Identification and Significance of the Problem or Opportunity

Electrically conductive coatings are used on a variety of military aircraft to control electrostatic discharge, provide lightning strike protection, and for various classified applications. Conductivity is imparted through the use of a conductive pigment; silver, nickel, copper and carbon pigments dispersed in polyurethanes or epoxies. They are applied over aluminum or graphite epoxy composite substrates, which have been treated with a nonchrome-based primer to control corrosion. Even though this nonchrome based primer offers adequate corrosion protection, it does not protect the substrate when conductive coatings are applied over it and just below the topcoat.

The most common method to prevent a metal from corroding or retard its corrosion is to provide an impervious coating over it. Hence, if a perfect barrier layer is applied to the surface of a metal exposed to a corrosive environment, then neither oxygen nor water can reach its surface and corrosion will be prevented. But most coatings are not perfect barriers, and all eventually fail, either through existing pinholes in the coating or by diffusion of oxygen and water. Therefore, there is a need for secondary methods that involve both chemical and electrochemical techniques, such as chemical inhibitors, cathodic protection, and anodic protection. Other than hexavalent chromium, electrically conductive polymers are the only other materials capable of providing all three types of protection. This is important because conductive polymers are used in stealthy aircraft and are effective from the visible to the microwave regions of the electromagnetic spectrum, with applications from camouflage, thermal and radar signature reduction (1)

Phase I Technical Objectives

The primary objective of Phase I is to study the corrosion mechanism of a silver filled coating and develop a process for inhibiting the corrosion of Aluminum 2024 T3 when deployed over qualified nonchrome-based primers. The specific objectives are to: 1. Study the kinetics and mechanism of corrosion of nonchrome primed Al 2024 T-3; 2. Prepare and apply silver paint containing inhibitors and additives over the primer; 3. Evaluate the painted aluminum panels; 4. Optimize and identify the best corrosion protection systems; and 5. Prepare the final report.

In pursuit of fulfilling these objectives and determining feasibility of the concept, Phase I will answer the following questions:

(a) What are the actual mechanisms of corrosion? (b)What are most likely protective schemes? (c) What is the best methodology for studying the kinetics and mechanism of corrosion? (d) What is the salt spray resistance of panels coated with the baseline paint? (e) When does the base line coating fail after exposure to Xenon Arc accelerated aging at 50°C?

Phase I Work Plan

Phase I Work Plan Outline

1) <u>Scope.</u> The research plan during Phase I involves a research and development program to study the kinetics and mechanism of corrosion of Al 2024-T3. Simultaneously, various strategies will be deployed to ultimately inhibit the corrosion induced by the presence of silver in the paint.

2) <u>Task Outline</u>. The work plan is divided into four main tasks which will be carried out in iterative fashion and these are: 1. Study the kinetics and mechanism of corrosion of nonchrome primed aluminum alloy: 2. Prepare and apply silver paint; 3. Evaluate the painted aluminum panels; 4. Optimize and identify the best corrosion protection systems. 5. Prepare the final report.

3) <u>Milestone Schedule</u>. The relevant milestones are answers to some of the basic questions posed in the Technical Objective section of the proposal. Table 1 is a tentative schedule for reaching significant milestones during Phase I.

Table 1. Phase I Milestone Schedule.

Milestone	Months following SOW
Identification of precise mechanisms of corrosion	3
Identification of most likely protective schemes	4
Selection of the best methodology for evaluating the panels coated with Ag + potential inhibitors	3
What is the salt spray resistance of panels coated with the baseline paint with polyurethane topcoat	4
When does the base line coating fail after exposure to accelerated aging	1
Reasonable estimate of feasibility of concept	6

4) Deliverables. a. Kickoff meeting within 30 days of contract start; b. Progress reports; c. Technical review within 6 months; d. Final report with SF 298; and Optimized aluminum panel coated with Ag paint containing the most promising inhibitor.

TASK 1. KINETICS AND MECHANISM OF CORROSION

Corrosion is the destructive result of chemical reactions between a metal or metal alloy and its environment. The general forms of corrosion that are relevant to our understanding are: uniform or general corrosion; galvanic corrosion; pitting corrosion; crevice corrosion; environmentally induced cracking; hydrogen damage; intergranular corrosion; dealloying; and erosion corrosion. In this phase of the program, we are concerned with the first three.

