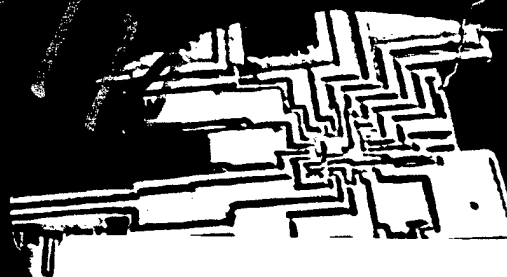


Innovative Science and Technology

**Ballistic Missile
Defense Organization**

**Technical Program
Information**

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Abstract: The Innovative Science and Technology (IST) program was created to pursue, from scientific feasibility to concept demonstration, innovative technologies that revolutionize the BMDO technology base. It began as a novel experiment. Today the experiment is considered a success. Since it was established, breakthroughs in material science, directed energy, distributed processing, solar concentrators, superconductivity, propellants, and dozens of other technologies have sped from theory to prototype.

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Dear Colleague,

As scientists, researchers, and engineers we share the opportunities, challenges, and responsibilities of an age of technology revolution.

One of those responsibilities, national security, gives us an incredibly difficult technical challenge, defense against missiles carrying weapons of mass destruction. The mission of the Innovative Science and Technology (IST) Program, of the Ballistic Missile Defense Organization (BMDO), is to stimulate and support revolutionary advances in science and technology to help meet that challenge.

The IST Program is managed by the Science and Technology Directorate of BMDO. Our address is now BMDO/TOI, but the program itself is still referred to as IST, as it has been since its origin, shortly after the establishment of BMDO's predecessor, the Strategic Defense Initiative Organization (SDIO), in 1984.

The IST program will adjust its technical focus, but its philosophy remains constant. New projects will be added as BMDO missions evolve and breakthroughs occur. Subtraction will occur as maturing technologies are passed to advanced technology demonstrators, to the system engineers or technology contractors.

This brochure tells you about IST, the type of research it seeks, and how to propose candidate efforts for funding. We also provide a list of our Science and Technology Agents (STAs), and invite you to contact the appropriate STAs with your novel ideas. The STAs are some of the most capable and forward thinking technical managers in government. They stand ready in our name to find where and how your ideas can contribute to meeting the IST challenge and support our national security.

Len Caveny

Leonard H. Caveny, PhD
Director
Science and Technology

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History and Charter

The Strategic Defense Initiative Organization (SDIO) was established in 1984 to explore the development of a defense system and advance technological protection against nuclear ballistic missiles. Since then dramatic technological breakthroughs have proven the feasibility of such a defense.

The use of ballistic missiles in the Middle East in 1991 reconfirmed the wisdom of the development of a ballistic missile defense system capable against all weapons of mass destruction. To recognize the importance of tactical, as well as strategic, defense, SDIO was renamed the Ballistic Missile Defense Organization (BMDO) in 1993. While emphasis was placed on the immediate development of a ground-based theater missile defense (TMD), efforts continue to ensure that the technology is developed to eventually field a national missile defense (NMD). Recently, renewed support for this NMD development, coupled with an emphasis on the TMD front, sustain the need for technology advancements in both space and ground arenas.

The Innovative Science and Technology (IST) program was created to pursue, from scientific feasibility to concept demonstration, innovative technologies that revolutionize the BMDO technology base. It began as a novel experiment: establish a government funding office that shortens the normal decades-or-longer time to transform scientific breakthroughs into usable products. The program still adheres to basic precepts, employed whenever possible, to accomplish this objective:

- 1) Respond quickly with funding to breakthroughs and unique opportunities.
- 2) Limit to one the number of layers of technical management between the sponsor and investigator.
- 3) Sponsor, in parallel, the basic research and exploratory development to expedite delivery of a product.
- 4) Push the development of the breakthrough from inception to concept demonstration.
- 5) Forge strong interaction among government, academia, and industry to speed technology transfer and product development.
- 6) Explore and publicize novel techniques for transitioning dual-use technology into industry to foster US competitiveness, reduce costs, and mature the technology.

The IST experiment succeeded! Since it was established, breakthroughs in material science, directed energy, distributed processing, solar concentrators, superconductivity, propellants, and dozens of other technologies have sped from theory to prototype.

Program Overview

The current IST program consists of five general research areas:

- Information Processing and Computer Technology
- Power
- Electronic Materials
- Propulsion and Energetic Materials
- Sensing and Phenomenology

BMDO's IST program is pursuing more than 20 distinct, but interrelated, efforts within these general areas. It is a unique collaborative effort. The research program is truly a team pursuit by the core BMDO IST staff, Science and Technology Agents (STAs) in other government research agencies, and more than 1000 scientists in academia and industry. The continued flow of important information and often new ideas into the program from this team, followed by quick funding from BMDO, sparks critical new projects. Efforts in optical computers, superconductors, thin-film diamond quality, and artificial neural networks - all funded by IST before they became fashionable - show the diversity of the program.

This brochure lists the objectives and a basic program description for each of the efforts. In some instances, a case example is given, illustrating how specific advances progressed or are progressing toward a successful demonstration. For some efforts, "initiatives under consideration" are outlined. While there is no certainty, these initiatives represent the type of new efforts that may be explored in the near future.

The projects described in this brochure were selected on the basis of potential relevance to the BMDO mission, potential for rapid, dramatic advancement, and innovative content. Revolutionary, not evolutionary, advances are sought. Research encompasses fundamental science and engineering, as well as devices and system technologies, and, in some cases, proof-of-principle demonstration programs.

The IST program is dynamic. The current program, outlined here, may not include all areas of potential interest. Thus the scientific and technology community is invited to define and justify IST support for efforts both within and outside the currently defined program.

To attract all parts of the research community - including universities, national laboratories, and industry - the program has developed multiple participation options. For example, IST sponsors efforts by consolidated research organization groups (i.e., consortia), by individual investigators, and by large and small businesses.

BMDO's Science and Technology Directorate manages the BMDO Technology Applications program to promote spin-offs of all BMDO research into allied areas of defense programs, aerospace, electronics, and medicine. The Technology Applications program, in cooperation with the National Technology Transfer Center, publishes an annual Technology Applications Report, and also a quarterly update. Further information is available by calling (703) 518-8800, ext. 500, or via the internet at leslie@nttc.edu.

The Directorate also administers the entire BMDO Small Business Innovative Research (SBIR), a separately funded, congressionally-mandated program. BMDO SBIR maintains a home page on the World Wide Web: <http://www.futron.com/bmdo/sbir.html>, and there is also a Hotline at 800-937-3150.

Program Overview

Program Administration

IST's Science and Technology Agents (STAs) provide the technical management for IST-sponsored research. The STAs are affiliated with such defense research agencies as the Army Research Office, the Office of Naval Research, and the Air Force Office of Scientific Research, and also with more specialized R&D organizations, such as NASA Lewis Research Center, Army Space and Strategic Defense Command, USAF Wright Laboratory, USAF Rome Laboratory, Naval Research Laboratory, and the Army's Electronic Technology and Devices Laboratory. In general, administration, procurement, and reporting of sponsored research is carried out by the parent agencies of the cognizant STAs.

The STAs are official representatives of the BMDO IST program. Research will generally only be considered for funding by BMDO after STA review and recommendation. For this reason, proposals in current areas should be sent to the appropriate STA, not to BMDO. The name, address, phone number, and e-mail address for each STA is shown in Appendix A.

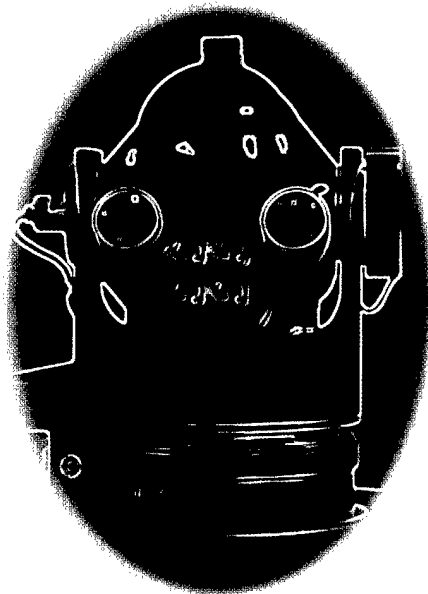
Proposers should identify a program component and contact directly the appropriate STA to initiate a dialogue. If, as a result of this dialogue, an STA determines that a proposal is of interest to BMDO, the researcher will be encouraged to follow-up with additional documentation - for example, a white paper or formal proposal. In addition to basic program efforts, IST funds some advanced projects, such as several programs currently executed through NASA's Jet Propulsion Lab (JPL). These programs generally rely on research achievements from the basic programs, so proposers should first contact the basic program STA.

