AIR FORCE
STTR PROPOSAL PREPARATION INSTRUCTIONS

The responsibility for the implementation and management of the Air Force STTR Program is with the Air Force Research Lab, Wright-Patterson Air Force Base, Ohio. The Air Force STTR Program Manager is Mr. Steve Guilfoos, (800) 222-0336. The Air Force Office of Scientific Research (AFOSR) is responsible for scientific oversight and program execution of Air Force STTRs.

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For general inquires or problems with the electronic submission, contact the DoD Help Desk at 1-866-724-7457 (8am to 5pm EST). For technical questions about the topic during the pre-solicitation period (1 Jan through 28 Feb), contact the Topic Authors listed for each topic on the website.

The Air Force STTR Program is a mission-oriented program that integrates the needs and requirements of the Air Force through R&D topics that have military and commercial potential. Information can be found at the following website: http://www.afrl.af.mil/index/htm

Unless otherwise stated in the topic, Phase I will show the concept feasibility and Phase II will produce a prototype or at least show a proof-of-principle.

Phase I period of performance is typically 9 months, not to exceed $100,000.

Phase II period of performance is typically 2 years, not to exceed $750,000.

The solicitation closing dates and times are firm.

Air Force Fast Track

Detailed instructions on the Air Force Fast Track and Phase II proposal instructions will be given out by the awarding Air Force directorate along with the Phase I contracts. The Air Force encourages businesses to consider Fast Track application when they can attract outside funding and the technology is mature enough to be ready for application following successful completion of the Phase II contract. Further information on the STTR Fast Track can be found in Section 4.5 of this solicitation.

Commercial Potential Evidence

An offeror needs to document their Phase I or II proposal's commercial potential as follows: 1) the small business concern's record of commercializing STTR or other research, particularly as reflected in its Company Commercialization Report http://www.dodsbir.net/submission; 2) the existence of second phase funding commitments from private sector or non-SBIR funding sources; 3) the existence of third phase follow-on commitments for the subject of the research and 4) the presence of other indicators of commercial potential of the idea, including the small business' commercialization strategy.

Proposal Submission Instructions

ALL PROPOSAL SUBMISSIONS TO THE AIR FORCE MUST BE SUBMITTED ELECTRONICALLY.

It is mandatory that the complete proposal submission -- DoD Proposal Cover Sheet, **ENTIRE** Technical Proposal with any appendices, Cost Proposal, and the Company Commercialization Report -- be submitted electronically through the DoD SBIR/STTR website at http://www.dodsbir.net/submission. Each of these documents is to be submitted separately through the website. Your complete proposal **must** be submitted via the submissions site on or before the **6:00am EST April 15, 2004** deadline. A hardcopy **will not** be required. Signatures are not required at proposal submission when you submit your proposal over the Internet. If you have any questions or problems with electronic submission, contact the DoD SBIR/STTR Help Desk at 1-866-724-7457 (8am to 5pm EST).

Acceptable Format for On-Line Submission: All technical proposal files must be in Portable Document Format (PDF) for evaluation purposes. The Technical Proposal should include all graphics and attachments but should not include the Cover Sheet or Company Commercialization Report (as these items are completed separately). Cost Proposal information should be provided by completing the on-line Cost Proposal form.

Technical Proposals should conform to the limitations on margins and number of pages specified in the front section of this DoD solicitation. However, your cost proposal will only count as one page and your Cover Sheet will only count as two, no matter how they print out after being converted. Most proposals will be printed out on black and white printers so make sure all graphics are distinguishable in black and white. It is strongly encouraged that you perform a virus check on each submission to avoid complications or delays in submitting your Technical Proposal. To verify that your proposal has been received, click on the "Check Upload" icon to view your proposal. Typically, your uploaded file will be virus checked and converted to PDF within the hour. However, if your proposal does not appear after an hour, please contact the DoD SBIR/STTR Help Desk.

The Air Force recommends that you complete your submission early, as computer traffic gets heavy near the solicitation closing and slows down the system. **Do not wait until the last minute.** The Air Force will not be responsible for proposals being denied due to servers being "down" or inaccessible. Please assure that your e-mail address listed in your proposal is current and accurate. By the end of April, you will receive an e-mail serving as our acknowledgement that we have received your proposal. The Air Force cannot be responsible for notifying companies that change their mailing address, their e-mail address, or company official after proposal submission.

Electronic Submission of Proposal

If you have never visited the site before, you must first register your firm and create a password for access (Have your Tax ID handy). Once registered, from the Main Menu:

Select "Prepare/Edit Phase I Cover Sheets" –

1. **Prepare a Cover Sheet.** Add a cover sheet for each proposal you plan to submit. Once you have entered all the necessary cover sheet data and clicked the Save button, the proposal grid will show the cover sheet you have just created. You may edit the cover sheet at any time prior to the close of the solicitation.
2. **Prepare a Cost Proposal.** Use the on-line proposal form by clicking on the dollar sign icon.
3. **Prepare and Upload a Technical Proposal.** Using a word processor, prepare a technical proposal following the instructions and requirements outlined in the solicitation. When you are ready to submit your proposal, click the on-line icon to begin the upload process. You are responsible for virus checking your technical proposal file prior to upload. Any files received with viruses will be deleted immediately.

Select "Prepare/Edit a Company Commercialization Report" –

4. **Prepare a Company Commercialization Report.** Add and/or update sales and investment information on all prior Phase II awards won by your firm.

> NOTE: Even if your company has had no previous Phase I or II awards, you must submit a Company Commercialization Report. Your proposal will not be penalized in the evaluation process if your company has never had any SBIR Phase Is or IIs in the past.

Once steps 1 through 4 are done, the electronic submission process is complete.

Proposal/Award Inquiries
We anticipate having all the proposals evaluated and our Phase I contract decisions by mid-Aug. All questions concerning the evaluation and selection process should be directed to the Air Force Office of Scientific Research (AFOSR). AFOSR will mail award or decline letters after the evaluation and selection process is complete.

Submission of Final Reports
All final reports will be submitted to the awarding Air Force organization in accordance with Contract Data Requirements List (CDRL). Companies **will not** submit final reports directly to the Defense Technical Information Center (DTIC).

Phase II Proposals
The Phase I award winners must accomplish the majority of their primary research during the first six months of the contract. This six month effort alone, based upon the evaluation of the technical results as reported in the interim report(s) and reviewed by the Air Force Technical point of contact utilizing the criteria in section 4.3, will be the baseline for determination on whether the Air Force will request a Phase II proposal.

Air Force STTR Program Management Improvements
The Air Force reserves the right to modify the Phase II submission requirements. Should the requirements change, all Phase I awardees that are invited to submit Phase II proposals will be notified. The Air Force also reserves the right to change any administrative procedures at any time that will improve management of the Air Force STTR Program.

Air Force 04 STTR Topic Index

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Air Force 04 STTR Topic Descriptions

AF04-T001 TITLE: Improved Pressure- and Temperature-Sensitive Paint

TECHNOLOGY AREAS: Air Platform, Materials/Processes

OBJECTIVE: Develop paint for nonintrusive measurement of surface pressure and temperature on wind tunnel models using temporally gated optical imaging.

DESCRIPTION: The measurement of surface pressure- and temperature-distributions on wind tunnel models is required for assessment of aerodynamic performance, aero-thermal analysis, and determination of boundary layer transition location. Pressure transducers and thermocouples do not provide adequate spatial resolution and require machining of the model and routing of sensor leads. Pressure- and Temperature-Sensitive Paint (PSP and TSP) measurements overcome these limitations [1] but are still limited by residual temperature sensitivity of the PSP and by complications posed by combining PSP and TSP measurements [2]. The recent adoption of lifetime-based methods based on pulsed illumination and gated imaging suggests a new approach in which the current two-gate scheme for PSP is extended to a three- or four-gate scheme in which two signal ratios are measured, from which both pressure and temperature can be obtained [3]. This solicitation seeks the development of a paint that has the appropriate properties for such a pressure/temperature measurement scheme, by use of either a single or multiple fluorophores in the binder [4]. The desired paint should be compatible with 16-bit, scientific-grade, gated, CCD cameras that are used with current PSP systems. The paint must offer a pressure accuracy of 10 psf over the range 20-2100 psf, a temperature accuracy of 0.5 deg F over the range 40-120 deg F, and respond to excitation by diode arrays (preferably around 460 nm). A paint that emits at a single visible wavelength band is preferred, allowing pressure and temperature response to be discriminated in the time domain, preferably with lifetimes below 1 msec. The paint must not alter the aerodynamic characteristics (e.g. surface roughness) of the wind-tunnel model, must have good mechanical adhesion, good uniformity, low photo-degradation, diffuse reflectivity, and must respond to pressure fluctuations up to 200 Hz.

PHASE I: Proof of concept demonstration of a paint that meets the stated objectives. It is anticipated that a successful proposal would build upon prior PSP or TSP development by the offeror. Specifically, the development of a complete measurement system (cameras, illumination sources, software, image registration, etc.) in Phase I is strongly discouraged. The Phase I effort should concentrate on the development of paints, using existing PSP/TSP systems, or simplified measurements on samples exposed to a nitrogen jet in air to demonstrate paint response and optical and mechanical properties. Phase I proposals should outline specific fluorophores planned for incorporation in a new paint formulation, specify the required optical filters to be used, and explain the basis for this selection. Proposals offering to search for unidentified fluorophores are specifically discouraged. All aspects of the paint formulation and paint development—including pressure response, temperature response, uncertainty estimations in the calibration of pressure and temperature responses, paint mixing, application to models, mechanical adhesion, reflectivity and photo-degradation of the paint—will be considered in evaluations and should be specifically and clearly addressed in the proposal.

PHASE II: Continued development of the paint and refinement of procedures for easy mixing, uniform application, calibration, use, and removal of the paint; demonstration of the paint in conjunction with existing optical hardware in a wind tunnel test environment, including full calibration, measurement, and post-processing analysis for a complete evaluation.

DUAL USE COMMERCIALIZATION: There is a growing number of applications in the aerospace, automotive, and electronics industries that require nonintrusive measurement for quantitative and qualitative analysis, including health monitoring.

REFERENCES: 1. J. H. Bell, E. T. Schairer, L. A. Hand, and R. D. Metha, "Surface pressure measurements using luminescent coatings," Annu. Rev. Fluid Mech., Vol. 33, pp. 155-206, 2001.
2. T. Liu, B. T. Campbell, S. P. Burns, and J. P. Sullivan, "Temperature- and pressure-sensitive luminescent paints in aerodynamics," Appl. Mech. Rev., Vol. 50, pp. 227-246, 1997.

3. K. Mitsuo, Y. Egami, H. Suzuki, H. Mizushima, and K. Asai, "Development of lifetime imaging system for pressure-sensitive paint," AIAA Paper 2002-2909, June 2002.
4. J. Hradil, C. Davis, K. Mongey, C. McDonagh, and B. D. MacCraith, "Temperature-corrected pressure-sensitive paint measurements using a single camera and a dual-lifetime approach," Meas. Sci. Technol., Vol. 13, 2002, pp. 1552-1557. (This illustrates the use of a multi-fluorophore paint, though less-widely separated lifetimes would be preferred.)

KEYWORDS: Surface Pressure, Surface Temperature, Global Surface Measurement, Pressure-Sensitive Paint (PSP), Temperature Sensitive Paint (TSP), Lifetime Imaging

AF04-T002 TITLE: Stability and Quench Protection for HTS Superconducting Magnets

TECHNOLOGY AREAS: Materials/Processes, Weapons

OBJECTIVE: Assess potential for thermal damage in High Temperature Superconductors (HTS) and materials combinations for passive, active and preventative quench-protection strategies.