Protective coatings prevent underlying metal from corrosion through two major mechanisms: (a) passivation and (b) barrier. Passivation includes two measures. One refers to immersing the metal into a conversion coating cell that results in formation of insoluble, high density phosphate or chromate layer on the metal surface. Another refers to incorporating the corrosion inhibitor in the primer which will shift the oxidation voltage of the underlying metal (hundreds of mv to more positive direction). The barrier refers to blocking or lowering the rate of permeation of the corrosive agents (O_2, H_2O, Cl^-, SO_3^{-2}, etc.). Anodic protection, which involves chemical reaction of exhausting permeated oxygen, such as zinc-rich primer, is an extension of the purely physical

barrier. When these two corrosion protection mechanisms fail, metal corrosion starts or accelerates.

To identify the above mentioned corrosion mechanism, we will simulate and monitor the corrosion process, and address how the two protection mechanisms are deteriorated or destroyed. Based on our research, we will develop better protective technique or enhance the existing technique by adding inhibitors to the conductive coatings.

We will purchase (4 inches x 6 inches) panels of AL 2024-T3 already prepared with a nonchrome primer ((MIL-PRF-23377J) and coat them with the silver paint first and then the polyurethane topcoat (MIL-PRF-85285D). We will also prepare panels in our laboratory with and without a chromate primer for some of the experiments, which are described below in Tables 2 and 3.

During this task we will study and identify the corrosion process and simultaneously conduct a search for other corrosion inhibitors or additives for inclusion in the conductive coating. The failure of the protective coating might be attributed to one or a combination of the following paths: 1) galvanic corrosion; 2) corrosion inhibitor failing, either chemically or physically migrating toward conductive coating; 3) protective coating failing, becoming porous, or delamination. To identify which one is prevailing, the following techniques will be used in Phase I.

The baseline coating, commercially available silver paint (SPI #5001), will be applied on top of the nonchrome primer. After the primer is dry, a polyurethane topcoat will be applied and dried at room temperature to give a 50 μ thick film.

1.1 Electrochemical Impedance Spectroscopy

Electrochemical Impedance Spectroscopy (EIS) generates quantitative data that relates to the quality of a coating on a metal substrate. Its theory relies on analogies between the electrochemical cell and networks of resistors and capacitors that are thought to behave like the cell. It is useful here, because it can characterize a coated metal substrate by simultaneously measuring two phenomena: (a) the deterioration of the organic coating (top coating and primer) and (b) the increase in corrosion rate of the underlying substrate due to the deterioration of the coating and subsequent attack by the electrolyte.

In EIS, an AC voltage of varying frequency is applied to the sample. It is useful to think of the frequency as a camera shutter that can be very fast (high frequency) for fast reactions and very slow (low frequency) for slow reactions. This is the technical feature that allows EIS to gather so much information on an electrochemical reaction in one experiment. EIS can quantitatively measure both resistances and capacitances in the electrochemical cell. A resistance corresponds to electron transfer reactions such as corrosion. The capacitance of a metal electrode in contact with an electrolyte is important information for any electrochemical system. For organic coatings, the capacitance measurement is particularly revealing. As the organic coating deteriorates with time during exposure to an electrolyte, EIS can track changes in the capacitance of the coating. The capacitance changes as the coating swells or absorbs water, for example. In addition, we can measure changes in the porosity of the coating. EIS also simultaneously monitors

the rate of corrosion of the metallic substrate which generally increases as the protective coating fails, allowing the electrolyte to contact the substrate.

The physical and chemical properties of the coating that affect the capacitance are

$$\mathbf{C_{coating} = (\varepsilon)(\varepsilon_0)(A)/t} \tag{1}$$

Where ε is the dielectric constant of the coating, ε_0 is 8.85×10^{-14} Farads/cm, A is the area (cm^2), and t is the thickness (cm).

The capacitance is related to the magnitude of the impedance ($|Z|$) by

$$\mathbf{|Z| = 1/(2\pi f \ C_{coating})} \tag{2}$$

where f is frequency of the applied AC voltage.

$\mathbf{R_{pore}}$ is pore resistance---the resistance of the coating changes during exposure due to the penetration of electrolyte into the micropores of the coating. Upon immersion, the pore resistance can be very high ($>10^{10}$ ohm) and usually decreases with time of exposure to the electrolyte.

$\mathbf{R_p}$ is polarization resistance---the corrosion rate of the metal substrate beneath the coating is described by the polarization resistance. For a metal in the absence of a coating, the corrosion rate can be determined from the polarization resistance. The polarization resistance is inversely proportional to the corrosion rate. A typical polarization resistance for a bare metal is 5000 ohm-cm^2.