For research outside the current areas, for which no STA is listed, a three page proposal summary of the project should be sent to BMDO/TOI. The summary should stress the innovative nature of the proposed work, its relationship to perceived BMDO needs, and potential results. A sample format is included in Appendix B.

The IST program encourages early contact with the STAs regarding novel concepts or approaches in any scientific or technology discipline that is applicable to Ballistic Missile Defense. We are seeking revolutionary advances that have high payoff potential, and we provide the opportunity for broad participation by the entire research community.

The following pages describe components of the current IST program, including the technological challenges. These challenges point the way toward tomorrow's technology frontiers.

TOPIC ONE



**Information Processing,
Computer Technology, and
Communications**

Laser Communications

STA: Mr. Steve Hammonds

Army Space and Strategic Defense Command

Objective Develop and demonstrate advanced high data rate, anti-jam, low probability of intercept laser cross-links between satellites and among Theater Missile Defense (TMD) and National Missile Defense (NMD) communications networks on the ground, in the air, and in space.

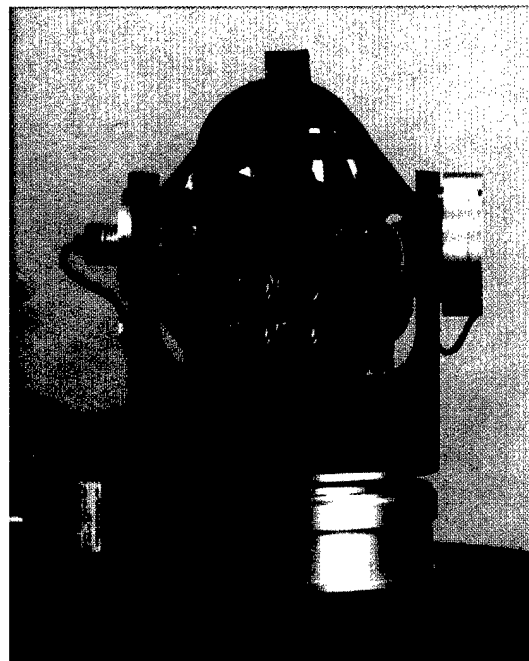
Program Description Determine the system issues for cross-links across all potential BMDO platforms through component testing and system demonstrations. Coordinate technology developments among government laboratories and private contractors in the following areas: ultra-stable laser sources, novel beam steering concepts, spatially incoherent transmitter arrays, extremely high-bandwidth receiver systems and novel networking concepts. Under this program, researchers successfully demonstrated an operational laser communications system in the presence of platform motion experienced in high altitude aircraft. Future plans include a system demonstration between an aircraft and the ground, at ranges of up to 100 km. Finally, a satellite-to-ground demonstration of a similar system is planned for mid-1998.

Opportunities Research directed toward lasercom technologies that provide reliable, high-throughput networking under realistic platform conditions. Concepts include wide field-of-view acquisition and tracking, novel beam steering, extremely high data rate receivers, and advanced network switching technologies for rapid deployment of high-bandwidth TMD and NMD telecommunications systems using rapidly deployed lasercom high-bandwidth trunk lines.

Case Example

Lasercom Demonstration

Scientists and engineers in this program have demonstrated high data rate (1.2 Gbps), long-range (150 km) laser communications systems under realistic platform vibration environments. The laser source for these measurements was located on Mauna Loa, Hawaii, and was received on Haleakala, Maui. The demonstration measured the atmospheric parameters of interest (scintillation and fade) and proved that the lasercom transceivers can remain pointed at each other with one mounted on an aircraft motion simulator. The data transfer rate was 834 Mbps.



Lasercom transceiver on 3-axis mount

Mathematical Methods and Algorithms

STA: Dr. Jagdish Chandra
Army Research Office

Objective Develop mathematical models, techniques, algorithms, and their respective implementation while focusing on reliable methods for high-resolution imaging, distributed decision-making, and robust tools for battle management.

Program Description Investigate reliable and efficient techniques for high-resolution imaging and compression, and reconstruction of optical images in various practical contexts that have been blurred by some aberrating function (such as atmospheric turbulence and/or rough optical components). Using a newly developed technique of truncated scanning singular value decomposition, a typical reconstruction process is sped-up by more than six orders of magnitude without loss. Also, establish scaleable frameworks for maintaining control of distributed decision-making. Program emphasis is placed on applying these frameworks to develop robust methodologies and techniques for advanced simulation, such as: Army Theater Missile Defense battlefield scenario simulation; initial simulation transient mitigation; and distributed and parallel simulation(s) for the growth of advanced electronic materials.

Opportunities High-resolution imaging, innovative techniques for handling large image databases, techniques for dynamic flow field visualization, scaleable parallel algorithms for visualization, and rigorous mathematical formulation and analysis of physics-based models. In addition, faster, more efficient approaches are needed for parallel processing, large-scale computing networks, nearly autonomous computing, and high-throughput signal processing.

Distributive Computing and Simulation

STA: Mr. Larry Hayes

US Army Strategic Defense Command

Objective Support BM/C³ and system simulation by providing a demonstration of high-bandwidth interconnects combined with optimistic algorithm technology for TMD, NMD, Cruise Missile Defense, and space applications.

Program Description Design and construct a prototype, eight-node, multi-GFLOP, distributed computing system based on next-generation commercial-off-the-shelf (COTS) workstation processing elements. The workstations will have unique, low-latency, high-bandwidth interfaces between their processors/memories and their optical interconnection network. This program will also develop advanced algorithms for future missile control and BM/C³ implementation. The goal of this initiative is to synergistically merge the hardware and software efforts to provide low cost, distributed Adaptive supercomputer capability for a variety of applications, including real-time conflict resolution; faster than real-time mission planning; and synthetic environments for training and exercises. The results of this research will be demonstrated on missile defense software such as the Theater High Altitude Air Defense (THAAD) Integrated Evaluation Simulation and the Synthetic Scene Generation Model (SSGM).

Opportunities Techniques to efficiently distribute computational loads, and to provide cost-effective exploitation of the COTS computing platforms, which host operationally deployed software, yet also remain user-friendly.

Multi-Sensor Tracking and Survivable Communications

STA: Dr. Rabinder Madan
Office of Naval Research

Objective Develop and test advanced algorithms for the optimal processing of information within survivable networks of distributed sensors for multiple target acquisition, discrimination, and tracking using the next generation of imagery that utilizes registration and fusion techniques.

Program Description Perfect multi-scale registration using new algorithms for detecting image boundaries; boundary detection as an optimization problem that results in robust boundaries as well as approximations for use in image compensation; new, fast and adaptive eigenspace techniques for data decorrelation of image representations; advanced algorithms for guidance and control of an interceptor pursuing a highly maneuverable target; practical advanced algorithms for optimal processing of the information obtained from various remote sources for tracking targets; and coupling the information processing with sensor resource allocation in order to optimize system-level performance. Near term plans include further investigating image segmentation techniques for precision target tracking with application to moving objects in a desert and certain biomedical applications (e.g., galvano-taxis directional cellular locomotion).

Opportunities Innovative approaches to tracking multiple targets with multiple sensors in an optically noisy environment. Similar approaches to protecting communications links in many sensor architectures.

Initiatives Under Consideration

"Fused" Machine Vision

To advance the state-of-the-art of massively parallel image recognition techniques by comparing multiple images in order to increase the probability of proper classification/detection, and to eliminate false alarms. This demonstration would serve as a companion program to the BMDO Viewing Images/Gimballed Instrumentation Laboratory and an Analog Neural 3-D Experiment (VIGILANTE), providing the opportunity to investigate a variety of methods to solving the automatic target recognition (ATR) problem, while processing at near Tera-FLOPs speeds.