DESCRIPTION: Early magnets wound with HTS have typically been operated in the 20-30K range and have not stored energy at high density. The Air Force is pursuing high-energy superconducting magnet technology for power components such as generators and gyrotron tubes. Because these power components are destined for aircraft applications, refrigerator weight is a significant factor that must be reduced by operating at temperatures near 77K. Analysis has shown that as temperature increases, the thermal diffusivity of the superconductor decreases, and the quench propagation velocity slows to a few cm/sec, causing the stored energy in the magnet to be discharged rapidly into a small volume, possibly destroying the magnet. There are concerns in the HTS community that temperatures above 30K may not allow magnet protection by the same measures used at lower temperatures (4-10K). New methods of quench protection, e.g., involving dielectric insulation with enhanced thermal/electromagnetic properties will be required as operating temperature is raised to minimize refrigeration weight and volume. A strategy for managing stored energy in HTS magnets must be developed based on fundamental understanding of the dynamic electromagnetic, thermal, and mechanical conditions in the entire magnet. The effect of rapid temperature rise and upper temperature limits on HTS materials must be understood at the most fundamental level because of the sensitivity of HTS properties to precise oxygen content.

PHASE I: Identify and determine the temperature rise for simulated energetic HTS magnets undergoing rapid quench conditions over a range of temperatures. Assess the maximum temperature permitted without permanent damage to the magnet. Develop approaches (active or passive) to magnet protection by using appropriate thermal and electromagnetic properties in materials that can be placed in proximity to the HTS. Select a strategy (active, passive or hybrid) for protecting a high-energy HTS magnet. Prepare an implementation plan for Phase II.

PHASE II: Fabricate and test small HTS coils with quench protection measures that can be used to verify modeling programs. Utilize materials with different thermal properties to assess effectiveness in protecting against quench damage. Assess the impact of quench management measures on thermal stability and minimized ac loss. Determine optimal performance of quench protection measures in an energetic magnet (of >kilojoule) typical of an Air Force power application, and test such a magnet with sufficient sensors to detect and monitor a rapid quench condition under different operating temperatures. Provide quench protection strategies for several types of power magnets.

DUAL USE COMMERCIALIZATION: Quench protection for commercial utility power applications is important for this potential $1B/yr activity because the magnets and energy stored are large and a catastrophic quench could destabilize the market. Industry has acknowledged the quench-protection problem and has reduced the proposed operating temperature for power components to near 30K. A successful passive quench-protection strategy that is cost effective would be implemented by the commercial sector.

REFERENCES: 1. M K Chyu and C E Oberly, "Effects of Transverse Heat Transfer on Normal Zone Propagation in Metal-Clad HTS Coil Tapes", Cryogenics, V31, No7 (1991)-also see other papers in this volume from the 1990 Yokohama Conference on Thermal stability and protection.
2. Y Iwasa, "HTS Magnets: Stability; Protection; Cryogenics; Economics; Current Stability/Protection Activities at FBML", Cryogenics, V43, 303 (2003).
3.Y Iwasa, et al, "Quench and Recovery Processes of YBCO Tape", IEEE Trans Appl Supercond, V13, 1772 (2003).
4. F Trillaud, et al, "Normal Zone Propagation Experiments on HTS Composite Conductors", Cryogenics, V43, 271 (2003).
5. R Grabovickic, et al, "Measurements of Temperature Dependence of the Stability and Quench Propagation of a 20-cm-long RaBiTS YBCO Tape", IEEE Trans Appl Supercond, V13, 1726 (2003).

KEYWORDS: high temperature superconductor, quench protection, thermal stability

AF04-T003 TITLE: <u>All-Nitrogen or High-Nitrogen Compounds as High Energy Density Materials</u>

TECHNOLOGY AREAS: Materials/Processes, Space Platforms

OBJECTIVE: Develop synthesis methods for High Energy Density Matter (HEDM) from all- or high-nitrogen compounds for rocket propellants, explosives, or gas generators.

DESCRIPTION: All-nitrogen compounds, also known as polynitrogen compounds, or nitrogen-rich compounds, such as polyazides, store large amounts of energy that can be released when these materials decompose to molecular nitrogen. The synthesis of these materials is very challenging because the reactants, intermediates, and desired products have high endothermicities. These high endothermicities make many of these compounds shock sensitive and extremely difficult to handle. As a consequence, only two energetic polynitrogen species are presently known that possess sufficient stability to be useful for practical applications. These two species are the well known azide ion and the recently discovered pentanitrogen cation.

The goal of exploiting the potential of polynitrogen compounds for HEDM applications requires research to identify new target molecules that possess sufficient energy and kinetic stability to warrant attempts at their synthesis, to develop new methodology for their preparation, and to prepare amounts sufficient for the determination of their structures and properties.

PHASE I: Identify potential polynitrogen HEDM candidates and predict their barriers towards decomposition using theoretical calculations. Design strategies and experimental approaches for their attempted syntheses.

PHASE II: Develop methods for the synthesis of the proposed target compounds. Prepare sufficient amounts of material on the laboratory scale to allow the determination of the structure and the chemical and physical properties of these new materials. Evaluate the potential of the new compounds for HEDM applications.

DUAL USE COMMERCIALIZATION: Continue the development of this technology, carry out process research, and prepare larger amounts of these materials to allow their testing and evaluation for applications such as propellants, explosives, energetic ingredients, or gas generators.

REFERENCES: 1. T. Curtius, Ber. Dtsch. Chem. Ges. (1890) 22, 3023.
2. K. O. Christe, W. W. Wilson, J. A. Sheehy, J. A. Boatz, “N5+: A Novel Homoleptic Polynitrogen Ion as a High Energy Density Material,” Angew. Chem.Int. Ed., (1999) 38, 2004; A. Vij, W. W. Wilson, V. Vij, F. S. Tham, J. A. Sheehy, K. O. Christe, “Polynitrogen Chemistry. Synthesis, Characterization, and Crystal Structure of Surprisingly Stable Fluoroantimonate Salts of N5+,” J. Am. Chem. Soc., (2001) 123, 6308; W. W. Wilson, A. Vij, V. Vij, E. Bernhardt, K. O. Christe, “Polynitrogen Chemistry: Preparation and

Characterization of (N5)2SnF6, N5SnF5, and N5B(CF3)4," Chem. Eur. J., (2003) 9, 2840.
3. M. Glukhovtsev, H. Jiao, P. von Rague Schleyer, "Besides N2, What Is the Most Stable Compound Composed Only of Nitrogen Atoms?," Inorg. Chem., (1996) 35, 7124.
4. W. Fraenk, T. M. Klapoetke, "Recent Developments in the Chemistry of Covalent Main Group Azides," Chapter 16 in "Inorganic Chemistry Highlights," G. Meyer, D. Naumann, L. Wesemann, Eds., Wiley-VCH, Weinheim, Germany, (2002).

KEYWORDS: Polynitrogen, Polyazido compounds, High Energy Density Materials

AF04-T004 TITLE: Advanced Antenna Pattern Prediction Software

TECHNOLOGY AREAS: Information Systems, Sensors, Electronics, Battlespace

OBJECTIVE: Develop efficient prediction code based on aircraft geometry for patterns of low observable antennas, able to account for single layers of Radar Absorbing Material (RAM).

DESCRIPTION: Computational Electromagnetics (CEM) codes are important for avionics design and integration because they permit a priori evaluation of coverage achievable for proposed antenna placements. CEM codes may be divided into those that implement rigorous numerical algorithms and those that provide efficient approximate solutions based on the high-frequency asymptotics. Since computational efficiency is essential in a design/optimization process, the high-frequency codes are frequently preferred for analysis of antenna-pattern platform effects in cases where the electrical size of an aircraft is large. While the Physical Theory of Diffraction and the Uniform Geometrical Theory of Diffraction are both widely used in platform CEM analyses, only the latter includes the creeping-ray mechanism which is essential for providing antenna-pattern values in the shadow region. Implementation of the Uniform Theory of Diffrection (UTD), which has traditionally involved platform geometrical modeling in terms of simple canonical shapes, has recently been extended to accommodate fully realistic aircraft representation. Application of current UTD codes to cases where aircraft are designed for low observability is, however, limited by the failure of these codes to adequately account for the presence of surface materials. In particular, the existing codes do not represent the propagation of creeping rays and surface rays over conducting surfaces coated with material layers. The code developed under this effort will be a computationally efficient high-frequency code that exhibits none of the above deficiencies. Creeping-ray contributions will be computed for propagation over curved coated surfaces in a way that fully and accurately accounts for the surface geometry and the presence of the material coating. For a source antenna mounted on an aircraft fuselage/wing/stabilizer and possibly embedded in a material layer, pattern values will be available in the lit, far-shadow and shadow-boundary transition regions, as well as in the paraxial region in the case where the antenna site geometry is cylindrical. The effects of all significant aircraft external features, such as wings, stabilizers, engine pods, etc. will be included.

PHASE I: Investigate methods for performing high-frequency pattern computations for antennas mounted on an airframe of general shape and embedded in a layer of dielectric/magnetic material. Identify approaches to computing the fields in the lit region, the shadow region, and the shadow boundary transition region. Address the following mechanisms: surface diffraction; edge/wedge diffraction; corner/tip diffraction.

PHASE II: Develop a suite of computational modules that implement the methods identified in phase I. Ensure the proper functioning and efficiency of all numerical algorithms. Demonstrate approximate continuity across region boundaries. Demonstrate the applicability of the modules in likely Radar Absorbing Material (RAM) scenarios.

DUAL USE COMMERCIALIZATION: Incorporate the modules developed under Phase II into a functional, user-friendly antenna pattern prediction code. The final code should be Graphical User Interface (GUI)-driven, able to access aircraft geometrical models in standard Computer Aided Design (CAD) representations, and should allow for convenient designation of portions of the aircraft surface as covered with RAM of a specified type or material characterization. Efficient pattern computation for aircraft treated with known RAM materials should be demonstrated. Comparison with measurements performed on existing aircraft is highly desirable, though the availability of such measurements may be extremely limited. Adoption by the commercial and general aviation communities is anticipated in light of the trend to replace standard metal (aluminum) components with strong, light-weight composites.

REFERENCES: 1. W.D. Burnside, J.J. Kim, B. Grandchamp, and R.G. Rojas, "Airborne Antenna Radiation Pattern Code User's Manual." Ohio State University ElectroScience Laboratory Report 712242-14, Dec. 1982

2. User's Manual for APATCH, DEMACO, 100 Trade Center Drive, Champaigne, IL

3. P. Hussar and V. Oliker, "UTD Prediction of Radiation-Pattern Platform Effects on Fully Realistic Aircraft Models," USNC/URSI National Radio Science Meeting 1998 Digest, (1998) , p. 46

4. P. Munk and P.H. Pathak, "A UTD Analysis of the Radiation and Mutual Coupling Associated with Antennas on a Smooth Convex Surface with a Uniform Material Coating," IEEE Antennas and Propagation Society International Symposium 1996 Digest (1996), pp 696-699.

5. P.E. Hussar and E.M. Smith-Rowland, "An Asymptotic Solution for Boundary-Layer Fields Near a Convex Impedance Surface," Journal of Electromagnetic Waves and Applications , (2002) Vol. 16, , No. 2, pp. 185-208.

KEYWORDS: Antennas, Radiation Pattern, Radar Absorbing Material, Low Observability

AF04-T005 TITLE: <u>Two-Dimensional Micro-Colloid Thruster Fabrication</u>

TECHNOLOGY AREAS: Materials/Processes, Space Platforms

OBJECTIVE: Development of Silicon Micro-Fabrication Technology for colloid thruster emitter clusters, complete and ready for spacecraft integration.

DESCRIPTION: Colloid Propulsion is a subset of Space Electric Propulsion, in which the accelerated medium is a charged colloidal stream (a collection of charged nanometer-sized droplets), or following recent developments, a collection of ions extracted from the same liquid. The acceleration is electrostatic, and, significantly, no plasma is involved in the charged particle production. There are significant progress made on the development of 1-D micro-fabricated colloid arrays operating in the regime with a single Taylor cone per emitter, This research will extend the micro-fabrication range to 2-dimensional arrays, which can provide much higher thrust density. A more compact arrangement, with fewer external assembly steps would be possible if the emitters were arranged in a 2D array on the surface of the wafer. For instance, even if the emitter-to-emitter spacing were increased to 340 micrometer, a square array of size 34 x 34 mm would contain 10,000 emitters, for a I. milliNewton total thrust. In addition, experimental and analytical study of "highly stressed" multi-cone regime is necessary , as well as other potential regimes that may provide alternative avenues towards high thrust per emitter, and hence high overall thrust density.