$\mathbf{C_{dl}}$ is double layer capacitance---the coating is not the only structural feature of the sample that gives rise to capacitance. There is a charge on the metal electrode and a charge in the electrolyte that are separated by the metal-electrolyte interface. Since this interface is commonly known as the double layer in electrochemical theory, the capacitance is called the double layer capacitance. This capacitance is in the range of 10-40 $\mu F/cm^2$. So $\mathbf{C_{dl}}$ can sometimes be related to delamination of the coating.
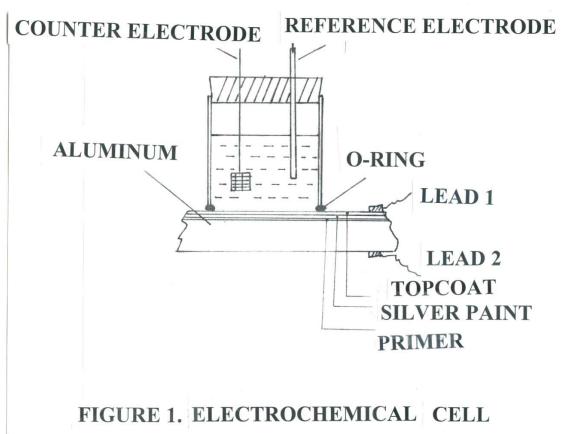
EIS will be performed in a customized electrochemical cell shown in Figure 1 by Policell Technologies in Newark, NJ. To accumulate the precise data, it is necessary to conduct a series of tests. Hence, four basic test configurations are listed in Table 2

Table 2. Test sample configurations

Sample #	Description
1	Topcoat
	Non-chrome primer
	Passivated Al 2024-T3
2	Topcoat
	Silver paint
	Nonchrome primer
	Passivated Al 2024-T-3
3	Topcoat
	Chrome primer
	Passivated Al 2024-T-3
4	Topcoat
	Silver paint

| Chrome primer |
| Passivated Al 2024-T-3 |

COUNTER ELECTRODE   REFERENCE ELECTRODE

ALUMINUM   **O-RING**

LEAD 1

LEAD 2
TOPCOAT
SILVER PAINT
PRIMER

FIGURE 1. ELECTROCHEMICAL CELL

Each sample will be subjected to the EIS-Stressed test-EIS cycle. The stressed test includes the cabinet test, electrochemical oxidization (potential sweep) etc.

1.2 Potential Sweep Method

The complete electrochemical behavior of a system can be obtained through a series of steps to different potentials with recording of the current–time curves. More information can be gained in a single experiment by sweeping the potential with time and recording the i-E curve directly. The technical name for the method is Linear Sweep Voltammetry. A typical i-E curve is shown in Figure 2:
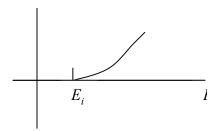
E_i

Figure 2. i-E curve

In Figure 2, E_i is initial potential, oxidation or reduction depending on the sweep direction. Based on our experience, we plan to focus on the initial oxidation potential where corrosion starts. Seven test samples will be prepared as shown in Table 3.

Table 3 List of Second Test Configurations

Sample #	Target Metal	Description
5	Al 2024-T3	Topcoat
		Non-chrome primer
		Passivated Al 2024-T3
6	Al 2024-T3	Topcoat
		Silver paint
		Non-chrome primer
		Passivated Al 2024-T3
7	Silver	Topcoat
		Silver paint
		Nonchrome primer
		Passivated Al 2024-T3
8	Al 2024-T3	Top coat
		Chrome primer
		Passivated Al 2024-T3
9	Al 2024-T3	Topcoat
		Silver paint
		Chrome primer
		Passivated Al 2024-T3
10	Silver	Topcoat
		Silver paint
		Chrome primer
		Passivated Al 2024-T3
11	Silver	Free standing silver paint film

Comparing the E_i of sample pair, we will determine the over potential of aluminum and silver. This indicates the effects of different corrosion inhibitors on the metals. The dependency of the E_i with time will tell us whether the corrosion inhibitor is destroyed or migrated from aluminum to outside. These tests will be performed by Dr. Chen in the proposer's laboratory.

1.3 Open Circuit Potential Measurement

Any conducting metal in an electrolyte solution always forms an electrochemical interface between the metal surface and solution surface facing the metal. This interface is associated with an electrochemical potential difference called Open Circuit Potential (OCP) or Free Corrosion Potential which is always in state of dynamic equilibrium. OCP

is an indicator of the thermodynamic stability of the metal in that test environment. The higher (positive) the OCP is, the more stable. The surrounding environment has an important effect on the OCP of metal. OCP can change with the applied inhibitor in primer, pH and temperature.

