically contains a catalyst, accelerator, and additives such as thickening agents, pigments, fillers, and fire retardant compounds.

2.1 Determination of Liquid Resin Properties

During this subtask the properties shown in Table 5 will be determined in the proposer's laboratory; values for a typical VER are shown.

Table 5. Liquid resin properties

Property	Value
Density, 25°C	1.046 g/ml
Dynamic Viscosity, 25°C	370 mPa.s
Kinematic Viscosity	350 cSt
Shelf Life, Dark, 25°C	7 months

2.2 Determination of Gel Times

Table 6 provides the guidelines to be used in constructing a methyl ethyl ketone peroxide gel time chart.

Table 6 Typical Gel Times Using NOROX MEKP-925H and Cobalt Napthenate (6%) at 25°C.

Formulation	#1	#2	#3
MEKP	1.5 phr	1.5 phr	1.25 phr
CoNap6%	0.30 phr	0.30 phr	0.30 phr
Dimethyl aniline	0.20	0.05 phr	0.05 phr
2,4-Pentanedione			0.04 phr
Gel Times, minutes			

2.3 Curing of VERS

After we have determined the gel time, we will prepare resin castings and cure them at room temperature for 24 hours using the appropriate concentrations of catalyst and accelerator. This will be followed by a post cure at 120°C for 2 hours in our laboratory.

2.4 Preliminary Ignition Resistance Tests

RWG Corporation Topic No. AF071-321 Proposal No. F071-321-2610
 Convenient Class I FR Compliance from current VERs is obtained by using a brominated vinyl ester premixed with antimony pentoxide (3-5%) or by formulating with standard antimony synergists. This entails a lower concentration of styrene, typically from 45% to 35%. Thus the density increases from 1.046 to 1.16 g/ml, the dynamic viscosity increases from 370 to 420 mPa.s, and the shelf life decreases from 7 to 4 months.

These tests are performed on laminates rather than neat resin and they include:
 Burning Rate (ASTM D-635);
 Limited Oxygen Index Test (ASTM D-2863);
 60 Second Burning Test (ASTM D-757);
 Intermittent Exposure Test (HLT 15);
 Tunnel test flame spread (ASTM E-84).

Extensive testing of the fire resistance will be performed during Phase II, but it is sufficient here to determine whether the postcured resin possesses self-extinguishing properties after a flame is removed during exposure in the vertical test of UL-94 in our laboratory.

TASK 3. EVALUATION OF POSTCURED VER CASTINGS

During this Task, we will send samples to the Akron Development Laboratory (ARDL) to measure the physical properties of postcured VERs. This is necessary to determine if they meet or exceed the requirements of VERs cured with styrene. Accordingly, Table 7 summarizes the properties that will be measured according to the indicated test methods by ARDL. It also includes bench mark values for the typical conventional VER cured with styrene.

Table 7 Physical and Mechanical Properties that will be determined in Phase I

Property	Value	Test Method
Barcol Hardness	30	ASTM D-2583
Tensile Strength	86 Mpa	ASTM D-638
Tensile Elongation at Break	6.5%	ASTM D-638
Flexural Modulus	3.4 Gpa	ASTM D-790
Flexural Strength	141 Mpa	ASTM D-790
Heat Deflection Temperature	100°C	ASTM D-648

For the UL-94 vertical flame test, we will send samples with four specimens each having dimensions of 6 inch x 6 inch to the Akron Rubber Development Laboratory. In this, the following will be determined and reported to the Air Force:

1. Time until the flame extinguishes itself;
2. Distance the burn propagates;
3. Linear burning rate in mm per minute;
4. Whether the flame burns through the test sample;

5. Or whether flaming drops from the test sample ignite cotton below.

TASK 4. PREPARATION AND EVALUATION OF FIBER REINFORCED COMPOSITES

4.1 Preparation of Glass Laminate

The optimal VER based on the results from the preceding Tasks will be used to impregnate glass fabric at two different levels of glass, 60% and 35%. The impregnated glass fiber 7 mm (0.28 inch) thick laminate will be placed in a mold and pressed at 60 psig for 24 hours at room temperature, followed by 6 hours at 80°C.

4.2 Determination of mechanical properties of postcured glass laminate.

The following properties will be measured by (ARDL):

4.2.1 Tensile Strength

4.2.2 Tensile Modulus

4.2.3 Flexural Strength

4.2.4 Flexural Modulus

4.2.5 Compressive Strength

4.2.6 Compressive Modulus

ARDL will also conduct the UL-94 test on the optimal glass laminate.

4.2.7 Vertical Flame Test (UL-94)

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

We are not aware of any research and development to develop an organometallic monomer to replace styrene in VERs. It is known brominated derivatives of styrene are commercially available, but brominated polystyrene with 66% Br is not an effective synergist with the oxides of antimony. Fire retardant VERs consist of 35% styrene, a brominated aromatic compound with micron sized Sb_2O_3 or Sb_2O_5 , and the remainder is the bisphenol A epoxy acrylate. There is no compelling drive to replace styrene because of its low cost and the high cost of the bisphenol A epoxy acrylate.

Relationship with Future Research or Research and Development

Phase I involves the formulation of organometallic and brominated vinyl and acrylic monomers in VERs, which will be evaluated and compared with current VERs. The properties of the liquid resin and those of the post-cured castings and laminates will be measured in efforts to demonstrate the feasibility of the concept.

RWG Corporation

Topic No. AF071-321

Proposal No. F071-321-2610

During Phase II and with the assistance of a collaborating commercial partner, a cost effective manufacturing process will be developed and tested to produce commercially viable structures without any volatile organic compounds present in the VERs. Structural analyses by computerized simulation will be performed and a prototype composite structure will be fabricated to demonstrate that it is compliant with requirements of the Air Force.