Compact High-Resolution Radar/Distributed Aperture Concept for Interceptor Aimpoint Selection

To investigate the possible insertion of small, ultra-precise radar technologies radar components; algorithms for 3-D radar imaging; ISAR/SAR (synthetic aperture radar) technologies and algorithms; and real-time, high-throughput signal processing for use on advanced interceptors. For exo-atmospheric interception, radar imaging capabilities that correctly capture target features and dynamics will greatly enhance BMDO endgame performance, especially within the areas of aimpoint selection and discrimination.

Opto-Electronic Computer Networking

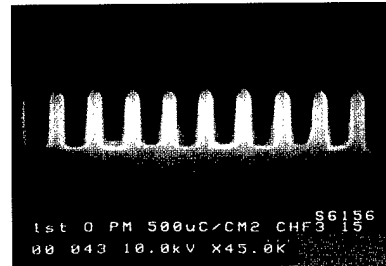
STA: Dr. Alan Craig

USAF Office of Scientific Research

Objective Develop new devices and architectural concepts for photonic computer interconnects.

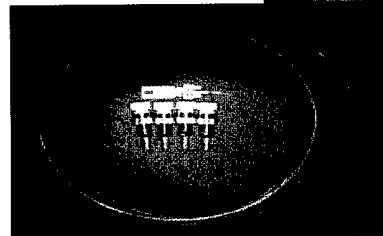
Program Description Current interest is in semiconductor devices, subsystems, packages, and integrated circuits (OEIC) for broadband fiber interconnects between computers including innovative laser, detector, amplifier, modulator, switching, and memory structures and enabling physics mechanisms. Subsystems of particular interest include, for example, opto-electronic error detection and correction codes and decoders (EDAC), monolithically integrated transmitters and receivers, and architectures based on innovative packaging technologies, including three dimensional optically integrated wafer stacks. Devices of interest include innovative laser and detector structures, advanced optical power limiters, optical phase - conjugate mirrors four wave mixing in semiconductor amplifiers whose modulation depth may depend on the frequency response of a gain mechanism (such as hole burning, carrier heating, and carrier modulation) as a function of pump-probe detuning.

Opportunities New advances in wavelength-encoded, spectral processing systems (including techniques for producing stable frequency sources with narrow bandwidths); advances in semiconductor lasers with amplitude or phase modulation, electronic carrier and photon densities, and thermal fluctuations. Breakthroughs in quantum interference effects, non-degenerate four-wave mixing, and spatio-temporal processing. Specific innovative topics in the areas of phase-sensitive optical power amplifiers in cascaded X^2 media, persistent spectral hole burning (PSHB) tailored dispersion in low-energy soliton transmission, and microsphere resonators using microcavity polariton effects or discrete state non-linearities.



Submicron Grating

Monolithic Array



Packaged Array

Initiatives Under Consideration

Terabyte Optical Memories

Develop dense mass optical WORM data storage with gigabyte per second file transfer rates. Demonstrate high speed retrieval from image data bases and parallel transfer to broadband optical fiber network. The benefits to BMDO would include successfully applying high-performance computer and communication (HPCC) systems to many TMD applications that are presently I/O and memory constrained, such as multi-spectral image fusion, phased-array radar signature analysis, faster-than-real-time tactical planners, and knowledge discovery in large peta-byte databases.

Miniature Interceptor Technology

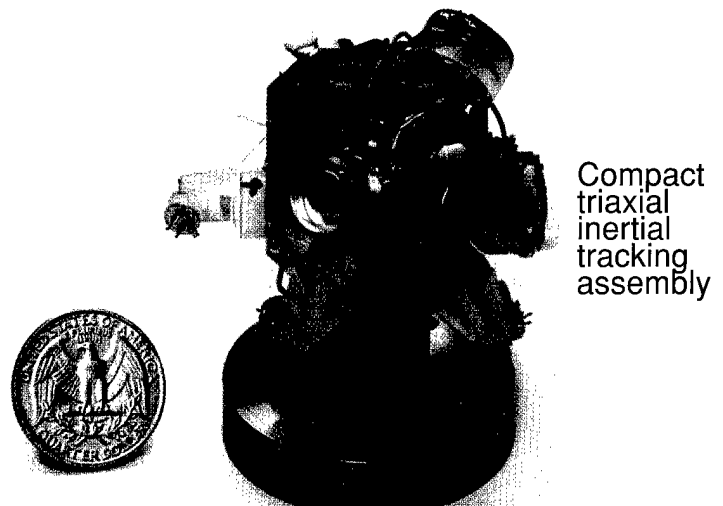
STA: Dimitrios Lianos

Army Space and Strategic Defense Command

Objective Develop interceptor technologies that enable low mass, highly efficient, extremely agile interceptors to defend against current and projected BMDO threats.

Program Description Develop miniature interceptor components that reduce size and mass, improve control, reduce on-board power consumption, increase accuracy of guidance and control, and increase divert capability. For example, develop fiber-optic and ring laser gyros that offer fast accurate operation from a dormant state, but are extremely compact. Also pursue new guidance and control concepts that address agile miniature endo interceptors, aimpoint shift, maneuvering targets. Develop spinning projectiles with advanced reticles and polarimeter seeker.

Opportunities Innovative technologies include: non-linear control that reduce time constants and increase divert capability; low cost, low mass, compact, accurate inertial measurement units; target discrimination; tracking and prediction with centimeter accuracy; small steerable sensors; and dispensing mechanisms.



Initiatives Under Consideration

Leader-Follower Coordinated Interceptor Technologies

An investigation that could support possible inter-communicating, coordinated strike interceptors, based upon information collected and processed by a "leader" intercept vehicle. Leader-follower allow BMDO a possible long-term solution, with a high probability to kill, for early release threats.

- early look at targets
- assigns small interceptors

- Divert to targets
- Inertial guidance

- Kill assessment
- Available to hit a single remaining target

Millimeter and Terahertz Sources

STA: Dr. Paul Fischer

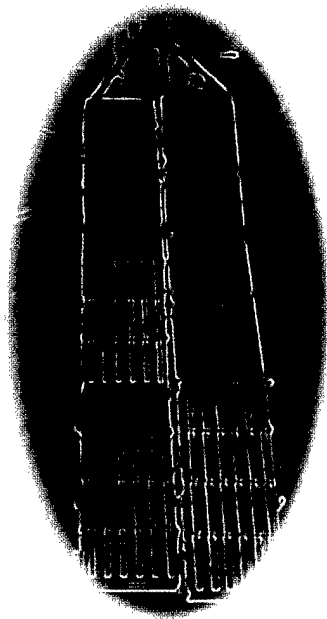
Army Research Laboratory

Objective Develop new technologies to demonstrate the feasibility of generating, amplifying, and modulating/processing electromagnetic energy at millimeter wavelengths, and terahertz and optical frequencies.

Program Description Develop two vacuum electronics devices, a traveling wave tube (TWT) and a backward-wave oscillator (BWO), and two Solid-State devices (heterostructures). TWT is wideband and high power, with a novel, high energy, permanent magnet: 200 W output power at 140 GHz (total package less than 1500 cm³, and 20 kg). BWO is voltage-tunable, octave-bandwidth, at 600 GHz to 1000 GHz and ten watts. Heterostructures are AlGaAs/GaAs and CoSi₂/Si containing two-dimensional plasmas in quantum wells. TWT and BWO are for space-based, compact, and lightweight RF source units. Heterostructures are for communications devices for source-integrated modulation and processing of optical and terahertz signals.

Opportunities Research topics on new ideas as well as modification development based upon above devices. The desired source unit must weigh 33 kg and have a volume of less than 2600 cm³. It will have an output of 5 W_{av} ERP for continuous waves, or 10 W for pulsed; and an efficiency of at least 10%. Both relativistic and non-relativistic devices will be considered.

