AIR FORCE RESEARCH LABORATORY [AFRL]

The Air Force Office of Scientific Research | The Basic Research Manager of the AFRL

Research HIGHLIGHTS

JAN FEB 99

AFOSR Co-locates

Becomes Part of "Science City"

In addition to its annual count of 300 to 400 significant technology transitions and transfers for Air Force and industry applications, the Air Force Office of Scientific Research marked a transition of its own this past fall. After its move from Bolling AFB, D.C. to the Ballston area of Arlington, Va., AFOSR is now a next-door neighbor to the National Science Foundation and the Defense Advanced Research Projects Agency, as well its two sister service basic research organizations — the Office of Naval Research and the Washington office of the Army Research Office.

Part of a Department of Defense initiative to streamline its acquisition organizations, the move creates a "Science City" in the Ballston area that will enhance interaction and coordination within the research community.

According to a Secretary of Defense study regarding the move, "the (DoD) 6.1 basic research program is vigorous and effective. It supports high quality research efforts at universities, in industry and in the intramural research program in the service

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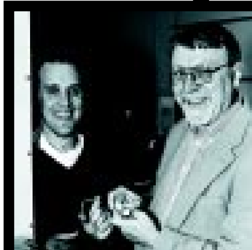
"Perfect" Mirror Design Technology

Applications Will Range From Communications to Radiation Emission Control

The discovery of a significant advance in mirror design technology, which began with AFOSR funding, offers potential for vast improvements in many Air Force applications. MIT researchers and graduate students have invented a "perfect" mirror which combines the best features of the two previously known types of mirrors — metallic and dielectric — by reflecting light at any angle with virtually no loss of energy. Among other benefits, the anticipated advance will provide:

- large diameter low-loss mirrors in space for advanced communication and surveillance systems
- coatings on aerospace systems with controlled radiation emission in specific frequency ranges
- advanced optical and optoelectronic systems such as non-mechanical laser beam steering devices



Yoel Fink (left) and Prof. Edwin Thomas

The discovery of the new mirror results from a design innovation created by MIT professor Edwin L. Thomas and graduate student Yoel Fink in collaboration with other researchers from MIT's Department of Materials Science and Engineering, Department of Physics, and the Plasma Science Fusion Center. The MIT team expanded the existing layering design concepts used to create mirrors. Their "perfect" mirror permits

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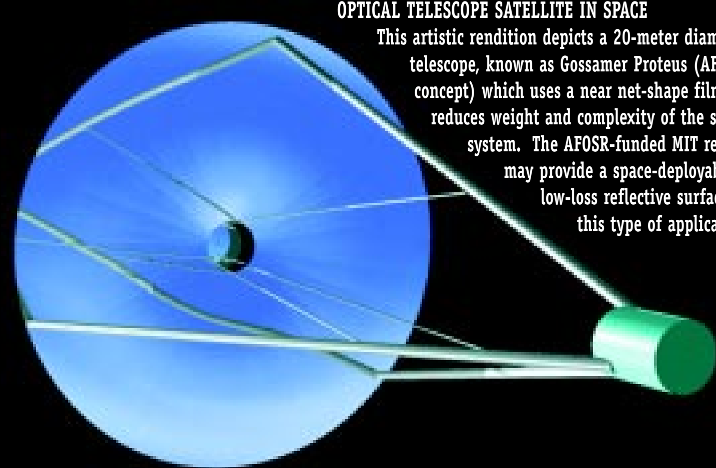
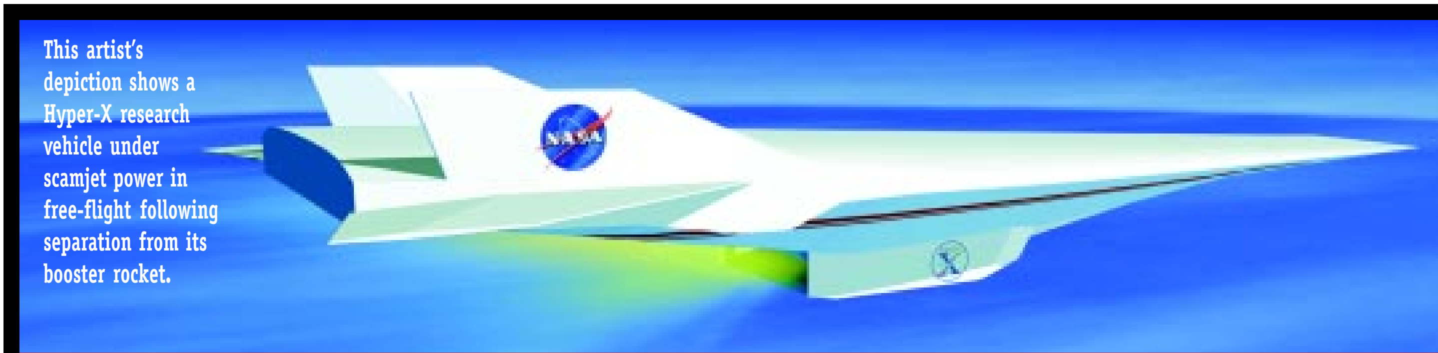