Commercialization Strategy

Commercialization strategy is based on securing qualification by the Air Force during Phase II and filing patent applications as a result of the project early in Phase I. This project is innovative and it attempts to offer flame retardance using a 100% solids, VER resin. Dow Chemical, Ashland and other large companies will be approached, and should be interested, if the testing by the independent laboratories indicates feasibility early in the program. Sartomer, a supplier of Bisphenol A epoxy vinyl ester resins, might be interested in marketing the organometallic monomers.

The overall markets for the resulting technology are fiber reinforced composite materials. The entire market for VERs is large and diverse. Specific sales information for most companies is not available.

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.

There are two drivers which support commercialization. First is the environmental and occupational concern with styrene monomer. Second, successful demonstration of the flame retardant properties of the proposed VER with extensive mechanical tests by independent laboratories will ensure acceptance by the Air Force. Commercialization of the technology should therefore be successful, if the product is placed on the Qualified Products List. All materials are commercially available and manufacture of the coating involves simple blending.

Key Personnel

Dr. Ronald W. Gumbs, a materials scientist with over thirty years of combined academic and industrial experience in the synthesis, characterization and evaluation of polymeric materials, will serve as principal investigator on the project. He was an instructor at the Summer Institute in Polymer Science and Technology at SUNY New Palz, May 21 - June 27, 1979, and has served on the advisory board of the New Jersey Institute of Technology Enterprise Development Center from 1987 to 1997. A member of the American Chemical Society Divisions of Polymer Chemistry and Polymeric Materials, he has served as a consultant to Yulex Corporation since November, 2001. His resume is shown below. He will be assisted by Dr. Chengchang Chen, a polymer chemist.

NAME: **RONALD W. GUMBS**

EDUCATION: Ph.D. -Chemistry, 1969, SUNY College of Environmental Science and Forestry.
Dissertation on Cationic Polymerization of Nvinylcarbazole
Research Professor: Michael Szwarc
M.S. -Chemistry, 1965, Polytechnic University
Thesis on Cyclopolymerization
Research Professor: Herman F. Mark

B.S. -Chemistry, 1962, Brooklyn College

EXPERIENCE: RWG Corp. 6/2003 to Present Scientist
Conceived and founded an intellectual property development company with the sole purpose of selling or licensing new technologies.

Gumbs Associates 2/73 to Present 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.

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.

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

Publications:

1. R. Gumbs, S. Penczek, J. Jagur-Grodzinski and M. Szwarc, "Simultaneous Cationic Homopolymerizations of Vinylcarbazole and Oxetane", *Macromolecules* 2, 77-82 (1969)
2. D.F. Paul and R.W. Gumbs, "Solar Energy Collector Coatings from Cyclopolymers of Butadiene and Acrylonitrile", *J. Appl. Polymer Science* 21, 959 (1976).
3. P. Chandrasekhar, A.M. Masulaitis and R.W. Gumbs, "Novel Synthesis, Spectro-electrochemical, Electrochemical and Chrono-voltabsorptometric Characterization of Poly (Isothianaphthene)", *Synth. Met.*, 36, 303-326 (1990).
4. P. Chandrasekhar and R.W. Gumbs, "Electrosyntheses, Spectroelectrochemical, Electrochemical, and Chronovoltabsorptometric Properties of Family of Poly(Aromatic Amines), Novel Processible Conducting Polymers: I. Poly(Benzidines)", *J. Electrochemical Soc.*, 138, No. 5, 1337-1346 (1991).
5. G.V. Kulkarni, P. Chandrasekhar and R.W. Gumbs, "Electronic Structure of Conducting Polymers," Poster Paper A-5 presented at Gordon Research Conference on Polymers, Wolfboro, NH, June 24-28, 1991.
6. R.W. Gumbs, "Synthesis of Electrically Conductive Vinyl Copolymers," *Synth. Met.*, 64, No. 1, 27-31 (1994).
7. Y. Wei, J.M. Yeh, D. Jin, X. Jia, J. Wang, G.W. Jang, C. Chen and R.W. Gumbs, "Composites of Electronically Conductive Polyaniline with Polyacrylate-Silica Hybrid Sol-Gel Materials", *Materials*, 7, No. 5, 969 (1995).
8. G.W. Jang, C. Chen, R.W. Gumbs, Y. Wei and J.M. Yeh, "Large-Area Electrochromic Coatings. Composites of Polyaniline and Polyacrylate-Silica Hybrid Sol-Gel Materials", *J. Electrochem. Soc.*, 143, No. 8, 2591 (1996).
9. R.W. Gumbs, "Polythiophene and Polypyrrole Copolymers", in *Handbook of Organic Conductive Molecules and Polymers: Vol. 2, Conductive Polymers: Synthesis and Electrical Properties*, edited by H.S. Nalwa, John Wiley & Sons, New York, 1997, pp. 469-504.

10. Ronald W. Gumbs, "Conducting Polymers," in Encyclopedia of Chemical Processing, edited by Sunggyu Lee, Marcel Dekker, New York, 2006, pp. 526-537.

Patents:

1. M.F. Carty, M.R. Dock, C.P. West, P. Esemplare and R. Gumbs, "Micro-filter for Tobacco Smoke", Fr. Pat. 1,484,033, 9 June, 1967.
2. R. W. Gumbs, "Nonlinear Optical Shield", U.S. Pat. 5,173,811, 22 December 1992.
3. P.E. Esemplare and R.W. Gumbs, "Hot Melt Adhesive Composition that Melts at Relatively Low Temperatures," U.S. Pat. 5,326,413, 5 July 1994.

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. Dr. Ira Whitman of the Whitman Companies has agreed to serve as an environmental consultant to the proposer.

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, picosecond 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°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

No prior, current, or pending support for the proposed work.