TOPIC TWO



Power

Power, Energy Conversion, and Thermal Management

STA: Dr. Jerry Beam

USAF Wright Laboratory

Objective Develop and demonstrate efficient, low cost techniques to generate and distribute electric power. Establish advanced thermal management approaches to allow electronic devices to achieve their maximum performance. Particular emphasis is on developing integral approaches to power generation, conditioning, and thermal management of systems operating at cryogenic temperature using high-temperature superconductors.

Program Description Develop and demonstrate components for an all cryogenic ground-based radar system including the generator, power conditioning devices, and thermal management system. The keys to the approach are a high efficiency generator design that provides a 50 to 100 volt DC output and a >99% efficient power conditioning system. The cryogenic power conditioning efforts include development of capacitors, switches, and insulation. The thermal management part of the program is evaluating high heat flux cooling for both cryogenic and ambient temperature electronic devices. Cooling techniques include miniature and micro heat pipes, spray cooling, thermoelectric coolers, and heat spreading approaches. For example, incorporating micro heat pipes in a power device's ceramic substrate results in thermal conductivity that is 200 times that of copper. Develop advanced lithium thermal batteries as onboard power sources for future interceptors to improve reliability, safety, and energy density.

Opportunities Materials and devices that exploit the use of cryogenic temperatures for use in ground-based radar power conditioning systems, novel approaches to cooling electronic device that use wide-bandgap materials such as GaN and SiC, and robust lithium thermal batteries using high energy cathodes such as Cl or SF₆.

Initiatives Under Consideration

Cryogenic Ground-Based Radar (GBR) System Key Technology

This program will demonstrate a revolutionary approach to GBR that is based upon operating all major subsystems (i.e., radar, power, and electronics) at cryogenic temperatures. Integration of these cryogenic subsystems into a new GBR should result in the reduction of more than 60% in size, mass, cost, and fuel consumption by the total system.

Lithium Ion Spacecraft Battery, Flight Demonstration and Life Test

Flight demonstration of an innovative lithium ion, rechargeable battery that is presently being developed in a BMDO SBIR Phase II program. Flight opportunities are being sought. The lithium batteries deliver over 100 W-hr/kg, or three times the specific power of nickel-hydrogen batteries now used on several spacecraft.

Interceptor Onboard Power Source

Development and demonstration of an advanced onboard thermal battery provides improved reliability and safety over current reserve and thermal batteries. The new battery also reduces the packaging volume on the interceptor by 40% compared to Li-FeS₂ thermal batteries or Li-SOCl₂ reserve batteries to increase interceptor fly-out range and cost. Consider thermal battery approaches with a robust mechanical design to ensure high reliability and high energy cathodes for improved energy density. Advanced materials and designs for battery components such as the ignitor, heat paper, and seals will be included in the development program.

Photovoltaic Space Power Technology

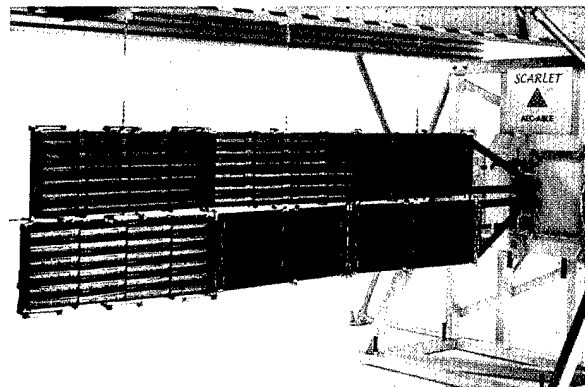
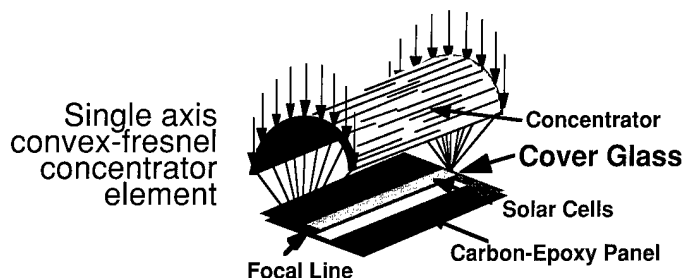
STA: Dr. Dennis Flood

NASA Lewis Research Center

Objective Develop advanced space concentrator cell and array technology to achieve low cost and low mass satellite power sources. Provide support to the space flight demonstration of Solar Concentrator Arrays with Refractive Linear Element Technology (SCARLET).

Program Description Develop and test innovative technologies to improve the performance of future SCARLET systems. New multiple bandgap photovoltaic cells are researched based on closely matching the lattice structure of the substrate with that of the active layers to achieve >30% efficiency. Alternate methods to grow wafers including liquid phase epitaxy (LPE), molecular beam epitaxy (MBE), and metal organic chemical vapor deposition (MOCVD) are studied to produce low cost, high efficiency cells. Research and test polymer materials to identify candidate concentrator lens materials. Develop manufacturing processes to simplify and reduce the cost of SCARLET structural production. Test the SCARLET GaInP₂/GaAs/Ge cells to characterize degradation rates in high radiation environments.

Opportunities A monolithic polymer material for use as the SCARLET concentrator lens must exhibit the following properties: optical clarity for all cell response wavelengths, tolerance to Van Allen belt radiation, sufficient stiffness and stability to be self supporting in a linear arch shape when held by the edges, and maintain optical properties when exposed solar VUV/UV wavelengths. Material processing must allow easy formation of sharp fresnel facets a few microns high across one surface.



200 W SCARLET deployment test

Initiatives Under Consideration

Advanced Photovoltaics Research

A fundamental research program to address the physics of solar cells and associated components that provide the basis for revolutionary advances in understanding the long-term performance of photovoltaic cells in harsh environments. The majority of BMDO photovoltaic R&D activities has evolved into the demonstration of concentrator arrays called the SCARLET program; this initiative is critical in continuing to improve the fundamental database in order to improve the capability and performance of future BMDO systems.

Gallium Nitride Microwave Power Amplifiers

STA: Mr. Tony Kikel

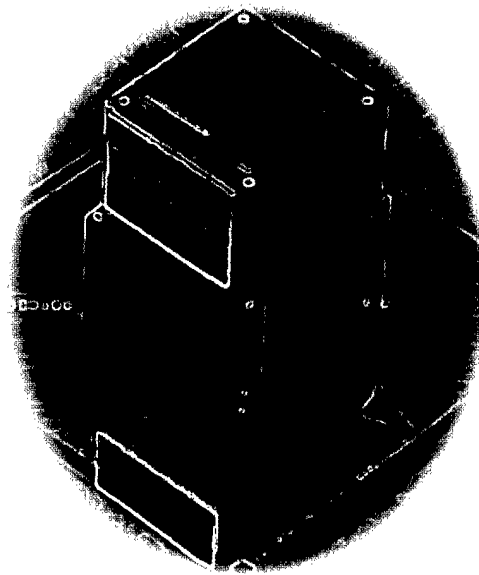
Army Space and Strategic Defense Command

Objective Develop high-performance X-band power amplifiers (e.g., a 5mm wide heterojunction field-effect transistor (HFET), single-stage amplifier with 20 W power output at 10 GHz) based upon gallium nitride for future ground-based radar and missile seekers.

Program Description The current technological challenges for a SiC power amplifier are small sizes for wafers/substrates; micropipes/microvoids throughout the material; high overall defect density (including impurities); passivation difficulty due to electric field termination; and doping difficulties. We therefore chose to demonstrate a microwave power amplifier using a GaN substrate grown by vapor phase epitaxy as the wide-bandgap material of choice, and initiated a multiple government/industry/academia team approach. The HFET design chosen has the following advantages: high mobility and high carrier concentration; high versatility (i.e., many combinations and choices of channel material); high breakdown voltage and high gain; proper engineering of channel composition using alloy layers; and low susceptibility to micro-pipe defects.

Opportunities Key non-material issues in GaN FET development remain: ohmic contacts and parasitic resistance reductions; improved thermal conductivity of the substrates; selection of the ultimate device design; and advanced packaging with special attention to heat dissipation.