In this experiment, we plan to use the same electrochemical cell as shown in Figure 1, and test samples are the same as those listed in Table 3.

Monitoring the OCP change over time, we will learn the stability information of the inhibitor. Meanwhile, the OCP method will be used for evaluating the potential inhibitor and primer formulation. These experiments will be performed by Dr. Chen in the proposer's laboratory

1.4 Cabinet Test and Other Stressed Damage Method

The cabinet test is an accelerated stressed method to test protective coating. It includes UV, salt solution, and wet/dry process. In our laboratory, we will use ASTM D 5894 in these experiments. The other stressed damage method is to connect Lead 1 and Lead 2 in Figure 1, in order to form a galvanic couple. Measuring the current passing through the connect line will show us the performance of the passivation function of protective coating. Insertion of these damage processes into EIS measurements will help us to interpret the EIS data or establish a better model for the circuit network.

1.5 Optical Spectroscopy (UV-Visible, FTIR)

Optical spectroscopy methods are auxiliary in Phase I. We are not sure if they will provide the response signal we are expecting. But UV-Visible Spectroscopy will be used to probe the inhibitor in electrolyte, which is extracted from primer over time. Most inhibitors are water soluble and will be extracted over long time immersion in an electrolyte during the above mentioned experiments. If the inhibitor is UV-Visible sensitive, we can measure its extraction rate and furthermore determine the effect of the conductive coating on the loss of inhibitor from primer.

FTIR will be used to examine the change of coating molecular structure over time. The change refers to either bond scission in the coating polymer chain or production of new chemical species. If the extreme situation occurs, the barrier function or passivation function of the protective coating will fail, and the effect from the conductive coating will be traced.

The first four experimental methods will be used to screen and evaluate the potential inhibitors and their derivatives.

To enhance the barrier function of the protective coating, we will use fillers with an average particle size in nanometers in conductive coating. The impermeability of the coatings and its corrosion protective capability will be monitored in the preceding experiments.

TASK 2. PREPARATION AND APPLICATION ON SILVER PAINT CONTAINING POTENTIAL INHIBITORS AND ADDITIVES

2.1 Potential causes and solutions based on empirical and theoretical considerations

There is a large body of research and development on nonchrome inhibitors, combined with 100 years of actual experience with hexavalent chromium. It is perhaps

helpful to review the reasons why chromates are so effective and to present a list of compounds which may be effective inhibitors or additives for the silver paint.

The four functions that chromate performs are:

1. Rapid exit from a carrier matrix to the surface of the metal;
2. Adsorption of the chromate anion on the bare metal or metal oxide. This alters space charge distributions at the interface, lowering the isoelectric point of the protective anodic metal oxide layer naturally forming on active metals. This repels chloride attack and/or shifts the corrosion potential of that metal and or its pitting potential in the noble direction.
3. Instead of oxygen reduction at cathode sites, reduction of Cr (VI) anion occurs to form an acid insoluble (persisting), Cr (III) oxide layer at cathodic sites. This fills oxide voids over cathodic sites and blocks further corrosion reaction.
4. Buffering the pH or neutralizing increasing acidity at the metal/electrolyte interface which comes from metal oxidation in the absence of air. Increasing acidity accelerates corrosion exponentially (2, 3).

Thus, a combination of several of nonchrome inhibitors is necessary to achieve a synergistic effect that results in the performance of all functions.

Based on the historical evidence and with the objective of achieving a synergistic effect, a list of the inhibitors that will be considered in Phase I is shown in Table 4.

Table 4.List of inhibitors that will be screened.

Poly(aniline) Emeraldine base	Bis (2-methacryloxy ethyl) phosphate)	Copper (II) dimethacrylate
Poly(o-ethoxy aniline) Emeraldine base	3-Methacryloxypropyl trimethoxy silane	Magnesium acrylate
Poly(diphenyl amine) Emeraldine base	Boron vinyl dimethyl siloxide	Zinc dimethacrylate
	Zinc cyanamide	Aluminum triacrylate
	Zirconium (bis-2,2-(allyloxymethyl)- butoxide tris(dioctyl phosphate)	Zirconium methacrylate

It is noteworthy that zinc, cobalt, nickel and lead cyanamides have been used to passivate silver (4-8). This suggests that minute or catalytic amounts of **hydrogen cyanamide**, boric, phosphoric, fluorotitanic, dihydrohexafluorotitanic, dihydro hexafluoro zirconic, or molybdic acid can be added to the emeraldine bases of the conducting polymer candidates and rapidly screened after inclusion in the baseline silver paint.