PHASE I: Investigation of 2D Colloid Array Architecture: Through a combination of modeling, microfabrication and laboratory testing, to assess the relative advantages of several possible 2D arrangements of colloid sources. A partial list of the configurations to be researched includes simple through-wafer designs, porous substrates with impervious, perforated coverings, arrays of externally wetted needles and fused bundles of stretched tubes.

PHASE II: Microfabrication of Colloid Thruster Array: design and fabricate, and test 2D initial prototype demonstrator, completing fabrication of the thruster. Functional tests will be carried out at each iteration step. Performance mapping will be performed.

DUAL USE COMMERCIALIZATION: Several miniaturized satellite configurations could benefit from this thruster.

REFERENCES: 1. Luis F. Velasquez, Manuel Martinez-Sanchez and Akintunde Akinwande,

"Development of a Micro-fabricated Colloid Thruster Array". Paper JEPC-03-138, 28~ International Electric Propulsion Conference, Toulouse (Fr), March 2003.
2. Paulo C. Lozano, Studies on the Ion-Droplet Mixed Re2ime in Colloid Thrusters. Ph.D. Thesis, MIT, Feb. 2003.
3. Juan Fernandez de Ia Mora and I.G. Loscertales, "The Current Emitted by Highly Conductive Taylor Cones". J. Fluid Mech., (1994), Vol. 260, pp. 155-184.
4. Jorge Carretero and Manuel Martinez-Sanchez, "Modeling Developments in Colloid Thrusters", paper IEPC-03-265, 28~" International Electric Propulsion Conference, Toulouse, (Fr), March 2003.

KEYWORDS: Satellite, electric propulsion, colloid array

AF04-T006 TITLE: User-Safe "Virtual Laboratory" Environment for High-Voltage Radiation Source Experiments

TECHNOLOGY AREAS: Information Systems, Electronics, Weapons, Nuclear Technology

OBJECTIVE: Computer-based physics modeling capability for safely and inexpensively conducting basic research on innovative high-voltage radiation source concepts.

DESCRIPTION: Electromagnetic radiation sources driven by high-voltage, high-current electron-beams offer an immensely rich area of basic research opportunities. Applications abound from directed-energy weapons and nuclear effects simulations for the DoD to novel imaging concepts for the commercial medical community. Unfortunately, laboratory experiments on such sources currently require the use of life-threatening and expensive high-power electronics. Stringent safety regulations often make such a course of experimentation prohibitive to many talented researchers in both the university and industrial R&D arenas. Fortunately, modern computational physics has advanced nearly to the point of being able to accurately model the detailed science of such experiments.

Under this topic, researchers will create a state-of-the-art, object-oriented software environment expanding upon proven particle-in-cell (PIC) electromagnetic simulation capabilities. This environment will form a "Virtual Laboratory" for high-voltage radiation source research by precisely simulating their detailed physics. To accomplish this, new modeling algorithms must be created for the first time to accurately simulate the following: (1) Electron emission from a moving cathode plasma surface, (2) The scattering of energetic electrons from metals and insulating materials, (3) High-voltage electrical breakdown on insulator surfaces, (4) Intense heat fluxes, (5) X-ray generation and effects, and (6) Detailed structural visualization.

PHASE I: Design and describe the detailed software that will permit the realization of such a "Virtual Laboratory." This must include the complete theoretical formulations that will be used to create the algorithms necessary for items (1) through (6) above.

PHASE II: Create a complete computer-based software system that will accurately model the physics enabling "Virtual Laboratory" research into high-voltage radiation sources.

PHASE III DUAL USE APPLICATIONS: The resulting "Virtual Laboratory" environment will be required by all scientists, engineers, and students involved in the design and/or fabrication of high-power, electron-beam-driven sources of electromagnetic radiation. This includes not only military researchers working on new communications, electronic warfare, nuclear weapons effects, or directed energy weapons sources; but also civilian researchers in communications, radar, or the highly lucrative medical imaging fields. Commercial profits on this software will probably be an order-of-magnitude greater than those from the military.

REFERENCES:
1. JW Luginsland, et al., "Chapter 11: Computational Techniques" in High-Power Microwave Sources and Technologies, RJ Barker & E. Schamiloglu, Eds., IEEE Press, New York, 2001.
2. CK Birdsall and AB Langdon, Plasma Physics via Computer Simulation, Institute of Physics Press,

London, 1995.

KEYWORDS: high-power microwaves, nuclear effects simulation, computational physics

AF04-T007 TITLE: Real-Time Detector of Human Fatigue

TECHNOLOGY AREAS: Biomedical, Human Systems

OBJECTIVE: Develop and validate a non-intrusive system to estimate human alertness/fatigue status for display in real-time.

DESCRIPTION: In many operational environments, any departure from alert human performance can have extremely serious consequences. Recent technological and modeling developments provide an opportunity for breakthrough developments in the area of real-time, continuous monitoring of fatigue. Improvements in video and laser Doppler vibrometry (Andersen et al., 1997), machine vision algorithms, bio-behavioral modeling and readiness-to-perform assessment techniques indicate that a real-time fatigue monitoring system can be developed. One key challenge is to integrate multiple bio-behavioral measures that can be remotely sensed, i.e., physiologically non-invasive and also non-intrusive with respect to the primary task. Individualized sleep/wake/work histories and/or computations from an appropriate mathematical model of sleep/wake dynamics should also be considered. A second key challenge is to validate the system with respect to objective metrics of human performance.

PHASE I: Design a promising remote-sensing software/hardware system to acquire and process relevant physiological and behavioral data in real-time. Design the system for use with workstations or other configurations in which the human operator is seated and oriented to a workstation, but is not otherwise constrained from making normal movements while seated. Develop a plan to validate the system. Report preliminary tests to determine feasibility for continuous application and real-time display.

PHASE II: Build the system and implement a first-cut optimization by conducting, analyzing and reporting validation tests with human operators in one or more simulated military command and control environments. Use simulated task environments that (a) provide a dynamic, information-rich workload and (b) permit an objective assessment, via task modeling, of expected standards of human performance. Relate the system output and performance data to an appropriate mathematical model or algorithm for estimating human fatigue.

DUAL USE COMMERCIALIZATION: This system will be useful in 24/7 military command and control applications, such as a ship's Combat Information Center (CIC) or an Air Operations Center (AOC), to help assure optimal staffing and work-scheduling, as well as to assist operators in fatigue-management and countermeasures for fatigue-induced errors. The system will be equally useful for fatigue risk management in the operation of non-military emergency services and other civilian applications.

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KEYWORDS: Fatigue monitoring, human performance, neurobehavioral assessment, operational readiness, performance optimization

AF04-T008 TITLE: Automated Detection of Steganographic Content

TECHNOLOGY AREAS: Information Systems

OBJECTIVE: Design and build an automated "anti-steganography" application in the fashion of common anti-virus applications.

DESCRIPTION: Because of the availability of steganographic software as both freeware and licensed software, it is becoming increasing easier to steganographically embed data within media files. This creates a need for an application that can detect the presence of steganography in such files, alert the user to its presence, and quarantine the file to minimize the impact of the embedded content on the user's system. This application should run both unobtrusively in the background and in a manual mode, and provide the user the capability to scan all email attachments, downloaded materials and accessed files with an appropriate steganalysis algorithm, reporting any abnormal results (i.e. the presence of steganography). The program should be written in such a way as to allow the user to customize the scope of the checking (i.e. specify folders, filetypes, etc.) as well as the algorithms used. Most importantly, the application should be written in an extensible manner with a published Application Program Interface (API) that allows for the insertion of both new and improved algorithms. Due to the changing nature of the field, this equates to constructing an application that would act as a scanning engine, able to run any steganalysis technique implemented to interface with the engine. Such an application would give the user a level of protection from embedded content in much the same way as virus scanning software does today, and like virus scanning software provide extensibility to detect new and even novel embedding that may be developed in the future.

PHASE I: Design and implement an anti-steganographic engine that checks for the presence of steganography in media files. The application should be extensible and allow for the automatic and manual checking of files, and perform checks unobtrusively. The application should be customizable and allow for additional features to be added by way of a robust, published API.

PHASE II: Implement algorithms for the engine developed in Phase I, and thoroughly test and verify the software. The algorithms selected for development should be deemed both relevant, robust, and on the cutting edge of the current work being done in the area. These implementations shall then be used to thoroughly test and tweak the application, and to evaluate the end product for its usefulness and the validity of the approach.

DUAL USE COMMERCIALIZATION: Demonstrate the flexibility of the design by extending the engine and algorithms to work in a web-environment with minimal rework and re-engineering. The resulting application should interface with a well-known and widely used browser (such as Internet Explorer or Netscape) through that browser's published interface. The intent of this application would be to scan media downloaded into the browser for steganographic content, and alert the user when such content is discovered. When content is discovered, the user should be given the capability to quarantine and/or flag the content for further investigation. This application would have similar commercial potential to virus software and might be expected to included in current virus software packaging.

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KEYWORDS: Steganalysis, Anti-Virus, Malicious Code

AF04-T009 TITLE: Automated Design Optimization for Hypersonic Plasma-Aerodynamics

TECHNOLOGY AREAS: Air Platform, Materials/Processes

OBJECTIVE: Develop an automated design optimization tool for electromagnetic control of hypersonic flow.

DESCRIPTION: Over the last few years, a great deal of interest has arisen in the use of hypersonic flow control methods based on weakly-ionized plasmas and strong applied magnetic fields. Military applications include heat transfer mitigation on reentry vehicles and magnetohydrodynamic bypass concepts for scramjet-powered vehicles. Civilian dual-use applications include ignition of combustion in engines, materials processing, biological sterilization procedures, and electronics manufacturing. Numerical methods for simulating these systems, such as those used in the AFRL FDL3DI-mhd code, have matured to the point where it is feasible to consider work on automated design optimization methods for electromagnetic flow control (Poggie & Gaitonde, 2002). Adjoint aerodynamic shape optimization methods, for example, have been highly successful for the transonic flight regime (Jameson et al, 2003), and could be adapted for the hypersonic regime and ionized gas flow. Possible topics include, but are not restricted to: optimization of vehicle shape to obtain maximal electrical conductivity, optimization for maximum power extraction from an Magnetohydrodynamic (MHD) generator, minimization of total heat load, and maximization of control moments. Emphasis is placed on methods that incorporate the physics of the problem in a highly optimized algorithm.

PHASE I: Develop computer code for solutions of compressible, viscous flow with non-equilibrium chemical kinetics and capability to predict electrical conductivity. Develop solver for corresponding adjoint equation system. Carry out exploratory computations to find optimal body shape to maximize electrical conductivity for external flow control applications. Optimal seeding with alkali metals may be explored. Incorporate reduced-order model of MHD generator/pump into code as boundary condition. Explore optimization for minimum heat transfer, maximal control force generation, or maximum power extraction.

PHASE II: Expand capabilities of computer code to include magnetohydrodynamic equations in the low magnetic Reynolds number approximation. Develop solver for corresponding adjoint equation system. Apply code to hypersonic reentry flow, explore optimization for minimum heat transfer, maximal control force generation, or maximum power extraction.

DUAL USE COMMERCIALIZATION: Develop existing code into robust, general-purpose, automated-design tool with potential for commercialization. Explore application of code to problems of commercial and military interest. Explore design optimization of atmospheric entry vehicle utilizing electromagnetic control concepts.

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KEYWORDS: Hypersonic, Magnetohydrodynamics, Design optimization, Adjoint optimization methods

AF04-T010 TITLE: Organic Based Flexible Transistors and Electronic Devices

TECHNOLOGY AREAS: Materials/Processes, Sensors, Electronics, Battlespace

OBJECTIVE: Develop organic and polymer based transistors and electronic devices on flexible substrate to enable fabrication of smart skins and conformal electronic structures.