TOPIC THREE



Electronic Materials

Diamond Technology and Wide-Bandgap Semiconductors

STA: Mr. Max Yoder

Office of Naval Research

Objective Develop new and better approaches to the synthesis, processing, and metalization of single crystalline, semiconductor grade diamond and other wide-bandgap materials, and exploit their superlative properties for BMDO insertion opportunities. Future applications include Solid-State replacements for high power vacuum tube amplifiers and switches, as well as ultraviolet photodetectors.

Program Description Investigate the nucleation and growth of large area, single crystalline diamond and other wide-bandgap semiconductor (e.g., III-IV nitrides and II-VI heterostructures) films on economical substrates. Improve the structural and electronic quality of these films, exploit potential homoepitaxial interfaces with these materials, and create new, innovative electronic devices and structures. Specifically, search materials for solar blind and related UV detectors, cold cathodes for high power millimeter wave amplifiers, cold cathodes to advance the state-of-the-art of negative electron affinity devices, non-volatile memories for various systems, and possible new UV LIDAR for warhead discrimination.

Opportunities Materials and applications that exploit the intrinsic advantages of refractory semiconductors: high power, high-temperature, high-radiation immunity, extremely high-frequency operation, low friction, low optical loss from the FUV to MWIR, high thermal conductivity, intrinsic hardness, corrosion and erosion resistance, and low density. Determine the nature of ballistic transport in diamond/selected nitride thin film, electronic field emitters. Future research will emphasize the nucleation of large area single crystalline diamond on non-diamond substrates and the synthesis of related high-bandgap semiconductors.

Case Example

Diamonds Sparkle for Electronics, Optics, Medicine

This program created artificial diamond films of unsurpassed quality, size, and economy. These films are used as optical coatings, thermal heat spreading circuit boards for electronics, and for hard surfacing of cutting tools. More recent applications exploit the negative electron affinity of the diamond surface for use as an extremely robust cold cathode and the related use of diamond as an emitter requiring much lower electric fields. IST-sponsored diamond research has pioneered most of the recent advances in diamond technology including economical low-temperature growth, growth from carbon monoxide, safe growth using liquid sources, films of higher quality than the best natural diamond, diamond transistors, and diamond cold cathodes and field emitters.

Electronic and Optical Materials

STA: Colin Wood
Office of Naval Research

Objective Develop advanced semiconductor materials and devices for real-time, ultra-fast information sensing, acquisition and processing; provide improvements in the operational speeds of signal processors approaching 1000 times greater than with current technologies.

Program Description Utilize molecular beam epitaxy (MBE), metal-organic chemical vapor deposition (MOCVD), and atomic layer epitaxy (ALE) to prepare new semiconductor heterostructures with improved optical, electrical, and structural characteristics. Specifically, search for new materials and device concepts; concepts for integration of optical and electronic systems; and develop a technology base for sensors and self-contained data processors capable of real-time operation at remote locations, including terrestrial and outer space. Investigate novel light emitting materials and related devices for opto-electronics, double heterostructures composed of AlGaIn, GaN, and InGaIn based layers for laser diode applications, as well as number of other programs for advanced opto-electronic devices.

Opportunities Innovative EO materials based upon new high-frequency structures; new transistor structures; high-speed, quantum-well switching effects; novel miniature, Solid-State lasers; novel diode-array-pumped, rare-earth-doped, Solid-State laser/amplifier configurations; and wide-band, superlattice optical detectors.

Initiatives Under Consideration

100 Watt Average Power, Eye-Safe Laser Radar for TMD Applications

An advanced research program to expand upon the framework laid down by BMDO using noncritically phased matched (NCMP), KTP (Potassium Titanyl Phosphate), non-linear optic (NLO) crystals and a diode-pumped Yb:YAG laser pump to achieve 1.50 mm eye-safe 'signals' for future TMD laser radars. Wavelength-tuned Yb lasers that minimize 'idler' absorption within the KTP crystal may be the only way to achieve powers on the order of 100 W, as all other options have extremely limited scalabilities.

SSL-Pumped Praseodymium Fiber Amplifiers for Ultra-Fast Transmission

An advanced research program to integrate various diverse activities in the areas of opto-electronics and fiber optics such as high power, Solid-State-laser-pumping of rare-earth-doped amplifiers, ultra-low phonon glass-matrix structures, polarization-maintaining cables, variable polarization-beam splitting, and SOA electro-optic modulators and wide bandpass photodiodes. The major insertion opportunities within BMDO are within the area of satisfying ultra-fast data requirements during the terminal phase of guided kinetic-energy weapons (i.e., LANs), as well as the BM/C³ advantages that will evolve from commercial MAN (metropolitan area network) applications.

Material Plasma Processing

STA: Dr. Jack Davis

Naval Research Laboratory

Objective Develop plasma processing technologies for the bulk generation of thin films, such as diamond-like materials and gallium nitride, to help solve various issues in future BMDO systems that require heat dissipation from miniature sensors, and electronics operating in harsh environments.

Program Description Industry has recently found that plasmas offer a unique domain for materials processing technology. This experimental program supports the modeling and validation of RF induction-generated plasma reactors that use plasma enhanced chemical vapor deposition in the processing of amorphous films of semiconductor devices, thin film transistors for flat panel displays, optical coatings, abrasive coatings, and heat diffusers for compact electronics. Plasma modeling consists of unified solutions to a complex set of equations describing the plasma, coupling to the RF sources, non-equilibrium electron and hot radical chemistry, diffusive and mass transport, surface physics, and the various radiative processes. The design of intelligent process controls based on non-intrusive spectral diagnostics can be optimized with proper simulation models.

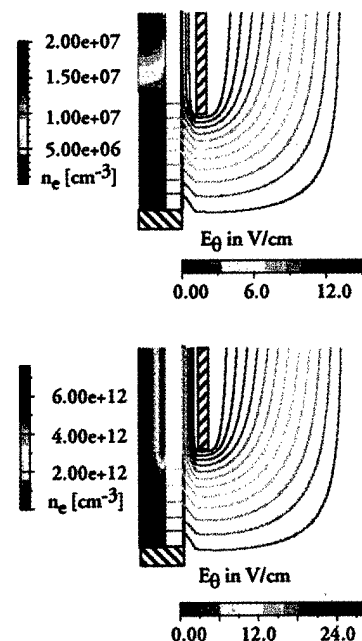
Opportunities Innovative techniques into understanding radiative signatures that offer a non-invasive diagnostic to the plasma processing. In particular, which emissions reveal details of process phenomenology, and how spectra could be used to effect on-line control methodologies.

Simulation of plasma electron density (on left) and azimuthal electric field (on right) in a cylindrical reactor with a single turn applicator coil (cross hatched in red). The plasma expands along the coil and increases in density as the applied power increased (from top to bottom).

Case Example

A Plasma as a Secondary Transformer

Plasmas offer a unique domain for materials processing technology because of their highly reactive energy content, arbitrary composition, and formation in a number of geometrical configurations. However, precisely because of this broad variability, plasma processing embraces a broad range of choices in physical parameter space. The figure below illustrates the magnetic flux lines surrounding a single turn loop coil and the development of a thin electron "sleeve" along the outside of the cylindrical plasma chamber where the growth surface is maintained. This sleeve represents a secondary current induced in the plasma by the coil due to a nonlinear skin effect.



Organic, Polymeric, and Solid-State Optical Materials

STA: Dr. Charles Lee

USAF Office of Scientific Research

Objective Develop unique, organic-based, optical materials and data processing techniques for potential insertion into future BMDO sensors and photonic networks. The performance characteristics of novel materials are tailored at the molecular level by controlling the chemical precursors and reaction conditions during synthesis.