OPTICAL TELESCOPE SATELLITE IN SPACE
This artistic rendition depicts a 20-meter diameter telescope, known as Gossamer Proteus (AFRL/DE concept) which uses a near net-shape film. This reduces weight and complexity of the satellite system. The AFOSR-funded MIT research may provide a space-deployable, low-loss reflective surface for this type of application.



This artist's depiction shows a Hyper-X research vehicle under scamjet power in free-flight following separation from its booster rocket.

Space Vehicle Communications, Navigation System Performance Will Improve

Research Insight into High-Temperature Plasmas

Future Air Force space vehicles re-entering the earth's atmosphere will benefit from enhanced communications, connectivity, and navigation capabilities due to award-winning AFOSR basic research. Dr. Albert A. Viggiano, a senior research scientist with the Air Force Research Laboratory's (AFRL) Space Vehicles Directorate, won the 1998 AF Basic Research Award for making direct measurements of plasma chemical reactions over the entire temperature range needed by AF radio propagation models.

The high-temperature plasmas associated with both space-vehicle reentry and future hypersonic propulsion systems greatly affect radio frequency signals, thus AF operations and mission effectiveness. With Dr. Viggiano's newly developed measurement techniques, the precise impact of the plasma's ion-molecule reactions can be quantified. This critical research advance is leading to more accurate ionospheric modeling data, which has resulted in corrections of up to 50% in predicted electron concentrations. Improved modeling data will lead to:

- fewer GPS navigation position and radar ranging errors, and
- concepts for new hypersonic vehicle engine designs, and
- new techniques to mitigate communications outages.

The natural ionosphere, reentry plasmas, and engine combustors reach temperatures of 2000 Kelvin (3140 degrees Fahrenheit). Previous laboratory measurements were only able to study reaction rates at temperatures of approximately 900 Kelvin, well below the actual plasma temperatures.

Dr. Viggiano led an effort to design and build an apparatus called the High Temperature Flowing Afterglow (HTFA). The HTFA measures plasma processes at temperatures up to 1800 Kelvin, doubling the previous limit. This basic research allows the study of ion-molecule reactions at the true temperatures of interest to AF operations. Previously, modeling data available to AF researchers was extrapolated from lower temperature measurements and was unable to separate the effect of the multiple types of energy influencing plasma behavior. The data was subject to greater uncertainty and thus greater potential error. (Development of a Variable Temperature Selected Ion Flow Drift Tube created a tool which provides a detailed chemical picture of ion-molecule reactivity. For the description, *see the additional text on this article on the AFOSR website.*)

Dr. Viggiano

Dr. Viggiano's research efforts involve collaboration with Prof. Mario Molina, recipient of the 1995 Nobel Prize in Chemistry. The partnership, along with Aerodyne Research Inc., looked at how sulfur dioxide, a component of aircraft exhaust, is converted into sulfuric acid. This conversion affects contrail formation and acid rain. In addition, Dr. Viggiano has just finished building a high-pressure turbulent flow reactor, a technique developed in Prof. Molina's laboratory. The Air Force apparatus is the first of its kind for studying ion-molecule reactivity. With this apparatus, Dr. Viggiano plans to study ion processes that may be used in chemical ionization mass spectrometers to find unexploded ordnance and to detect chemical and biological weapons both on the battlefield and during manufacture.