DESCRIPTION: Organic and polymeric based transistors have been fabricated. These devices can be processed on flexible substrates and at temperature much lower than conventional transistors. These features make this technology ideal for integration with other complex functionalities such as flexible memory, flexible waveguides and flexible photovoltaics to form conformal smart skins and multifunctional structures with built in signal processing and functional control circuitry for Air and Space applications. The performance of these transistors however is not high, mainly because of low charge mobility in the organic and polymeric materials in comparison with conventional semiconducting materials. Current state-of-the-art mobility figures for polymers are typically below 10-2 cm2/Vs, and 0.01 to 0.1 cm2/Vs for well ordered small molecules. This research topic will seek to improve the performance of the mobility of these materials by 2 orders of magnitudes, (polymers to 1 cm2/Vs and small molecules to 10 cm2/Vs). Such improvement will enable high external efficiency Light Emitting Diodes with 10-20% external efficiency and pro-longed service life, thin film transistors with expanded bandwidth and performance level suitable for logic and memory applications for medium to large density ICs.

The research should include innovative approaches to improve the charge mobility of the organic phase to enhance the performance of the transistors. In addition to electronic transistors, other electronic devices can be included. Issues relating to balanced charge (electron and hole) mobility in devices should be considered. Device design and fabrication techniques appropriate for the material technology should be implemented to fabricate devices for performance testing. Testing should be conducted to compare with published performance level of polymer and organic transistors and relevant devices, and with devices based on amorphous silicon technology.

PHASE I: Assess approaches to improve charge mobility, and to address charge-balancing issues, if necessary, in organic and polymeric phases. Simple device structure will be fabricated to give indication of device performance.

PHASE II: Continue development of the concept and demonstrate the improvement of performance over current polymer transistor technology and devices based on amorphous silicon technology.

PHASE III DUAL USE APPLICATION: Successful demonstration of the concept will lead to many applications of the technology in civilian markets. These can include flexible displays, low cost electronic papers, smart membranes and textiles, and smart structures in automotive and transportation industry.

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KEYWORDS: Polymer based transistors, polymer electronic devices

AF04-T011 TITLE: Cooperative Tracking of Moving Targets by Teams of Autonomous Unmanned Air Vehicles

TECHNOLOGY AREAS: Information Systems, Ground/Sea Vehicles, Sensors, Electronics, Battlespace

OBJECTIVE: Demonstrate the capability of small autonomous Unmanned Air Vehicles (UAVs) to cooperatively find, acquire and track multiple moving ground or sea-based targets.

DESCRIPTION: Many proposed concepts of operation involving teams of UAVs include cooperative autonomous behavior to execute distributed sensing functions. Use of teams of low cost UAVs would allow inexpensive, persistent Intelligence, Surveillance & Reconnaissance (ISR) and Battle Damage Assessment (BDA) under cloud layers. Cooperative operation of multiple UAVs using various payloads (video Electro-Optic (EO), Infrared (IR), laser designators, etc) further extends the potential mission scenarios. Of interest in many applications is the potential to use teams of UAVs to find, acquire and track moving ground targets in a stealthy manner. Current state-of-the-art for small ground launched UAVs allows extended semi-autonomous operations with visual and IR cameras for ground surveillance. The avionics packages for these vehicles are sufficiently mature to support reasonably sophisticated mission profiles. Algorithms that lock onto the pixels or targets of objects specified by the user will need to be adaptively tracked as the perspective, light, and motion of the target(s) vary. On-going research in cooperative, coordinated path and mission planning for multiple UAVs will produce the necessary flight path control algorithms to enable the UAVs to execute the distributed sensing functions while adapting in real time to changing, uncertain conditions. The range and endurance capabilities of small UAVs now allow operations of up to 24 hours and several thousand miles. Even though these capabilities are now feasible in UAVs at low enough cost to make the vehicles selectively attritable, thus extending the potential utility in high exposure scenarios, realistic applications will still require that the tracking be conducted at stand-off distances to increase the stealth of the surveillance. Thus, in order to execute Cooperative Search, Acquisition and Tracking (CSAT) missions, a major technology challenge will be to integrate stand-off line of sight trajectory following with the cooperative path and mission planning capabilities. This integration will need to account for the characteristics of the sensors to be used as well as the required inter-vehicle communications. Since it is expected that the moving targets will employ terrain masking to escape surveillance, real time estimation algorithms to construct likely target paths will need to be incorporated. Tracking targets from multiple UAVs requires that trajectories be expressed in a common geographical coordinate system. Therefore, in order for UAVs to cooperate, tracking must not only be in sensor coordinates, but also in geographical coordinates. Geo-referenced target trajectories and descriptions based on multiple sensors and UAVs are stored in a common database, which can either reside in a ground station, or onboard the UAVs. The database serves as a data fusion system, and provides the data necessary for UAV flight planning. The estimated movement of the targets then will have to be integrated into the UAV intra-team task allocation and associated path planning algorithms. Integration of the payload processor hosting the CSAT algorithms with the primary UAV flight control and communications processor will be required.

PHASE I: Identify suitable UAV platforms and ground targets for concept demonstration to focus development activities. Assess candidate target tracking algorithms that are robust enough for the candidate sensor suites. Develop an architecture for tracking onboard the UAV or with ground station control. Assess sensors, guidance and control methodologies for the autonomous search, acquisition and tracking mission. Develop an approach for modeling typical scenarios. Develop an integration plan for incorporating on-board dynamic cooperative path and task planning algorithms with path following for constant line of sight constraints and the communications requirements. Define the integration interface with primary UAV flight avionics. Develop an implementation and test plan for Phase II including hardware-in-the-loop simulation.

PHASE II: Improve target tracking algorithms and code in real-time for either ground-station or on-board implementation. Refine models and control laws developed in Phase I. Perform a physical demonstration of the complete system with representative UAV teams and ground target platforms.

DUAL USE COMMERCIALIZATION: Successful development of the autonomous CSAT capability for teams of inexpensive UAVs will lead to economically feasible applications in coastal and border surveillance as well as search and rescue.

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KEYWORDS: Cooperative control; cooperative search, acquisition and tracking; autonomous systems.

AF04-T012 TITLE: Scramjet Flight Test Instrumentation

TECHNOLOGY AREAS: Air Platform, Ground/Sea Vehicles, Weapons

OBJECTIVE: Acquire instrumentation capable of being utilized in future scramjet flight tests to determine overall combustor operation.

DESCRIPTION: The ability to obtain as much data as possible during any flight test is imperative. Conventional instrumentation, e.g. thermocouples and pressure transducers, provide local wall measurements that can be used to evaluate system operation and to some degree, system performance. Non-intrusive laser-based techniques permit measurements throughout the flowfield and have proven successful at targeting specific species of interest. Advances in infrared (IR) tunable diode laser absorption spectroscopy over the past decade have proven effective in both laboratory and ground-test experiments (see references 1-3). The type and amount of data provided with IR diode laser absorption would be extremely valuable in more accurately determining engine performance in flight. Essential to the process is acquiring as much data as possible for a given instrument position, which in this case means measuring as many species as possible along a single axis (in order to minimize the number of required combustor casing penetrations). One of the problems with current diode laser measurements is the inability to multiplex/demultiplex a significant number of wavelengths through a single fiber optic in a small space. Current demultiplexing schemes require several square feet for separation of 3 wavelengths. Practically, many more than 3 wavelengths will be needed. For example, a gas temperature measurement using water vapor requires 3 absorption lines, with one additional wavelength for each of CO, CO2, NO, O2, and unburned fuel. This brings the total near 10 wavelengths, so the need for a single fiber to accommodate numerous wavelengths is clear. If a substantial increase in the number of wavelengths transmitted by a single fiber can be realized, a valuable tool for flight tests will result.

PHASE I: Determine if a completely fiber coupled multiplexing/demultiplexing system of IR diode lasers for probing the exhaust gas of scramjet engines is feasible. The wavelengths of interest must be multiplexed/demultiplexed with minimal power loss in each channel and fibers with large numerical apertures, which are necessary for efficient optical collection and beam steering immunity, must be used in the process.

PHASE II: Design and build a prototype system with a minimum of four multiplexed/demultiplexed wavelengths targeting combustion exhaust species of interest. This prototype could be tested in a laboratory environment initially, and then in a ground test of a practical scramjet combustor.

DUAL USE COMMERCIALIZATION: A compact flight-weight system could be used in scramjet flight tests. In addition, such a system could possibly be utilized in gas turbine propulsion systems. The telecommunications market could benefit greatly from single fibers that are capable of carrying multiple wavelengths.

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KEYWORDS: Combustion, Combustion Diagnostics, Combustion Modeling, Atmospheric Monitoring

AF04-T013 TITLE: Active Silicon Nanophotonics

TECHNOLOGY AREAS: Sensors, Electronics, Battlespace

OBJECTIVE: Develop and demonstrate active all-optic and electro-optic devices for photonics on a Silicon Chip based on active and passive low-power components.

DESCRIPTION: Optics on Silicon (Si) enables integration of optics and microelectronics. It can open the door to a new technology that is free from conventional microelectronics with low power, high bandwidth, high speed. Currently, however, most of the proposed and demonstrated devices are either passive or are based on compound semiconductor materials and therefore remain discrete and not monolithically integratable with current CMOS technology. From the system integration perspective, there is a need for active silicon devices. Silicon as an optical material has unique advantages. Silicon is transparent in the range of optical telecommunications wavelengths, and is extremely mature in terms of processing. There has been a wealth of research that has mainly focused on passive integrated Silicon devices. Silicon single mode waveguides with less than 0.5 mm cross-sectional dimensions have been demonstrated with low loss of the order of 0.1 dB/cm . Extremely sharp curves, bends, an splitters have also been demonstrated, allowing a high level of integration. Multiplexers and demultiplexers using resonant structures such as ring resonators have been shown. In addition, Germanium detectors on Silicon for the 1.5 micron wavelength have recently been demonstrated as have silicon-based Light-Emitting Diodes (LED) with a significant external quantum efficiency of at room temperature. Silicon as an optical material also presents several challenges. These issues are fundamental limitations that arise from material properties, and result in difficulty of externally controlling Silicon structures for optical modulation and switching, and in poor light emission from Silicon devices due to Silicon's indirect band gap, low Electro-Optic (EO) and low non-linear coefficient. There is a need to develop novel devices that can overcome the limitations of Si-based photonics using novel materials and novel geometries, for enhancing the interaction of light with matter. Devices with novel functionalities that are compatible with Silicon for switching, amplifying, light emission and modulating need to be developed. Nanostructures and nanofabrication are seen as a potential solution to the challenges and limitations. Approaches ranging from quantum wells, superlattices, quantum dots, photonic bandgap structures, to plasmon resonance, novel doping and processing may be considered. Future battlefields systems will exploit highly sophisticated guided wave and wireless communications networks connecting command and control with dense arrays of intelligent sensors, compact reconnaissance platforms and unmanned and manned military assets. These environments will need ultracompact, lightweight, low-power, low-cost optical sources, antenna transmitters and detectors. Such technologies in turn require advances in design of ultracompact hybrid microelectronic/microphotonic systems. Successful completion of this program will aid the development of high quality, robust, photonic networks tightly coupled with high-performance microelectronic analog and digital processing units.

PHASE I: Design and fabricate novel structures for electro-optic and all-optical switches and modulators based on the principle used for the structure of confining light for minimizing power and size. Explore structures with different designs for enhanced functionalities, using different waveguide geometries for routing signals on-chip. Address integration of the different devices. The effect of the light confinement on bandwidth, losses, power and modulation depth would be analyzed. Explore structures with different degrees of light confinement. Model the dynamics of the different mechanisms for carrier absorption and recombination. Investigate novel materials, structures, and coupling schemes that are Si compatible for amplifying and generating light on Silicon. Materials with high emission cross section would be developed that are compatible with current CMOS technology and allow for monolithic integration on-chip. Novel geometries that enhance the interaction of light with matter for increased effective emission and absorption cross section would be investigated. Preliminary fabrication of the devices for the demonstration of their feasibility and application to DoD needs would be performed.