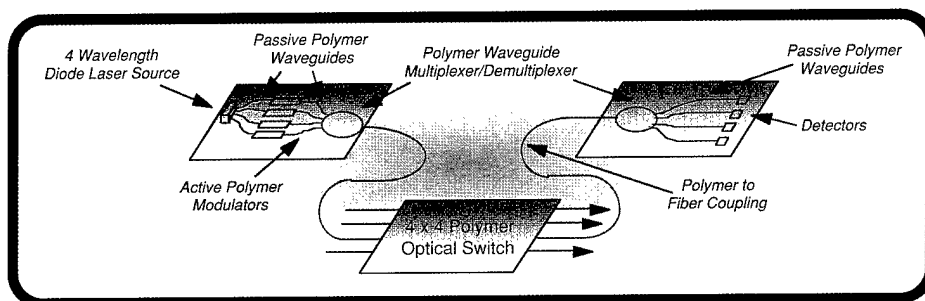
Program Description Investigate techniques in waveguide processing and device research that can be successfully mated with the current research databases on organic non-linear optics materials. Organic optical materials offer advantages in flexible processing with the promise of simultaneously tailoring the molecular properties within the polymer. Work focused on optical modulation/waveguide routing for communication networks, two-photon molecular absorption for optical data storage, and non-mechanical beam steering techniques for electronic displays. Current research focuses include controlling the size, purity, and distribution of quantum dot structures for improved optical non-linearity, chemical approaches to translate non-linear optically active chromophores into robust, device compatible electro-optical polymers, optimizing molecular properties of liquid crystals to enhance the operation characteristics of non-mechanical laser beam steering devices, and polymer blending approaches to enhance properties of light-emitting diode (LED) structures.

Opportunities Unique chemical approaches for ultra-fast EO external modulators; opto-electronic, ultra-high-speed signal processing; environmental sensing and monitoring of electromagnetic fields; and integrated polymer/semiconductor high-speed opto-electronics.

Initiatives Under Consideration

Organic Nanostructures for Advanced Electronic and Photonic Devices

The unique properties, including quantum mechanical properties, of nanostructures along with the possibility of fabricating ultra-compact devices on the nanometer scale using organic polymeric structures has only been researched at a modest level within BMDO for certain communication niches. The performance capabilities of organic nanostructures with an onboard "smartness" should simplify many operational concepts by eliminating the need for associated platforms housing non-disposable, and usually expensive, components that are required to guide and operate advanced BMDO interceptors.



Optical polymer enables bit rates over two times higher than semiconductor or LiNbO_3 materials

Reliable Wafer-Scale Electronics

STA: Dr. Nicholas Bottka
Office of Naval Research

Objective Develop novel computer architectures that are reliable and orders-of-magnitude more powerful than current state-of-the-art components.

Program Description Develop an integrated three-dimensional neural network architecture for image processing that has the potential to exceed the recognition rate of the human brain (i.e., TeraOPS for less than two watts). Tests indicate that the neural conditioning and processing modules and the lateral resistive layer are 100% functional, meet design criteria, and are suitable for use in silicon neurons. Develop a massive parallel computer architecture based upon a monolithic Wafer-Scale Associative String Processor (WASP) concept that is fault-tolerant, highly compact, cost-effective, programmable, scaleable, and capable of processing data at 100 - 1000 times faster than is possible with conventional technology. On completion of the WASP Test Bed (WTB), the massive parallel computing capability of the WASP technology for BMDO applications will be demonstrated.

Opportunities Innovative computer architectures offer massive parallelism in real-time processing of ballistic missile trajectory information: target acquisition, discrimination, tracking, and homing in a matter of seconds. It accomplishes these spatio-temporal image processing tasks at high frame rate utilizing compact low-power circuits and offers BMDO the needed breakthrough in interceptor capability.



3DANN - Three dimensional artificial neural network

Case Example

The Sugarcube-sized Supercomputer

A collaborative team of researchers at the Jet Propulsion Laboratory (JPL) and Irvine Sensors Corporation (ISC) are building a 3-dimensional artificial neural network (3DANN), the size of a sugarcube. It would be capable of complex image processing, especially tailored for real-time detection, identification, and tracking of objects such as cruise missiles, from any focal plane imagery data - testament to this capability will be soon demonstrated in a small, low-cost, and flexible multispectral sensing/processing testbed developed for BMDO's applications. The massively parallel computing architecture and low-power analog VLSI circuits in the 3DANN sugarcube, based on the models of biological neural networks in a human brain, allow the capture of an unprecedented computing speed of a trillion operations per second, while consuming only ~2.5 watts of power. With the conventional computing techniques, it would take several kilograms of state-of-the-art digital processing hardware and hundreds of watts of power, prohibitive to accomplish the time-critical task of cruise missile tracking on-board an interceptor.

Fault-Tolerant Computing

STA: Dr. Colin Wood

Office of Naval Research

Objective Develop a new hierarchic approach to implementing complex real-time, fault-tolerant systems consisting of a highly fault-tolerant network of inexpensive microcontrollers whose nodes are embedded in subsystems for local control/data collection, and a high-level, parallel processor.

Program Description Construct a highly fault-tolerant network of embedded microcontrollers based on an hierarchic and heterogeneous architecture that acts as an autonomous nervous system. Specifically, manage precisely-timed control of the subsystems, and provide continuing operation if the General Purpose Network (GPN) is delayed for fault recovery; provide fault-tolerance services to the GPN (e.g., stable storage, reasonableness checking, diagnosis, etc.); and relieve the GPN of most hard real-time requirements, simplifying its hardware, and software fault-tolerant requirements. The GPN will use conventional checkpointing and roll-back for most processes, with replication of a few time-critical applications.

Opportunities Innovative solutions using code analysis and incremental checkpointing seek to dramatically decrease the size of the saved processor state; rapid processor reboot from massive failures; heterogeneous load distribution and processor recovery; and dependable network and memory management.

Superconducting Electronics

STA: Dr. Dallas Hayes
USAF Rome Laboratory

Objective Develop advanced electronic components and signal processors that exploit the unique properties of superconducting electronics for space surveillance and communication systems in the millimeter and submillimeter wave regime.

Program Description Research superconducting electronic devices for sensitive signal detection, with wide-bandwidth and signal processing speed orders of magnitude faster than currently available. Such small, lightweight, rugged, low-power millimeter/submillimeter superconducting systems can be integrated into spread spectrum communication systems for space applications. Proof of concept development has been in low-temperature niobium with prototype demonstration progressing in niobium nitride, and someday perhaps high-temperature superconductors.

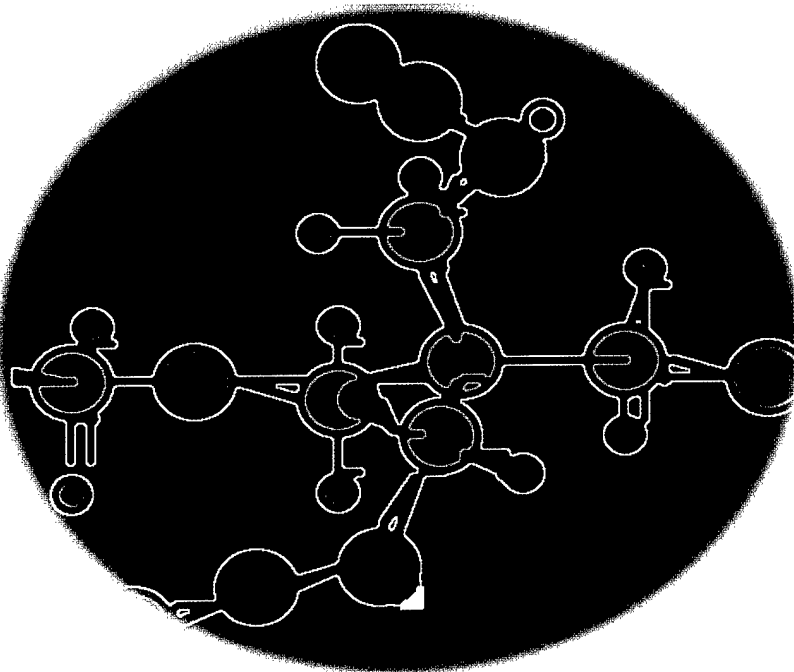
Opportunities Superconducting devices with integrated planar structures such as low-noise mixers and amplifiers, wideband phase shifters, low-power tunable oscillators, A/D converters and shift registers, and signal processors.

Initiatives Under Consideration

Superconducting Burst Processor for a High-Speed, Spread-Spectrum Modem

A fundamental development effort to design, fabricate, and test a burst synchronizer processor that provides Asynchronous Transfer Mode (ATM) capability with the incorporation into niobium superconducting, spread-spectrum communications. This burst processor, when combined with the spread-spectrum modem development, will provide BMDO with a data distribution network capable of meeting the required data rates called for in the recent Theater Defense Netting Study.