Dr. Viggiano's research data has successfully transitioned directly into several AFRL ionospheric models, and has assisted in addressing problems involving reentry vehicle connectivity and hydrocarbon combustion. Incorporating Dr. Viggiano's research data into high-temperature plasma computer models improved understanding of GPS navigation, and showed that ion-enhanced combustion can lead to significant reduction in ignition delay times for air-breathing engines.

Dr. Viggiano received the prestigious 1998 Air Force Basic Research Award for his advances in understanding the chemical and physical parameters of high-temperature plasmas. According to Dr. Michael R. Berman, AFOSR program manager for the basic research effort, "Dr. Viggiano's inventiveness and determination to collect data under the most realistic conditions is making huge contributions to our understanding of how plasma environments impact critical radio propagation and other Air Force operations." Dr. Viggiano's work has earned him worldwide recognition and has led to more than 150 publications as well as an impressive collection of citations, speaking invitations, and collaborations with other internationally renowned researchers.

(For information on 1998 Air Force Basic Research Award honorable mention winners, see this article on the AFOSR web page.)

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'Perfect' Mirror Design Technology
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truly omnidirectional reflectivity. The design is sufficiently generic so that it can be used to cover many different radiation frequency ranges of interest, offering immense potential for military and commercial applications.

The researchers demonstrated the new design by fabricating a mirror comprised of nine alternating layers of polystyrene (a plastic) and tellurium. The mirrors are made using polymer processing techniques that allow the manufacture of very high-quality optical devices for relatively low cost without a lot of specialized equipment. In addition, the materials are relatively common, easy to process, and can be used for applications covering large areas.

Because of the ease in processing, this type of mirror can be coated on practically any surface. This opens up many imaginative applications and devices. For example, "omniguides" comprised of rolled, spaghetti-thin tubes of the new "perfect" mirror material can be fabricated to guide light over a very long distance without loss. By minimizing the energy absorption characteristics, the need for amplifiers is reduced. Additionally, the new technique allows mirror design to be optimized as a planar film for specific reflective ranges and can serve as an efficient heat radiator or collector. Coated walls, windows, or even car interiors could very efficiently reflect heat while maintaining transparency. Applications for cellular telephones, photovoltaic batteries, and lightweight insulator clothing are also anticipated.

The team's work progressed rapidly from an initial idea to validated results, a classic example of the powerful combination of design innovation, theoretical insight, and prototyping flexibility resulting from leveraging other government research support (MIT also received DARPA funding.)

For more MIT information, view http://web.mit.edu/newsoffice/rd/1999/jan.html

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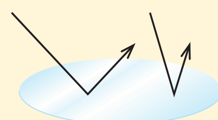
How the "Perfect" Mirror Technology Works

Metallic and dielectric mirrors each have their limitations. Metallic — like those on medicine cabinets and the most common type — waste energy, absorbing a small fraction of the light that falls on them.

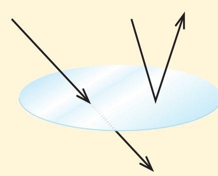
Dielectric mirrors, unlike metals, are not conductive and therefore reflect light more efficiently. Light travels in dielectric materials at speeds that are lower than in air. When light traveling in a particular direction through one type of dielectric material encounters another type, part of the light is reflected while the other part is transmitted at a different angle.

Conventional dielectric mirrors are made of multiple layers of transparent dielectric materials. Such materials, which can be made to be extremely low-loss compared to their metallic counterparts, are used to reflect a prescribed range of frequencies coming from within a limited set of angles. Such dielectric mirrors are used in devices such as lasers, which need very high reflectivity.

The new type of dielectric mirror developed at MIT can reflect light from all angles and polarizations, just like metallic mirrors, but also can be as low-loss as dielectric mirrors. In addition, it can be "tuned" to reflect certain wavelength ranges and transmit the rest of the spectrum. A device such as this, operating in the visible light, would appear to be one color, red for instance, while also being transparent.