PHASE II: Build upon Phase I work and demonstration of CMOS compatible active photonic structures relevant to compact military platforms. This phase would focus on the fabrication of the structures and their integration on a single chip. Active devices designed in Phase I would be fabricated and tested. The main source for loss of Si nano-size structures is the scattering losses, typical of in high index contrasts systems. Numerical analyzes of the scattering losses, and the use different fabrication methods such as post-etching oxidation for smoothing sidewall roughness would be performed. This investigation is important to the real implementation of the devices. Investigate the on-chip integration of passive waveguides, with the developed active devices. Different integrated systems with novel architectures would be considered, directed towards different military applications. Examples of such a system might be an on-chip reconfigurable Wavelength Division Multiplexing (WDM) system or multi spectral receivers. The maximum density of devices limited by the sizes of the devices as well as the overall losses of the system would be determined. The main effort of the integration of the structures would be on minimizing the losses, size and power of the system while maximizing the bandwidth. The analyzed systems would be fabricated and tested.

DUAL USE COMMERCIALIZATION: Si Nanophotonics has the potential for revolutionizing many fields including telecommunications, data communication, and sensing. In telecommunications, Si Nanophotonics can provide inexpensive optical cross-connects and optical add/drop multiplexers for direct optical connections without the need of optical-to-electrical conversion. This conversion is one of the main limitations of speed in communications. In data communications, Nanophotonics can solve the problems of bandwidth, pinout density, reliability, and complexity that threaten to end the advance of the silicon integrated circuit technology. In sensing, Si Nanophotonics will enable systems of unprecedented throughput through massively parallel array architectures.

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KEYWORDS: Nanophotonics, silicon nanophotonics, silicon microphotonics, silicon, Si, SiO2, optical interconnects, optical nanodevices, integration, waveguides, optical switching, modulators, lasers, wavelength division multiplexing, WDM, photonic bandgap, photonic crystal, erbium, chip scale optical networks

AF04-T014 TITLE: Optimal Training System

TECHNOLOGY AREAS: Human Systems

OBJECTIVE: Develop an automated system for training human operators in a complex task, based on an optimal model of the task.

DESCRIPTION: Many vital military tasks require skilled operators to perform complex tasks that involve asset allocation, scheduling, control or coordination. There is an urgent need for automated systems that can efficiently train human operators for these tasks. The goal of this project is build an “intelligent”

training system that will match the effectiveness of an expert human tutor in its sensitivity to the trainee's individual skills and abilities. Although attempts have been made to achieve such tutoring systems, several problems have prevented success. One problem is the lack of a way to objectively assess the effectiveness of the trainee's performance. The tasks of interest usually involve multiple measures (number of enemy downed, number of friendly aircraft lost, amount of fuel used, number of refueling events, distances from prescribed locations, elapsed time, etc.), and there has been a lack of clear criteria for assessing effective performance—apart from arbitrary weighting functions or subjective judgments by subject matter experts. A second problem is the lack of an adequate specification of high level information processing; there are few formal models of how human experts solve complex tasks. Without such a model, one cannot know what constitutes the differences between the beginner and experienced operator, and hence one cannot know how to efficiently turn a trainee into such an operator. An opportunity exists for applying Operations Research techniques to the training problem. Simplified versions of the tasks (such as have been implemented in some Simulated Task Environments) are often amenable to solution by analytic or algorithmic methods, allowing specification of a normative model of ideal behavior. Such a model could be used to breach the barriers of complex performance assessment and expert specification. In addition, once those barriers are breached, such techniques could be used to optimize the operator's training regime.
In summary, this project will employ a normative engineering model of a complex task as the core engine of an automated tutor. This model will provide a process-level description of expert behavior, thereby (a) allowing continuous and rapid assessment of the effectiveness of the human operator's performance (by comparing human to ideal performance), (b) enable identification of the key information processing difference(s) between the trainee and the experienced operator, and (c) allow the automated tutor to dynamically vary the training regime so as to most efficiently attain the targeted level of operator proficiency.

PHASE I: Investigate the concept of using a normative engineering model of the operator's task as the core engine of an automated tutor.

PHASE II: Develop an automated training system that employs a normative model of a complex task in order to minimize operator training, maximize performance, Use the system to determine specific training strategies that lead to optimal acquisition of operator expertise.

DUAL USE COMMERCIALIZATION: Develop an application of the above training system to a complex military or industrial decision making task.

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KEYWORDS: optimal models, human-computer interaction, automated tutors

AF04-T015 TITLE: Seamless Sensor Network Communications

TECHNOLOGY AREAS: Information Systems, Electronics

OBJECTIVE: Develop novel approaches for space-time coding of sensor networks to convert spatially distributed sensor nodes into efficient, robust and secure wireless networks.

DESCRIPTION: Common deployment practices often scatter multiple sensors over a limited geographic region in an effort to collect data of interest. Ideally, such data is subsequently analyzed and fused in a manner that most expeditiously achieves or facilitates a given mission objective, whether it be continued surveillance, reconnaissance, target identification, registration and disposition, or anything else along those lines. In such a system, each sensor in the network is expected to reliably and securely transmit its data to an appropriate receiver (collector) at various time intervals for further analysis, coordination and processing. Typically, each sensor has just a single antenna, due to size cost and power limitations. The collector, which serves many sensors, is planned to utilize an antenna array with many elements. Depending on the application at hand, different sensors may very well be responsible for different levels of throughput and fidelity. In many cases, some sensors will have to support several transmissions within a short time interval while others may only transmit sporadically or not at all. To accommodate such versatility in performance, network resource allocations must be prudently determined and continually reassessed.

Contemporary and future sensor network applications are expected to utilize anywhere from 10 to 1000 or more individual sensors in potentially hostile and militarily sensitive environments. Each sensor is likely to be required to support secure data-intensive collection and dissemination in a robust and oftentimes covert fashion. Furthermore, network elements are not likely to be guaranteed a line-of-sight transmission path to the collector nor promised to remain at a fixed position for any period of time. Accordingly multi-path propagation may be considered to be the rule rather than the exception.

To effectively operate under the aforementioned constraints we propose the use of advanced space-time coding and adaptive communications signal processing. By using space-time coding (collaborative transmission of different parts of the overall information data from more than one single-antenna sensor) and multi-user detection techniques, communications transceivers can simultaneously listen to transmitted signals while assessing and identifying channel characteristics. Due to the difference in multi-path signatures from each of the sensors, it is intended to facilitate wireless intrusion detection and mitigation. Furthermore, adaptive communications signal processing, including modulation formats, proactive and reactive interference mitigation, error correction and packet recovery, and information protection can also be employed to guarantee mission effectiveness or, perhaps, enable suitable reassignment or reconfiguration of corporately available resources

PHASE I: Determine an appropriate design for the multi-element collector antenna array and relate the number of elements needed as a function of the number of simultaneously transmitting sensor nodes to be serviced. Choose an operating algorithm for the receiving array that provides the channel sounding for each antenna element to each sensor node and provides for near optimum detection of each of the simultaneously transmitting sensor node signals with widely different received powers. The algorithm should place minimum restrictions on the choice of signal modulation schemes. Expense of hardware realization should also be considered in the choice of algorithm. Determine the impact of sensor node movement speed on data rate and power resource allocation to channel sounding.

Design a method of communicating between sensors the portion of the overall information signal (to be relayed to the collector) which is understood by each sensor to be its responsibility to transmit and how it is to be properly synchronized and coded. Compare strategies of how to partition the overall information signal and to determine the frequencies and durations of transmissions. Consider types of feedback information from the collector which can improve performance of the sensor transmissions. Calculate the capability of several orders of magnitude increase in overall communication throughput with increased security resulting from the multi-element collector antenna array with space-time coding of the sensor nodes.

PHASE II: Build and test a prototype sensor environment with a suitable multi-element array collector and communication between sensors to provide space-time coded transmission from the sensor network to the collector. Prototype should include RF hardware in a suitable microwave band (e.g., 2.4 GHz). Test error rates versus throughput. Test performance versus mobility of sensors. Measure the effects of various types of interference. Determine susceptibility to interception, detection and exploitation. Test schemes of wireless intrusion detection and mitigation, proactive and reactive interference mitigation, error correction and packet recovery, and reassignment or reconfiguration of corporately available resources. Test performance with a variety of modulation formats. Test methods of apportioning and synchronizing data transmissions among the sensors. Test methods of using feedback information from the collector to improve and protect sensor network space-time coded transmissions.

DUAL USE COMMERCIALIZATION: These sensor networks will be useful in a potentially hostile and militarily sensitive environment to collect and disseminate secure data-intensive information (e.g., continued surveillance, reconnaissance, target identification, registration and disposition) in a robust and oftentimes covert fashion. They will also be useful for commercial applications such as company fleets (taxi cabs, cable repair trucks, etc.) which need to communicate, oftentimes simultaneously, with their central office. Another example would be a network of ground temperature sensors throughout a forest to detect fast moving forest fires.

REFERENCES: 1. G. J. Foschini et al., "Analysis and Performance of Some Basic Space-Time Architectures" Journal on Selected Areas in Communications, 21: 303—320, April, 2003.
2. G. J. Foschini and M. J. Gans, "On Limits of Wireless Communications in a Fading Environment when Using Multiple Antennas," Wireless Personal Communications, 6: 311—335, 1998
3. J.A. Stankovic et al. "Real-Time Communication and Coordination in Embedded Sensor Networks," Proceedings of the IEEE, Vol. 91, No. 7, pp. 1002-1022, July 2003.

KEYWORDS: Space-Time Coding, Multiple Input Multiple Output (MIMO), Antenna Arrays, Interference Mitigation, Sensor Networks, Multi-path Signal Propagation, Adaptive Signal Processing

AF04-T016 TITLE: Rapid and Robust Dynamics-based Nondestructive Method to Monitor Structural Health

TECHNOLOGY AREAS: Air Platform, Materials/Processes

OBJECTIVE: Develop an accurate, rapid, dynamical method for detection of metallic and composite material internal damage and global structural health from external vibration data.

DESCRIPTION: Various metallic and composite materials are used in advanced aerospace structural systems, and the problem of determining damage in these structures, through both normal wear and tear as well as extraordinary circumstances, is one of the most serious and costly problems that the Air Force faces. This problem is compounded by the fact that damage can occur in many different forms, such as fatigue cracks, corrosion, and dents in metals; delamination, disbonding, and fiber breakage in composites; and battle damage. Large external damage can be detected by the naked eye, and small external and/or internal damage may be detected by using conventional Non-Destructive Evaluation (NDE)/I techniques. However, conventional Non-Destructive Intrusion (NDI) techniques are based on the use of eddy-current, ultrasound, radiography, thermography, etc., and they are limited to certain kinds of materials and structural geometries, and usually are weak at quantifying the damage. Moreover, they often require the structure to be at least partially disassembled and a skilled technician to interpret the observations, which increase labor costs and add to the time needed to complete the inspection. Besides, they are "local" methods in the sense that they can only find flaws in a small area in each test. Recent developments [refs. 1, 2, and 3] suggest that an approach based on analyzing the micro-amplitude high-frequency vibrations at the surface of a structure, such as those that can be measured by a scanning laser vibrometer, can lead to a damage-detection technology that avoids some of the current limitations of NDE/I.

PHASE I: Develop and demonstrate a technique capable of assessing damage to aerospace structures made of any materials. Demonstrate the proof-of-concept on composite and metallic test articles by determining the location and extent of damage such as small internal delaminations in composite panels, small cracks at the fastener holes of built-up aluminum panels, and corrosion on the opposite side of metallic panels.

PHASE II: Develop electronic chips/circuitries to replace/refine some of the subsystems of scanning laser vibrometers, or other vibration-measuring devices, and develop a portable system for on-site use.

Demonstrate the damage-detection system on actual metallic and composite aircraft structures with known flaws, similar to those found in practice, placed in the structures. Evaluate the efficacy of the damage-detection system by comparing the results with those from conventional NDI techniques.