TOPIC FOUR



Propulsion and Energetic Materials

Electric Propulsion

STA: Mr. John Sankovic
NASA Lewis Research Center

Objective Develop innovative, high-performance propulsion technologies for application such as orbit insertion, repositioning, and stationkeeping for a broad range of government and commercial space missions.

Program Description With the evolution of BMDO architectures towards small spacecraft, BMDO took the lead in identifying propulsion technologies in the Former Soviet Union with potential government and commercial applications. Russian Hall thruster technology was determined to be a high impact technology essential for US competitiveness. Over the past four years, various versions of three main types of Russian Hall thrusters were evaluated. Data was obtained not only on performance and life, but also on critical integration issues, such as plume erosion effects on solar arrays, plume emission signature, induced torques, radiated EMI, and communication signal impacts. With the determination that the performance offered significant spacecraft mass savings and that the integration issues were engineering in nature, the decision was made to proceed with a full system demonstration.

Opportunities Develop a simple, low cost power processing unit for 1.0 kW to 5 kW Hall thrusters with variable input voltage. Develop innovative propellant systems with multifunctional components. Concepts to increase system performance via alternate propellants, including basic research to develop a data base of Xe, Kr, and Ar properties at temperatures to -200°C and pressures to .001 Atmosphere. Develop a better understanding of the plasma plume and its effect of spacecraft interfaces.



EMI characterization at NASA Lewis Research Center Vacuum Facility 5 of Thruster with Anode Layer for RHETT II flight experiment

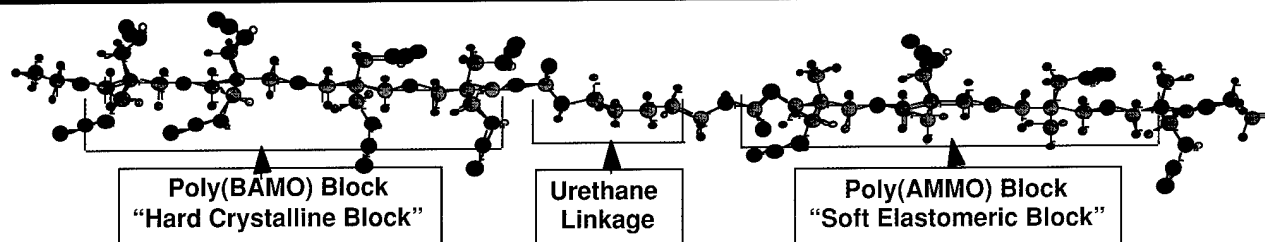
Case Example

Russian Technology Transfer

Under the program to evaluate the Russian Hall Electric Thruster Technology I (RHETT I), a Hall thruster propulsion pallet complete with a T-100 Hall thruster and US power electronics was demonstrated in January 1996. RHETT I was able to demonstrate the operation of a compact flight-like system and characterize the thermal, vibration, and EMI environments. With this success, a flight demonstration of a second Hall thruster system, featuring the D-55 Thruster with Anode Layer, will be conducted in 1997 under RHETT II.

Energetic Material Systems

STA: Dr. Judah Goldwasser
Office of Naval Research



Energetic oxetane thermoplastic elastomers provide significant life cycle cost savings for interceptor booster

Objective Develop new, affordable, explosive and propellant systems and devices for BMDO applications. Advancement requires characterization of new families of energetic materials and demonstration of novel concepts that use these materials for interceptor, satellite and gas-generator applications. These systems must operate safely over the full range of ambient, shipping and storage temperature conditions.

Program Description This new initiative builds upon the successes of previous energetic materials programs. Recent attention focused on high-density difluoroamino oxidizers, polymers and plasticizers including the latest technology for introducing geminal moieties into suitable substrates. Additionally, preliminary scale-up and safety characterization of target compounds was initiated.

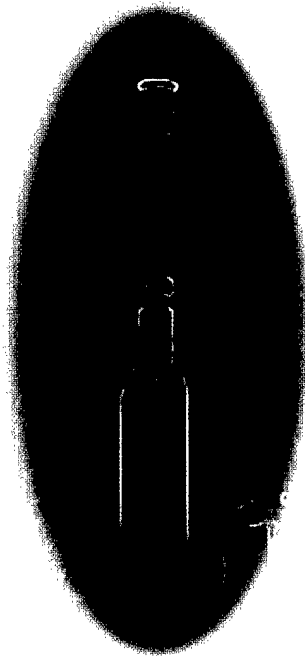
Opportunities Advanced, high performance solid materials based upon NF₂-compounds. Enhanced-materials capable of consuming dispersed nerve and biological agents; candidates should include fluorine based materials containing the NF₂, SF₅, and CF₂ moieties. Advanced, environmentally aware, and affordable liquid propellants (both monopropellants & bipropellants) for satellite and divert propulsion. Systems of interest include dinitramide compounds as well as heterocyclics such as the furazanes. Monopropellant solutions with specific impulse values exceeding N₂H₄ by >20%. Advanced, storable liquid oxidizer/blends which increase impulse-density >20% over that currently attainable via monomethylhydrazine/nitrogen tetroxide systems.

Case Example

Transfer of Advanced Propellant Technologies is Booming

Fluorine and oxygen-rich energetic crystals composed of environmentally friendly polymers are providing a new approach to increasing composite propellant and explosive energy density/release rates. In particular, energetic oxytane thermoplastic elastomers (TPEs), which have reversible crosslinking mechanisms, are one of the keys to achieving or even exceeding performance goals (+5%) while reducing life cycle wastes (-75%). Presently, there is an increasing emphasis across all services on the life-cycle cost reduction of "environmentally friendly" energetic materials (eg, free of chlorinated solvents), that is greatly pre-empting most demonstrations. Using technology leveraged from this BMDO program as well as the Navy's Energetic Manufacturing Technology (MANTECH) program, the joint US/France CPOCP program, and the Strategic Environmental R&D Program for Clean Agile Manufacturing of Energetics, this TPE technology is currently demonstrated in explosives.

TOPIC FIVE



Sensing and Phenomenology

Missile Signatures and Aerothermochemistry

STA: Dr. David Mann
Army Research Office

Objective Improve tracking and identification of missile components during various phases of their trajectories based upon the accurate prediction of temporal, spatial, and spectral radiation emitted from missile flowfields during powered or unpowered flight. Hypervelocity interceptors require a better understanding of all aspects of aerothermodynamics to reduce problems associated with control surfaces, transmission through disturbed flows, thermal protection, and imaging through shock layers.

Program Description Predict mid- to high-altitude signatures by determining flowfield simplifications needed to reduce calculation complexity; uncertainty in data needed to compute electronic, atomic, and molecular reaction rates; and to extrapolate these results to the control of TMD and NMD interceptor flowfields by, 1) boundary-layer control through recommended low-ablation materials and laminar-flow configurations, and 2) window-cooling control using innovative techniques.

Opportunities Advanced missile and plume flowfield computational techniques for signature analysis such as: cross-sections for rotational, vibrational, and electronic excitation of molecules during impact; cross-sections for electron-molecule interaction in intermediate and high-temperature flowfields; sensor characterization of the RVE stochastic distributions; and techniques in predicting flowfield structure in finite shock layer thickness. Innovative experiments to provide data verification of these predictions are also sought.