Metallic Mirror
Omnidirectional reflectivity with optical loss



Conventional Dielectric Mirror
Angular dependent reflectivity with very low optical loss

New "Perfect" Mirror
Omnidirectional reflectivity with very low optical loss

AFOSR Co-locates
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laboratories. This work is carefully scrutinized by the services to assure that it is aligned with their goals and has an excellent track record for transitioning 6.1 research results into service 6.2 and 6.3 programs and to industry for exploitation."

The move will strengthen AFOSR's $300 million investment portfolio which will continue to provide the foundation for Air Force advancements in high technology weapon systems.

"Our co-location allows day-to-day interaction of service program managers, promotes the exchange of research ideas, and encourages more partnerships in technical areas of mutual interest," said Dr. Joseph Janni, director of AFOSR. "The decreases in planned acquisition of new weapon systems creates an even more critical need to advance the state of relevant technologies for mission support. AFOSR's research partnerships with Air Force and other government laboratories, U.S. industry, academia, and the international research community are vital to ensure access to a broad base of fundamental research accomplishments needed for future Air Force air and space systems."

Dr. Joseph F. Janni
AFOSR Director

See AFOSR website for technology transitions/transfer file

Technology Transition Spotlight

Quality, Reliability of Ceramic Ball Bearings Benefits Mechanical, Propulsion Systems

Customer .... The Air Force, DoD, and NASA will benefit from more powerful and efficient mechanical and propulsion systems based on the use of more reliable ceramic ball bearings. The advance is based on experimental techniques developed under AFOSR support that aided in detecting early fatigue failures in bearing tests. The Air Force recently introduced ceramic bearings into F-16 auxiliary power units and a variety of devices used for attitude control. The Air Force also plans to use the ceramic ball bearings in air-breathing and rocket engines. *(See AFOSR website for NASA, Pratt & Whitney applications.)*

Benefit .... The Aerospace Corporation is developing standards for nondestructive evaluation (NDE) techniques for industry use. Use of the new standards will result in improved quality control during ceramic (silicon nitride) ball bearing production. The only existing standards are proprietary. The standards are based on a novel testing methodology that dramatically improves the accuracy of NDE techniques used to detect flaws.

Basic Research ..... Five years ago, the main problem in using ceramic materials in bearing applications was their lack of reliability. With AFOSR support, researchers developed a fundamental understanding of fracture and fatigue in silicon nitride material, particularly on relationships between microstructure, surface damage, and failure. They demonstrated the detrimental effects of surface flaws and showed that microstructure can affect the evolution of contact fatigue. They also identified various types of previously unknown types of damage, such as powder processing flaws and reaction layers. Based on their data, they developed reliable methods and standards to detect near-surface flaws. Their suggestions for processing steps to drastically reduce the population of surface flaws in ceramic bearings also greatly cut manufacturing costs.

Performer .... Prof. Jack Mecholsky of the University of Florida identified types of flaws on the surface of silicon nitride ceramic ball bearings, ranging from the innocuous to the dangerous, which cause quick failure such as bearing disintegration. However, causes of the damage were unknown. Dr. Brian Lawn, from the National Institute of Standards and Technology, and Dr. Helen Chan, from Lehigh University, led a research team which investigated contact fatigue damage as a function of microstructure under Herzian-cone indentation. Aerospace Corporation [Dr. Michael Hilton, (310) 336-0440], working in collaboration with Honeywell and Miniature Precision Bearings company, is adapting the Hertzian contact method to create the NDE standards.

(For more on customer uses, benefits, AFOSR research investment, and other performers, see this article on the AFOSR website)

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Research Highlights

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Research Highlights is published every two months by the Air Force Office of Scientific Research. This newsletter provides brief descriptions of AFOSR basic research activities including topics such as research accomplishments, examples of technology transitions and technology transfer, notable peer recognition awards and honors, and other research program achievements. The purpose is to provide Air Force, DoD, government, industry and university communities with brief accounts to illustrate AFOSR support of the Air Force mission. *Research Highlights* is available on-line at:

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