DUAL USE COMMERCIALIZATION: Apply the technology to all types of military air and rotorcraft. Rail, automotive, and trucking systems as well as civil aviation will also benefit from the application of this technology.

REFERENCES: 1. Doebling, S. W., Farrar, C. R., Prime, M. B., and Shevitz, D. W., Damage Identification and Health Monitoring of Structural and Mechanical Systems from Changes in Their Vibration Characteristics: A Literature Review, Report No. LA- I 3070-MS, Los Alamos National Laboratory, 1996.
2. Thyagarajan, S. K., Schulz, M. J., Pai, P. F., and Chung, J.H, "Detecting Structural Damage Using Frequency Response Functions," J. of Sound and Vibration 210(l), 162-170, 1998.
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4. Chung, J.H., BEEM-Laser System/Technique Application to F-16 Aircraft, F42620-02-M-0365 Global Contour Inc. Final Report, March 2003.

KEYWORDS: Vibration-based damage detection, surface evaluation, cracks, delamination, composite and metallic structures

AF04-T017 TITLE: Instrumentation for Monitoring Breath Biomarkers for Diagnosis of Health, Condition, Toxic Exposure, and Disease

TECHNOLOGY AREAS: Biomedical, Human Systems

OBJECTIVE: Design, develop, and test portable instrumentation and protocols for breath analysis as a simple and reliable indicator of health, readiness, and toxic exposure.

DESCRIPTION: Monitoring the presence and concentrations of endogenously produced molecules in exhaled breath has been demonstrated to be an exciting new area in clinical chemistry, with great potential application in sensing warfighter health, condition, and exposure to radiation or toxins. Progress toward extending and exploiting clinical demonstrations has been limited by the lack of suitable instruments capable of performing breath analysis in humans easily and reproducibly. Breath biomarkers of use on the battlefield could include ammonia, nitric oxide, carbon monoxide, formaldehyde, amines, and sulfur-containing compounds. A particularly interesting example, of great interest for battlefield and homeland security as well as broad clinical use, is ethane. The balance between the levels of oxidizing species and antioxidant species is termed Oxidative Stress Status (OSS). OSS defines the extent and magnitude of tissue damage by reactive oxygen species. It has been shown that breath measured changes in endogenous ethane production are associated with ionizing radiation and reperfusion injury, as well as liver disease, nutrition and smoking. Quantifying breath ethane can be a simple non-invasive method to assess in vivo OSS. Since ethane is a rapidly produced marker subsequent to radiation exposure, it could become an excellent measure of the degree of injury to soldiers or to victims of terrorist attacks. If current hypotheses are correct and OSS is a common etiology for many disease states, then identifying populations at risk to disease or to terrorist attacks due to poor OSS could represent a significant improvement in public health and public safety.

PHASE I: Provide evidence of a concept, design specifications, and protocols for use, for a portable device capable of measuring a militarily important breath biomarker, for example ethane, with required sensitivity. Provide a plan for producing a portable instrument for military and civilian applications.

PHASE II: Execute the plan provided in Phase I, and demonstrate the capability of the instrument by delivering militarily relevant measurement and performance data.

DUAL USE COMMERCIALIZATION: There can be enormous benefits from inexpensive, reliable, and convenient breath monitoring of molecular biomarkers. Ethane measurement to monitor therapeutic intervention, for treatment or prophylactic therapy by antioxidants, to improve OSS could be a huge potential market for the instrumentation of this topic. Early detection of reduced OSS could speed up diagnosis, reduce treatment costs, and enhance prognosis for diseases that affect over 10 million Americans per annum. Isoprene monitoring would provide another massive application. Isoprene is an elimination product in the pathway for the biosynthesis of cholesterol. Its concentration in exhaled breath can be used diagnostically to monitor the extent of endogenous cholesterol production in human subjects. Elevated serum cholesterol is a major risk factor for cardiovascular disease. Currently, it is impossible to quantify the magnitude of cholesterol from in vivo biosynthesis, apart from that which originates from diet; a noninvasive breath test for isoprene would fill this void. Additionally, approximately one million people in the USA are currently receiving therapeutic doses of HMGCoA reductase inhibitors to reduce their total serum cholesterol. Quantifying breath isoprene offers a unique approach to monitor this therapy rapidly. It is estimated that as many as 100 million total serum cholesterol tests are performed per annum. Early detection of elevated biosynthesis of cholesterol could speed up diagnosis, improve therapy, reduce treatment costs, and enhance prognosis for diseases that affect over 20 million Americans per annum.

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KEYWORDS: breath analysis, oxidative stress, health monitoring, toxic exposure

AF04-T018 TITLE: Ionic Liquid Lubrication

TECHNOLOGY AREAS: Materials/Processes, Space Platforms

OBJECTIVE: Demonstrate the use of ionic liquids as lubricants

DESCRIPTION: The Department of Defense requires new lubricant materials for aircraft, spacecraft, and microelectromechanical systems (MEMS) devices. Preliminary research has identified ionic liquids as promising lubricants on a wide variety of materials including: steel, aluminum, copper, silicon, silicon dioxide, silicon nitride, aluminum oxide, and sialon ceramics. In fact ionic liquids have been reported as out performing phosphazene and perfluoropolyethers.

Ionic liquids are attractive due to their non-flammability, low vapor pressure, large liquidous temperature range, and high thermal stability. In addition, the synthetic flexibility offered by ionic liquids provides the potential for tailoring the properties of these materials to fit a wide variety of applications. Recent work has shown that imidazolium based ionic liquids have impressive lubricant properties. Furthermore, the decomposition of these ionic liquids by tribological action appears to form boundary lubricant films on a wide variety of substrates. The properties of these imidazolium based ionic liquids suggest that they have good lubrication potential for high temperature engines (good thermal stability), space platforms (low volatility), and MEMS (surface affinity).

PHASE I: Determine the feasibility of ionic liquids and formulations as lubricant materials. This should include, but not be limited to, the synthesis of novel ionic liquid lubricants and formulations, the fundamental evaluation of the tribological properties of ionic liquids and formulations under a variety of conditions, and the modeling and simulation of ionic liquid lubrication.

PHASE II: Develop and test ionic liquid and ionic liquid containing lubricant formulations using progressively advanced lubricant testing. The evaluation scheme should progress from materials properties to accelerated tests to qualification testing. This effort should focus largely on engineering tests to qualify ionic liquid or ionic liquid based lubricants.

DUAL USE COMMERCIALIZATION POTENTIAL: Novel lubricants for aircraft, spacecraft and MEMS will be of use for a variety of civilian applications.

REFERENCE:
1. "Room-Temperature Ionic Liquids: A Novel Versatile Lubricant: Chengfeng Ye, Weimin Liu, Yunxia Chen, and Laigui Yu, Chem. Commun., 2001, 2244-5.

KEYWORDS: Lubricant, Ionic Liquid, Molten Salts

AF04-T019 TITLE: Intelligent Layout of Military Products

TECHNOLOGY AREAS: Air Platform, Materials/Processes

OBJECTIVE: Develop a tool that automates system design layouts for applications such as unmanned air vehicles.

DESCRIPTION: The design of unmanned air vehicles, satellites, missiles, and many other products is a repetitive task, yet each individual design can be different in terms of real estate (available and shape of volume), individual components and features, constraints, and performance criteria. For example, in the design of a missile, the components must fit into a well-defined volume meeting tight constraints, while allowing for an optimal optics path. The same approach to defining the missile layout problem can be used to layout the components in unmanned air vehicles, satellites, and even an air conditioner or a car. Subsystems, such as printed circuit board design are also a manual process where automation could improve design efficiency and reduce size, a critical feature in military products. A significant amount of time is spent repetitiously re-designing or re-arranging components in a system throughout the product development process. At times, 90% or more of an engineer's time is absorbed through this re-design effort. As one component changes shape or location, or the container itself that houses the components is re-designed, other components, wire routes, or optical routes must be re-configured or re-selected accordingly. Further, the verification of the packaging is often done through physical prototyping, an expensive process that often happens downstream in the process. If this layout process could be automated, the task could be reduced an order of magnitude in terms of time and cost. Further the evaluation of a virtual layout could be used earlier in the process to affect the basic design of a product, rather than react to the package quality late in the process. The 3-D layout space is nonlinear, multi-modal, discontinuous and highly constrained space mathematically defined as the representation of the space of configurations mapped against the cost per configuration. The problem requires efficient stochastic algorithms that effectively account for physical geometric complexities and constraints, as well as performance requirements. This project seeks computer technology to automate the solution to this repetitive task. In particular a technology that automates the layout of unmanned air vehicles, satellites, missiles and other products is desired. The technology should be generic in that the same core approach should be applicable in a wide variety of design problems of interest to the Air Force. The technology should accommodate the packaging of constrained 3-dimensional parts of arbitrary geometry.

PHASE I: Develop algorithm(s) that would solve this problem. Initial test on a simplified unmanned air vehicle and/or satellite layout, to demonstrate potential effectiveness. Determine feasibility of application to alternative (missile) product classes to demonstrate generality.

PHASE II: Detailed and complete application of the algorithm(s) to at least one system (unmanned air vehicle, satellite or missile) layout, accommodating a variety of constraints and requirements. Development of general approach to intelligent packaging of products that takes as input component and container geometries, goals, and constraints, and outputs feasibly, and potentially optimal layout solution.

DUAL USE COMMERCIALIZATION: Commercial applications are vast and include engine compartment, transmission, trunk packing and truck chassis layout in the auto industry, printed circuit board layout, layout of air conditioners and other durable goods, and placement and routing of parts in aerospace.

REFERENCES: 1. Yin, S. and J. Cagan, "Exploring the Effectiveness of Various Patterns in an Extended Pattern Search Layout Algorithm", submitted to: ASME Journal of Mechanical Design, 2000.
2. Yin, S., and J. Cagan, "An Extended Pattern Search Algorithm for Three-Dimensional Component Layout", ASME Journal of Mechanical Design, Vol. 122, No. 1, pp. 102-108, 2000.
Cagan, J., K. Shimada, and S. Yin, "A Survey of Computational Approaches to Three-dimensional Layout Problems", Computer Aided Design, Computer-Aided Design, Vol. 34, No. 8, pp. 597-611, 2002.

KEYWORDS: Design, Optimization

AF04-T020 TITLE: <u>3 Dimensional Nano-Scale Reinforcement Architecture for Advanced Composite Structures</u>

TECHNOLOGY AREAS: Materials/Processes

OBJECTIVE: Fabricate 3-D reinforced composite structures with high fiber volume content, using nano-scale reinforcement architecture to reduce component mass and dimension.

DESCRIPTION: Advanced fiber composites offer the potential to further reduce the mass and dimension of many structural components thereby saving the cruising or launching cost of aerospace systems. In special circumstances dictating extra small volume, packaging may be required such that thin composites can be folded or rolled and then later deployed. Both thin and thick structures of fiber composites should be 3-D reinforced to become sufficiently damage-tolerant and to endure foreign object impact, thermal cycling, and abusive handling conditions. During last two decades, composite materials made with 3-D woven or 3-D braided textile preforms have been considered for many load-bearing applications, especially in the case of thick structures. Their continuing promises are based upon unique performance characteristics, such as high damage tolerance, delamination suppression, and extended fatigue life. Additionally, near-net shape, single-ply integral textile preforms, combined with advanced resin infusion methods, show a great potential for achieving higher composites affordability by dramatically reducing manufacturing cost.

However, many technical challenges have been revealed in the course of development and application of 3-D textile composites based on conventional fibers of micron-scale diameter. Among them, the most critical weakness appears to be too low fiber volume fraction of resulting composites due to complex 3-D reinforcement architecture. Low fiber volume fraction, accompanied by resin-rich pockets, often leads to the deterioration of penetration failure resistance of composites under foreign object impact. In extending existing 3-D textile composites technology to the area of thin deployable structures, the same factor has become the major hurdle to go through. Within this context, the use of 3-D nano-scale reinforcement architecture is proposed to achieve the fabrication of advanced composite structures with high fiber volume fraction and improved mechanical performance, particularly higher penetration resistance under foreign object impact. The availability of nano-fibers, with their dimensions ranging up to 100 nm and exceptional physical properties in many cases, has strengthened new opportunities. Recent significant progress in automated 3-D weaving, 3-D braiding and manufacturing of 3-D textile composites [1,2] also indicates that 3-D reinforcement architecture can be formed in a reproducible manner.