Initiatives Under Consideration

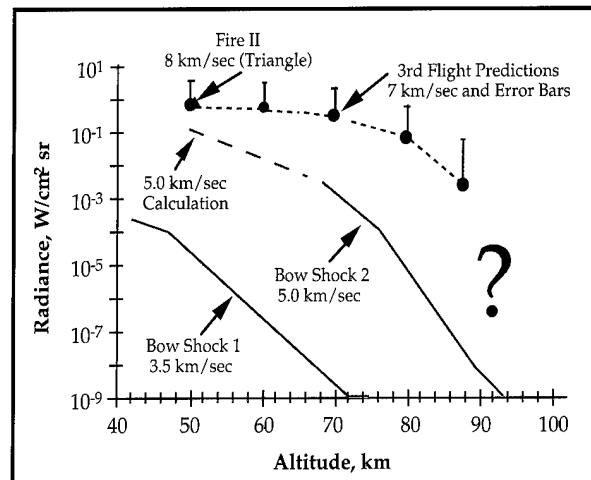
Sensor Blinding Flight Experiment

To develop an instrumental flight package for the BMDO EFEX program that will examine the spectroscopic and radiometric properties of the hot gas stream about an interceptor during its flight. This simple experiment will quantify whether sensor blinding (i.e., narcissus) could become a problem for BMDO interceptors as they reach velocities and altitudes of interest.

Case Example

UV Emissions

The prediction of optical signatures of hypersonic vehicles is crucial for the Ballistic Missile Defense Organization (BMDO) - National Missile Defense (NMD) and Air Force high altitude surveillance requirements. The figure shows that the uncertainties of the UV signature are currently too high for the robust specification of high altitude surveillance systems. (The lack of our ability to model the key physical mechanisms impacts high altitude IR hypersonic signatures as well.) The high altitude signature modeling efforts that were funded by IST to support the Bow Shock Ultraviolet Flight Experiment II continued. That work focused on the calculation of anticipated levels of UV emission generated by a 7 km/sec body at altitudes greater than 100 km through reentry. This led to major advances in the modeling capability as evidenced by the many conference presentations and journal publications. These advances led to the definition of laboratory and flight measurements that are needed to address the remaining major uncertainties in UV signature prediction.



Optical Target Characterization

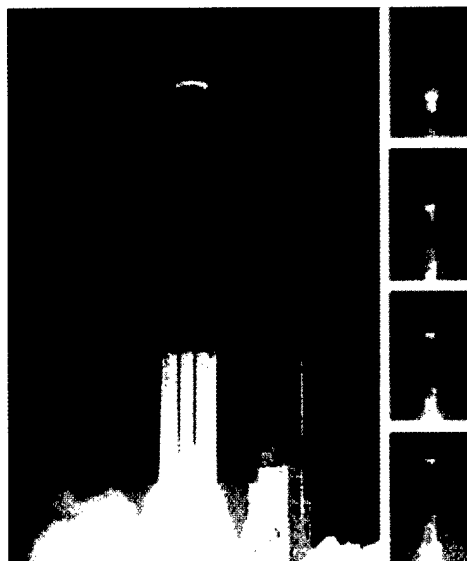
STA: Mr. Guy Beaghtler

US Navy Command, Control and Ocean Systems Center RDTE Division 85

Objective Develop innovative optical approaches, including both prototype systems/subsystems and new, enabling technologies, for tracking, discriminating, aimpoint selection, and/or kill assessment of BMDO targets. Demonstrate or test these schemes at the Innovative Science and Technology Experimentation Facility (ISTEF) at the Kennedy Space Center, FL.

Program Description Support active and passive imaging in wavelength regimes from UV to LWIR, plume and hardbody signatures, laser radar, and sensor data fusion. Provide testbed for Quantum Well IR Photodetectors (QWIP), Advanced Large Area IR Transducer (ALIRT), and various UV-LWIR sensor systems. Investigate the phenomenology of plumes, reentry/boundary layer phenomenon, and multi-spectral imaging. Establish methods for tracking and characterization of rocket targets through simultaneous high-resolution IR imaging of rocket plumes and intensity/frequency analysis of backreflected laser radiation. In the laser area, research advanced angle-angle-range radars, multiaperture coherent receivers, sparse receiver arrays, and Optical Synthetic Aperture Radar.

Opportunities Efficient, highly stable, eye-safe laser radars/Optical Parametric Oscillators systems; portable active/passive Rapid Optical Beam Steering (ROBS) capability; antenna-coupled, electronically tunable IR-FPAs; and very high capacity systolic/neural-net/optical processor technology.



Laser radar
plume &
hardbody
signatures of
a Delta rocket



Atlas plume phenomenology
(visible & MWIR)

Initiatives Under Consideration

Design and Demonstrate a Mobile Optical Tracking Mount with Flexible Laser Radar Testbed Capability

This proposed demonstration will take advantage of existing BMDO optical tracking mounts (ROBS and other integrated ISTEF systems) to acquire and track targets with the flexibility to be easily reconfigured while allowing evolving generations of laser radar technologies to be tested as they become available. Such a testbed would enable BMDO researchers to optimize their viewing location for each experiment, while maintaining the relatively low cost of a small fixed ground site, and to embrace advances in eye-safe laser radar technology as they evolve.

Appendix A

Core Programs and Science and Technology Agents

Topic One Information Processing and Computer Technology

Laser Communications

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Topic Two Power

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Topic Four Propulsion and Energetic Materials

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Topic Five Sensing and Phenomenology

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ACRONYM LIST

3DANN - 3-Dimensional Artificial Neural Network
ATM - Asynchronous Transfer Mode
ALE - Atomic Layer Epitaxy
BWO - Backward-Wave Oscillator
BMDO - Ballistic Missile Defense Organization
COTS - Commercial-off-the-Shelf
EFEX - Endo Aerothermal Mechanics Flight Experiment
ERP - Effective Radiative Power
EMI - Electro-magnetic Interference
EO - Electro-Optical
ERGM - Extended Range Guided Munitions
FUV - Far Ultraviolet
FPA - Focal Plane Array
GPN - General Purpose Network
GBR - Ground-Based Radar
G&C - Guidance and Control
HFET - Heterojunction Field-Effect Transistor
HPCC - High Performance Computer and Communication
I/O - Input/Output
IST - Innovative Science and Technology
ISTEF - Innovative Science and Technology Experimentation Facility
ISC - Irvine Sensors Corporation
JPL - Jet Propulsion Laboratory
LIDAR - Laser Imaging Detecting and Ranging
LED - Light-Emitting Diode
LAN - Local Area Network
LWI - Long Wave Infrared
MOCVD - Metal Organic Chemical Vapor Deposition
MAN - Metropolitan Area Network
MWIR - Mid-Wave Infrared
MBE - Molecular Beam Epitaxy
NMD - National Missile Defense
NSFS - Naval Surface Fire Support
MANTECH - Navy's Energetic Manufacturing of Energetics
NCMP - Noncritically Phased Matched
OEIC - Opto-Electronic Integrated Circuits

PSHB - Persistent Spectral Hole Burning
KTP - Potassium Titanyl Phosphate
RF - Radio Frequency
ROBS - Rapid Optical Beam Steering
RHETT I - Russian Hall Electric Thruster Technology I
STA - Science and Technology Agent
SBIR - Small Business Innovative Research
SCARLET - Solar Concentrator Arrays with Refractive Linear Element Technology
SOA - State-of-the-Art
SDIO - Strategic Defense Initiative Organization
SAR - Synthetic Aperture Radar
SSGM - Synthetic Scene Generation Model
THAAD - Theater High Altitude Air Defense
TMD - Theater Missile Defense
TPEs - Thermoplastic Elastomers
TWT - Traveling Wave Tube
VLSI - Very Large Scale Integrated [circuit]
VIGILANTE - Viewing Images/Gimballed Instrumentation Laboratory and an
Analog Neural 3-D Experiment
WASP - Wafer-Scale Associative String Processor
WTB - WASP Test Bed
WORM - Write-Once-Read-Many

Appendix B Proposal Summary

(for proposed efforts that lie outside the scope of programs described in this publication)

TITLE: _____
INVESTIGATORS: _____
ORGANIZATION: _____
ADDRESS: _____
TELEPHONE: _____
E-MAIL ADDRESS: _____
RELATED BMDO/TOI PROGRAM TOPIC: _____
FUNDING REQUIREMENTS: _____

(By year)

ABSTRACT:

(No longer than 24 lines; identify the BMDO-relevant technical problem that is to be addressed, and briefly describe the proposed approach and the nature of the anticipated results.)

SUMMARY:

(No longer than three pages; stress innovative nature of the effort, its immediate importance to BMDO, and its unique features that cause it to be outside the scope of the present BMDO/TOI program.)

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