The baseline coating, commercially available silver paint (SPI #5001), with potential inhibitors and additives suggested from the previous Task or experimental paints containing nanoparticles of Ag and some of the compounds shown in Table 4, for example, will be applied over the nonchrome primer. It will be dried at room temperature

for 24 hours and coated with the polyurethane before accelerated aging tests. Small samples of other commercially available silver paint will be procured and one preferably with an aliphatic polyurethane binder will be selected for comprehensive studies. And because Ag metal powders and flakes typically have dimensions in the micron range, we will prepare a paint using nanoparticles of silver in an aliphatic polyurethane binder with properties described in MIL-PRF-85285.

2.1.1 Direct addition of conducting polymers to the silver paint

The emeraldine base forms of the conducting polymers will be ball-milled and added directly to the baseline silver paint. The mixture will then be used to coat the nonchromed primed aluminum and dried for 24 hours. In addition, each base will be dispersed in the polyol component of a two part aliphatic polyurethane compound and subsequently mixed with the prepolymer to form another coating that will be screened.

2.1.2. Encapsulation of Silver Nanoparticles

Since the technology to encapsulate with polymers is mature, it seems logical to use a polymer that is known to inhibit corrosion of the alloy in question. Therefore, the intent of this subtask is to develop metal/semiconductor (M/SC) interfaces to achieve efficient corrosion protection for aluminum through the formation of a natural electronic barrier to corrosion. A key and immediate objective of this task is to encapsulate particles of silver with each of the following: emeraldine base of polyaniline; emeraldine base of poly(o-ethoxy-aniline); and emeraldine base of poly(diphenylamine).

Used in the Stealth Fighter and Bomber, polyaniline, $(C_6H_4NH)_x$, is a desirable candidate for the proposed work because of its air stability in its doped form, its excellent heat stability and rheological properties. Its emeraldine oxidation state can be represented by the general formula: $\mathbf{[(-C_6H_4-NH-C_6H_4-NH-)_{0.5}-(-C_6H_4-N=C_6H_4=N-)_{0.5}]_x}$.

The rationale for encapsulation, rather than the direct addition to the paint, is that a thin polymeric coating over the silver, while permitting intimate contact between Ag and the conducting polymer, provides a second barrier for the metal. And through the process of atom transfer radical polymerization (ATRP), there is the capability to polymerize many monomers directly on the surface of silver or copper. Hence, the potential inhibitors with vinyl and acrylic groups can be deployed using this technique. And conducting polymers can easily be incorporated into these vinyl and acrylic polymers to form composites at very low levels.

Encapsulation procedures

Although micro-encapsulation is a mature technology, its application to electrically conductive paints has not been exploited fully. The silver powder, which we will encapsulate, consists of nanoparticles. These nanoparticles possess a basic morphological feature which can be characterized as spheres, for illustrative purposes. For our purposes, we will refer to this morphological unit as the primary particle and it is this particle we propose to partially encapsulate. If it is completely encapsulated, it will not render the silver paint conductive because of the absence of conductive pathways in the insulating polyurethane matrix.

Accordingly, we plan to encapsulate silver nanoparticles using the following procedure: A round bottom 500- ml flask is charged with the following: cyclohexane (64 ml), low molecular weight polyethylene (1.0 g), ethyl cellulose + polyaniline (0.6 g), and

nanoparticles of Ag (10.5 g). The contents of the flask are mixed, heated to 80° C and allowed to boil for 5 minutes. After cooling, the mixture is filtered through cheese cloth and dried. We also plan to evaluate encapsulated silver particles at different core to wall ratios and to select that ratio which retains the electrical conductivity of the silver paint, but with a volume concentration of ethyl cellulose high enough to prevent corrosion of the aluminum alloy. Encapsulation of nanoparticles of silver and copper by ATRP will be deferred till Phase II.

TASK 3. EVALUATION

In addition to the tests described in Task 1, we will perform additional tests to provide additional evidence to support feasibility of the concept.