PHASE I: Manufacture a variety of sample 3-D woven and 3-D braided performs based on nano-fibers (e.g. carbon, silk, metallic and ceramic nano-fibers) as well as conventional fiber performs with nano-fibers as Z-reinforcement or interlaf reinforcement. Prepare "trial" composite coupons with polymer matrices and integrated 3-D reinforcement architecture using up-to-date composite processing techniques such as resin infusion or pultrusion. Perform several representative mechanical tests, in order to validate the possibility of achieving the fiber volume fraction not lower than 60% and improved mechanical performance, particularly higher penetration resistance under foreign object impact.

PHASE II: Optimize manufacturing condition for a selected system among 3-D woven or 3-D braided performs based on nano-fibers as well as conventional fiber performs with nano-fibers as Z-reinforcement or interlaf reinforcement. Assess the upper and lower limits of thickness for the system in terms of manufacturability. Conduct a systematic study on the manufacturability of composite systems with 3-D nano-scale reinforcement architecture relying on a selected process. Develop comprehensive Test Matrix (incl. in-plane stiffness and strength, notch sensitivity, compression-after-impact, fatigue, and penetration resistance under foreign object impact). Conduct mechanical characterization of manufactured composites in accordance with the Test Matrix to provide sufficient evidence that manufactured 3-D nano-scale textile composites possess substantially improved mechanical performance, in comparison with conventional laminates, with minimal trade-off of in-plane stiffness and strength.

DUAL USE COMMERCIALIZATION: For commercialization of developed materials and structural components in aerospace industry, conduct extensive manufacturing and testing program for utilization of 3-D nano-scale reinforcement architecture in integral 3-D braided stiffeners [3], skin-stiffener panels (stitched/bonded 3-D woven skin and 3-D braided stiffener), adhesive bonded joints, and other complex structural components of interest for Air Force systems. Assess the potential of reducing the mass and dimension of these substructures. Perform their cost analysis and affordability validation.

REFERENCES: 1. M. H. Mohamed, A. E. Bogdanovich, L. C. Dickinson, J. N. Singletary, and R. B. Lienhart, "A New Generation of 3D Woven Fabric Preforms an Composites," SAMPE Journal, 2001, Vol. 37, No. 3, May/June, pp. 8-17.
2. A. Bogdanovich and D. Mungalov, "Recent Advancements in Manufacturing 3-D Braided Preforms and Composites," A Keynote Paper, Proceedings of International Conference ACUN-4, UNSW, Sydney, Australia, 21-25 July 2002, S. Bandyopadhyay (ed.), pp. 61-72.
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KEYWORDS: Nano-fibers, Fiber Composites, 3-Dimensional Reinforcement, Textile Preforms, Braiding, Damage Tolerance , Penetration Failure, Foreign Object Impact

AF04-T021 TITLE: Midwave IR Avalanche Photodiodes

TECHNOLOGY AREAS: Materials/Processes, Sensors, Electronics, Battlespace

OBJECTIVE: Develop avalanche photodiodes that operate in the Midwave (MW) Infrared (IR) wavelength range.

DESCRIPTION: Current LADAR/LIDAR systems in the eye-safe wavelength region (lambda > 1.4 microns) typically use InGaAs avalanche photodiodes (APD) in scanned systems for sensing and tracking applications. There is considerable interest in direct detection laser radar in the 3-5 micron wavelength range that would enable passive/active sensing that would be extremely resistant to countermeasure techniques. Due to low light levels, direct detection systems need avalanche photodiodes, which are now possible in the Midwave IR region using technologies now used in the 2-2.5 micron region that include separate absorption and multiplication regions. This project would explore InGaAsSb/GaSb APDs with absorption regions tailored for 3-5 micron absorption and with a multiplication region that is used with InGaAs APDs. In order to get thick absorption regions that will efficiently absorb light, strain balancing in the absorption region will need to be accomplished.

PHASE I: A feasibility concept will be developed as an initial part of the Phase I effort. In accordance with this, the research would then explore techniques for growing candidate structures with low dislocation densities and with required characteristics to enable high gain APD structures. Strain balanced thick layers will be grown in this phase.

PHASE II: Phase II would grow single element APDs with low noise and high internal gain. Once they are available, the performance of these elements will be verified in a prototype demonstration.

DUAL USE COMMERCIALIZATION: In addition to military laser radar uses for target identification and tracking, MWIR APDs would be useful for laser communication systems in the MWIR and for remote sensing and spectroscopic applications.

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KEYWORDS: Avalanche photodiode, infrared, MWIR, laser radar, LADAR, LIDAR

AF04-T022 TITLE: <u>Field-Deployable Imaging System to Assess Potential Retinal Injuries</u>

TECHNOLOGY AREAS: Biomedical, Human Systems

OBJECTIVE: Develop a device to provide objective identification of retinal thermal injuries using digital imagery.

DESCRIPTION: With the proliferation of lasers in the modern battlespace, military forces are increasingly vulnerable to eye injuries from intense light sources. Some retinal injuries do not present in either subjective or objective fashion, yet visual performance may be compromised. Military aircrew members, as well as anyone engaging in a potentially dangerous activity requiring superb visual performance, would benefit from a field-portable screening device to detect retinal lesions before those lesions manifest themselves in the form of catastrophic failure of the vision system. Fundus photographs are the standard of practice in a clinical setting but even fundus photographs occasionally miss retinal lesions. A complete evaluation to detect finite retinal lesions presently rests on fluorescein angiography, an invasive procedure. In recent years, the development of Optical Coherence Tomography (OCT) has proven a positive supplement to Fundus photographs for detection of these lesions. However, current OCT devices are not field portable. The desired capability is a field-portable device to be operated by technicians, capable of fusing digital images from fundus photographs and a field-portable OCT giving a combined picture of retinal health. Because the images are digital, they could be send by electronic means to be analyzed by specialists. Successful demonstration of field deployable imaging systems will provide requisite instrumentation to rapidly screen flight personnel for laser retinal thermal injuries. A field-deployable imaging system that can rapidly screen for laser retinal thermal injuries will provide an additional measure of safety to insure flight personnel are able to conduct missions with full visual acuity.

PHASE I: Provide proof of concept and design specifications for a portable device capable of combining Optical Coherence Tomography and Fundus Photos in digital form of sufficient resolution to enable field screening for detection of retinal damage which could reveal potential for decreased visual performance. Include a technology development plan for demonstrating the concept.

PHASE II: Execute the technology development plan proposed in Phase I and demonstrate the solution by delivering measurement and performance data on one or more robust prototypes.

DUAL USE COMMERCIALIZATION: The potential for this device in clinical practice is enormous. Screening for retinal damage could become widespread and more affordable, leading to early detection of disease processes contributing to late stage eye disease and accompanying disabilities. In addition, any occupation with requirements for superior visual performance (such as aircraft pilots) would benefit from early detection of ocular insults from lasers and other bright light sources. Human factors research specialists in commercial aviation, the automobile industry, and academia, are likely to find applications for this system. The U.S. Department of Transportation (DOT) sponsors and supports a large human factors research program, a significant portion of which focuses on vision issues. Therefore, it seems reasonable to assume that, as a minimum, Federal Aviation Administration (FAA) and the National Highway Transportation Safety Board (NHTSB) human factors specialists could also use this capability.

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2. J. Liang, D. R. Williams, and D. Miller, "Supernormal vision and high-resolution retinal imaging through adaptive optics," J. Opt. Soc. Am. A 14, 2884-2892 (1997).
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KEYWORDS: Laser, Eye, Retinal injury

AF04-T023 TITLE: Modeling Languages and Analysis Tools for Complex Distributed

TECHNOLOGY AREAS: Information Systems, Materials/Processes

OBJECTIVE: Develop language and computational tool support for modeling and analyzing complex distributed system designs and integrate these methods to build distributed systems.

DESCRIPTION: Modern military and commercial distributed systems are growing in complexity. Systems must satisfy stringent safety, performance, and fault-tolerance requirements. At the same time, they must work on highly dynamic platforms such as the Internet, mobile networks, and sensor networks. This combination leads to complex designs, which are hard to understand, hard to implement correctly, and hard to maintain. Better computer support tools are needed to assist in the process of developing and maintaining such systems. These tools should include modeling languages that can be used to represent the systems and their components, analysis tools that can be used to validate correctness and performance properties, and ultimately, automated synthesis tools that can generate working code from system models. The languages and analysis tools must be based on a solid mathematical foundation, consisting of natural entities such as interacting state machines. They should support description of realistic aspects of the behavior of military and commercial systems, including ordering of discrete events, timing behavior, and continuous behavior. Because of the complexity of the systems, the languages and tools must support sound methods of decomposing designs, including "horizontal" decomposition into interacting components and "vertical" decomposition using multiple levels of abstraction. The language should allow a user to specify collections of automata that are meant to be mapped onto a single network node, and also collections of automata that are meant to constitute a single software subsystem. The tools should support traceability at all stages of system development, from high-level requirements, through high-level and detailed design, to executable code. The tools should facilitate mapping formally modeled systems to executable code. Ultimately, such a mapping should be automatic, but even the ability to perform a manual mapping according to a precise set of rules would be valuable and attractive to prospective users. Validation tools should include (a) tools for simulation, including simulation of a system at multiple levels of abstraction, and possibly automated invariant discovery from simulation results, (b) tools to aid a designer in proving theorems about system correctness; these should include theorems about invariant properties and abstraction relationships, and (c) simple state-space searching tools. The toolset should be designed to be extensible, incorporating new analysis methods as they are developed.

PHASE I: Develop a detailed design of a modeling language that includes event ordering behavior and timing behavior. Develop an implementation of a front end for this language, together with prototype tools to support simulation (including simulation at multiple levels of abstraction), and proofs of invariants and abstraction relationships. Develop demonstrations of the use of the tools for potential military and commercial applications.

PHASE II: Engineer the basic language and toolset for use by customers. Add invariant discovery capabilities, more advanced theorem-proving capabilities, and state-space searching capabilities.

DUAL USE COMMERCIALIZATION: Extend the language and tools to include continuous behavior. Incorporate some analysis methods from control theory along with methods derived from computer science. Provide a comprehensive set of rules for mapping models to distributed code.

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KEYWORDS: Distributed system, Modeling language, System decomposition, Levels of abstraction, Theorem-proving, Simulation, Invariant discovery

AF04-T024 TITLE: High Spatial and Temporal Resolution Velocimetry Measurements for Microfluidic Devices

TECHNOLOGY AREAS: Air Platform, Materials/Processes, Electronics

OBJECTIVE: Develop high spatial (sub-micrometer) and temporal (microsecond) resolution diagnostic technique to investigate slip flow or boundary layer regions of liquid and gas microfluidic devices.

DESCRIPTION: Devices with micrometer characteristic dimensions are becoming more prevalent in commercial and military applications. Inherent in many of these devices is liquid and/or gas flows through small channels for sample delivery and manipulation (lab-on-a-chip), heat transfer (microelectronics cooling), aerospace vehicle control (propulsion and flow vectoring), and combustion (injectors). For flows in microelectromechanical systems (MEMS) devices, the surface area to volume ratio is quite small which implies that the flow interaction with surfaces in the device become more important. Also, microscale flows tend to have low characteristic Reynolds numbers where the traditional continuum flow solutions are not applicable. The surface interactions and low Reynolds numbers complicate the nature of MEMS flows by inducing velocity slip at the wall and relatively large viscous boundary layers. Both of these factors make it difficult to analytically or numerically describe flows in micrometer scale geometries. Experimental diagnostic techniques are required to investigate the flows of both liquid and gas flows in MEMS channels to develop an understanding of the flow near a surface in the slip flow region or viscous boundary layer. A better understanding of the near-surface characteristics of liquid and gas flows in MEMS devices may lead to performance optimization techniques for many devices that are currently optimized by trial and error approaches. The diagnostic technique is also envisioned as a means by which numerical techniques can be validated with experimental data for MEMS flows.

Developed techniques such as micro-Particle Image Velocimetry (micro-PIV) have to date not shown sufficient promise in resolving the flow near the surface boundary in MEMS flows. Although further development may lead to improved diagnostic capability, this topic seeks the development of revolutionary advances in diagnostic capability.

Recent advances in fiber optic diagnostic techniques have shown that evanescent wave interrogation of microscale flows may lead to the spatial and temporal resolution required to fully understand MEMS flows near a solid boundary. This topic seeks the development of an evanescent waveguide diagnostic for liquid and/or gas flow interrogation at the surface of a MEMS flow. Since the slip region or viscous boundary layer is some fraction of the MEMS channel dimension, spatial resolution in the sub-micrometer range will be required to fully understand the nature of micro-flows. Many MEMS flows, with the exception of micropropulsion systems, typically operate in the subsonic flow regime; therefore, the diagnostic technique must also be capable of measuring the relatively low flow velocities at the surface interface. As a further complication, a typical MEMS flow may have a short residence time in a region of interest (based on the characteristic dimensions of the device) and may also be inherently unsteady which implies that the temporal resolution of the technique must also be sufficient to provide a complete understanding of the near-wall flow region. As an additional benefit, evanescent waveguides have shown promise as integrated diagnostic sensors in MEMS devices, although both off-device and integrated systems are of interest.

PHASE I: Identify a concept for a high spatial (sub-micrometer) and temporal (microsecond) resolution diagnostic system based on evanescent waveguide technology to investigate the slip flow or boundary layer regions of a microfluidic device. Perform benchtop experiments to demonstrate feasibility of critical aspects of the design, such as seeding, optical readout, and signal processing. Develop a preliminary design for a prototype system, addressing all critical design elements, including optics, alignment procedures, electronics, interrogation and readout systems. Identify the working fluids, liquid or gas phase, which are compatible with the measurement system.

PHASE II: Develop a prototype system diagnostic system and demonstrate the applicable resolution levels. Provide a proof-of-principle demonstration of the diagnostic system capability to determine flow parameters in a micro-scale geometry. Products from Phase II would include a the prototype diagnostic system, the demonstration data, and a final report.

DUAL USE COMMERCIALIZATION: The demand on microdiagnostics for small scale devices is so large, that once a diagnostic device is developed, the system can be put to use in a wide variety of MEMS-fabricated devices. The ability to improve the performance of MEMS devices would make for an attractive and a commercially viable system.

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KEYWORDS: Microfluidics, diagnostics, slip flow, sensors, evanescent waveguide, fiber optics, MEMS

AF04-T025 TITLE: Sensor Technologies for Detection and Measurement of Broadband Radiofrequency Pulses

TECHNOLOGY AREAS: Sensors, Electronics, Battlespace

OBJECTIVE: Develop and demonstrate minimally intrusive sensor technologies for the detection and measurement of broadband radiofrequency pulses

DESCRIPTION: Develop and demonstrate minimally intrusive sensor technologies for the detection and measurement of broadband radiofrequency pulses.
The potential research areas can include any of the following:

1. Single point, two-dimensional sheet style, or three-dimensional volumetric electric and magnetic field sensors. These may be pulsed propagating waves or short term standing waves.
2. Sensor technologies that can measure current in a wire or in a trace on a printed circuit board.
3. Sensor technologies that can measure voltages at nodes in an electronic circuit on a printed circuit board.

The sensor technologies should be minimally intrusive. The goal is to disturb the field, current, or voltage by less than 5%. The sensor technologies investigated should be broadband with a lower frequency range down to 100MHz or below. The current and voltage sensor technologies should be able to measure up to 5GHz but preferably up to 100GHz. The electric and magnetic field sensors should work up to 10GHz, but preferably up to 100GHz. Several sensor types may need to be investigated to cover different frequency regions. An integration of the power is possible, but faithful measurement of the signal, allowing for frequency analysis is preferred. Calibration issues and sensor stability, particularly due to environmental thermal effects must be minimized. The sensor sizes will be dictated by typical applications which can include military and civilian communication modules, computers, and navigation and guidance systems. The sensors can be interrogated via a variety of means including dielectric leads, remote optical methods or other means.

PHASE I: Investigate two or more sensor technologies to determine their feasibility in measuring broadband radiofrequency pulses through demonstrations of components or sensor concepts. Characterize sensitivity, and disturbance on the field, current or voltage. Model or experimentally determine thermal sensitivity, accuracy and frequency response. Ascertain expected calibration, size, damage threshold, dynamic range and costs.

PHASE II: Demonstrate a working sensor system for the measurement of a propagating or standing wave electromagnetic field, a current in wire, or a voltage in an electronic circuit at a frequency ranging from xx to 2GHz or higher. Determine sensitivity, accuracy, thermal sensitivity, frequency response, damage threshold and frequency response.

DUAL USE COMMERCIALIZATION: These sensor technologies have applications in almost all electronics systems – both military and civilian. The resulting sensors can be used to create monitoring systems for critical military and civilian facilities by detecting high power electromagnetic fields and thus initiating protection mechanisms. They can be used in the development of electronic assemblies for the design of built-in protection. They can be used in the testing of offensive directed energy systems. They will offer unique capability in research experiments designed to gather an understanding of electromagnetic wave propagation and coupling in electronic circuits and systems. They can be used in both military and civilian high frequency, precise RF circuit and systems development.

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KEYWORDS: Field Sensor, Pulse Measurement

AF04-T026 TITLE: Enhanced Dynamic Integrated Visualization (EDIV) of Physiologically Based Pharmacokinetic/Pharmacodynamic Models

TECHNOLOGY AREAS: Chemical/Bio Defense, Biomedical, Human Systems

OBJECTIVE: Dynamic multifunctional displays of scientific data to clearly articulate chemical toxic effects to the warfighter.

DESCRIPTION: There has been continued success and improvement by the science community in the development of physiologically based pharmacokinetic/pharmacodynamic (PBPK/ PD) modeling as tools to assess the risk of chemical and biological exposures and to advance scientific understanding beyond current capabilities. The Air Force has developed a number of these sophisticated, computerized PBPK/PD models for use in assessing the toxic effects of various chemicals. The goal is to relay this complex scientific information contained in the models to the commander/warfighter using interactive multifunctional visual displays (MFD) that depict the effect a chemical has on the appropriate target organ. Current PBPK/PD models provide numerical output for target organs that is not user-friendly. The addition of a dynamic MFD would result in an EDIV tool that produces interactive pictorials to help the mission planner and commander to understand complex physiological and toxicological phenomena within the warfighter.

PHASE I: Determine the feasibility of developing a state-of-the-art scientific computer modeling tool that links a PBPK/PD model with graphics and animation EDIV to clearly articulate toxic effects of chemicals to the warfighter, government officials and civilians. The initial goal is to develop a functional prototype that integrates one specific organ graphic, based on organ sensitivity to the toxic substance, with a chemical's specific PBPK/PD model. The output will be a visual MFD of the data that clearly shows the effect of the chemical on the tissue and will bring specific inferences to the change in individual health status at the specified exposure level.

PHASE II: Further develop the EDIV tool that brings together sophisticated PBPK/PD models with high quality interactive computer graphics to deliver complex scientific data in an easy, effective and accurate visual representation. The tool needs to incorporate current PBPK/PD data and state-of-the-art graphics with software capability that is adaptable to any body tissue or target organ and the resultant effects to the whole organism. The goal will be to produce an EDIV tool that will incorporate all the relevant compartments and organs for a PBPK/PD model to obtain the measurement of toxicity within the individual. The tool needs to be able to demonstrate pharmacological, toxicological and biochemical processes of the human and animal body in an accurate and reliable manner, and to predict possible outcomes from chemical exposure (e.g., environmental chemicals, pharmaceuticals, nutrients, biological warfare agents, etc.). The EDIV tool will serve as a product for identifying risk to the warfighter.

DUAL USE COMMERCIALIZATION: This product will assist the communication of complex scientific data in a simplified form to facilitate informed decision making by the Air Force, government agencies, industry and the public. The combined PBPK/PD model with MFD EDIV will be used by the Air Force, government agencies, pharmaceutical companies and risk assessment consulting companies to present toxicologic risk to management and the public. PBPK/PD models benefit the Air Force toxicology program and commercial drug design industry by reducing the costs of experimentation, while increasing understanding and accuracy of estimations of risk. Models will enable Environmental Protection Agency (EPA) to validate the extrapolation of dose-response relationships from laboratory animals to humans, especially for those effects, which cannot ethically be studied experimentally in humans.

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KEYWORDS: physiologically based pharmacokinetic, modeling, physiologically based pharmacodynamic, visualization, multifunctional displays, animation, graphics

AF04-T027 TITLE: Nonlinear Adaptive Actuation of Synthetic Jet Arrays for Aerodynamic Flow Control

TECHNOLOGY AREAS: Air Platform, Materials/Processes

OBJECTIVE: Demonstrate effective nonlinear adaptive control of the aerodynamic flow about a dynamic body using a distributed array of synthetic jets for actuation.

DESCRIPTION: Opportunities exist to apply emerging technology for active flow control to enhance the aerodynamic design and operation of a wide variety of traditional flight systems, and to enable a new generation of aerodynamic designs with revolutionary flight capabilities. In particular, the use of micro electro-mechanical fabrication techniques will make it feasible to economically apply arrays of micro actuators and sensors to enhance the performance of aerodynamic surfaces, or to create synthetic surfaces.

Techniques for controlling the shape and stiffness of flexible aerodynamic surfaces are presently being developed by researchers. One such approach is based on the modification of the apparent aerodynamic shape of a flexible surface by distributed arrays of surface-mounted fluidic actuators and sensors. The necessary forces to effect surface configurations are derived from the interaction of the fluidic actuators with flow over the surface. These actuators are based on synthetic jet technology and thus do not require a fluid source. The interaction of synthetic jets and the embedding flow leads to the formation of recirculating flow regions that displace the local streamlines of the cross flow thereby inducing an 'apparent' or 'virtual' change in the shape of the surface. Researchers have demonstrated that lift enhancement accompanied by a reduction in form drag can be achieved. It has been demonstrated that flow separation at high angles of attack can be mitigated.

Research has also shown that the inputs to the individual jets required to achieve the desired flow effect can be complex. Modulated input signals are needed to realize the full potential of the jet flows, and the required amplitude, waveform, and frequency exhibit nonlinear relationships with flight speed, angle of attack, etc. Past research has focused on experimental discovery of appropriate open loop actuation strategies at fixed flight conditions. The control action that results from applying these devices open loop may be very nonlinear. It is anticipated that dependence on open loop actuation strategies will be prohibitively expensive for all but special applications of the technology at select flight conditions. This is due to dependence of the open loop strategy on comprehensive, wind tunnel-validated flow models. It is presently very difficult to accurately model these effects. The application of distributed, autonomous adaptive control is particularly attractive for this reason.

PHASE I: (1) Develop adaptive control methodology tailored to the task of active flow control using distributed arrays of MEMS sensors/actuators; (2) design a wind tunnel experiment for concept demonstration of adaptive closed loop control.

PHASE II: Fully develop and demonstrate the proposed approach to adaptive control of an array of synthetic jets. The program will evaluate the developed technology in both simulation and wind tunnel testing of a dynamic flight body in varied flight conditions with at least one rotational and one translational degree of freedom.

DUAL USE COMMERCIALIZATION: Anticipated benefits of successful technical development include the ability to operate a wing at higher angles of attack without flow separation, leading to beneficial improvements in low speed maneuvering capability and reductions in take-off and landing speeds. Alternately, application of active flow control technology to achieve desired low speed characteristics could be used to mitigate the need for compromise in the optimization of wing design for cruise conditions, leading to enhanced range and endurance. This technology will find immediate application in the design of commercial aircraft.

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KEYWORDS: Aerodynamic Flow Control, Synthetic Jets, Neural Networks, Adaptive Output Feedback