3.1 Accelerated Aging

Accelerated aging will be conducted using the Xenon Arc at 50C by the Akron Rubber Development Laboratory Company (ARDL). In this artificial aging test, the panels will be exposed to a repetitive cycle, which includes exposure to UV light with a controlled irradiance of 0.35 W/m^2 for 102 minutes at a black panel temperature of 50°C followed by 18 minutes of water spray. After 500 hours of exposure, we will subject some of the exposed panels to EIS testing. A batch of 10 samples (4 inches x 6 inches) will be tested at the same time.

3.2 Salt Spray Resistance

We will send batches of 10 samples (4 inches x 6 inches) coated with the baseline and experimental paints to Matco Associates for salt spray testing according to ASTM B-117. This group, which specializes in conducting corrosion testing, is well equipped to assist us during Phase I with a comprehensive evaluation of the corrosion and environmental behavior testing required by the sponsor.

3.3 Filiform Corrosion

This type of corrosion normally occurs on aluminum when it is coated with an organic polymer and is exposed to warm, humid atmospheres. It is activated by chlorides, but the relative humidity is the predominant factor, especially between 85 and 95% relative humidity. And so we will devise a simple test that will be used to screen a large number of paints with potential inhibitors in our laboratory. This test will involve exposing the sample to HCl gas in a chamber where the relative humidity is between 85 and 95%. The sample will be inspected periodically for visible signs of corrosion.

TASK 4. OPTIMIZATION

The objective of this task is to select the most promising systems from the previous tasks and perform the tests necessary to demonstrate feasibility of the concept. We will seek the guidance of the Technical Monitor and potential Phase III partners such as PPG and Deft Coatings before selecting the proper test protocol for demonstrating that the candidate inhibitors when added to the silver paint do not contribute to corrosion of Al 2024 T-3.

TASK 5. FINAL REPORT

At the conclusion of the experimental effort, we will prepare a comprehensive report with a discussion of all results and experimental data, with digital photographs of panels before and after exposure to salt spray and accelerated aging, conclusions and an estimate of feasibility of the concept.

Related Work

Polarization resistance measurements for copper samples coated with a dispersion of doped polyaniline in acid environments indicated that there was both a shift in corrosion potential and increased polarization resistance compared to samples without the doped polyaniline coatings (9).

The emeraldine base form of polyaniline provided good corrosion protection both at open circuit potential and at high anodic potentials. The dissolution of metal (both Cu and Ag) was decreased by a factor of 100 when the metal surface was completely covered by the polymer. Curiously, it was found that poly(o-ethoxy-aniline) acts as a better corrosion inhibitor than polyaniline; the oxygen reduction and hence metal dissolution was completely inhibited. The anodic protection increases with an increase in film thickness. It is believed that the polymer network acts as a sieve for the metal ions and this restricts the dissolution of the ions in solution. The superior performance is attributed to its better solubility and its ability to form more homogeneous and adherent coatings than polyaniline (9).

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Relationship with Future Research or Research and Development

It is anticipated that several inhibitors for the baseline silver paint will be available early during Phase I and that the evidence will be accumulated to demonstrate that they inhibit corrosion of Al 2024-T3. During Phase II, based on the knowledge of the mechanism of corrosion, other conductive paints based on copper, nickel and carbon, along with silver will be extensively tested on Al 2024-T3 and graphite epoxy composite substrates. And it is quite clear that a database with increased salt spray exposure times combined with accelerated aging will be available for presentation to potential Phase III partners and the Air Force. Interaction with both is highly anticipated.

Commercialization Strategy

The proposer intends to file many patent applications as a result of the project early in Phase I because this project is innovative and it attempts to correct a significant problem with nonchrome primers used by the Air Force. The overall markets for the resulting technology are conductive aircraft coatings; specific sales information for most companies is not available. And manufacture of the proposed coatings does not present a problem because it involves simple dispersing an additive into a two component polyurethane coating containing the conductive filler.

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 coatings after they are placed on the Qualified Products List.

The main driver which supports commercialization is that the nonchrome primers do not function when conductive coatings are applied above the primer. A successful demonstration of the feasibility of the concept combined with extensive corrosion tests and accelerated aging tests by independent laboratories will ensure acceptance by the Air Force. Commercialization of the technology should therefore be successful, if the products are placed on the Qualified Products List.

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. He is a

member of the American Chemical Society Divisions of Polymer Chemistry and Polymeric Materials. He will be assisted by Dr. Chengchang Chen, an electrochemist.

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                                       Environmental Science and Forestry.
                                       Dissertation on Cationic Polymerization of
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                           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.

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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. 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 serves as an environmental consultant to the proposer.

Specific <u>major</u> 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 is planned during Phase I

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

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