

Research



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Breakthroughs In Infrared Technology Using Semiconductor Quantum Dots

Collaboration between researchers from an AFOSR-sponsored university program and the Air Force Research Laboratory (AFRL) is contributing significant progress in infrared sources and detectors, which form the basis of night flying and targeting systems.

The Future Aerospace Science and Technology (FAST) Center at the University of New Mexico includes Dr. Kevin J. Malloy, Director, Drs. Luke

Lester, Andreas Stintz and Tim Newell and many graduate and undergraduate students. Working closely with the UNM FAST Center are two directorates of AFRL. Collaborative research has been ongoing with Drs. David Cardimona and Anjali Singh of the Space Sensing Vehicle Control Branch of the Space Vehicles Directorate. Also working with the UNM FAST Center is the Semiconductor Laser Branch of the Directed Energy Directorate.

Research collaborations exist with AFRL scientists Drs. Andrew Angstad, Ron Kaspi and Ms. Sylvia Dorato. The collaborative efforts take advantage of the infrared detector fabrication facilities at UNM and the extensive infrared characterization facilities at AFRL.

Recently, these teams have made some important breakthroughs in infrared technology using semiconductor *story continued on page 2...*

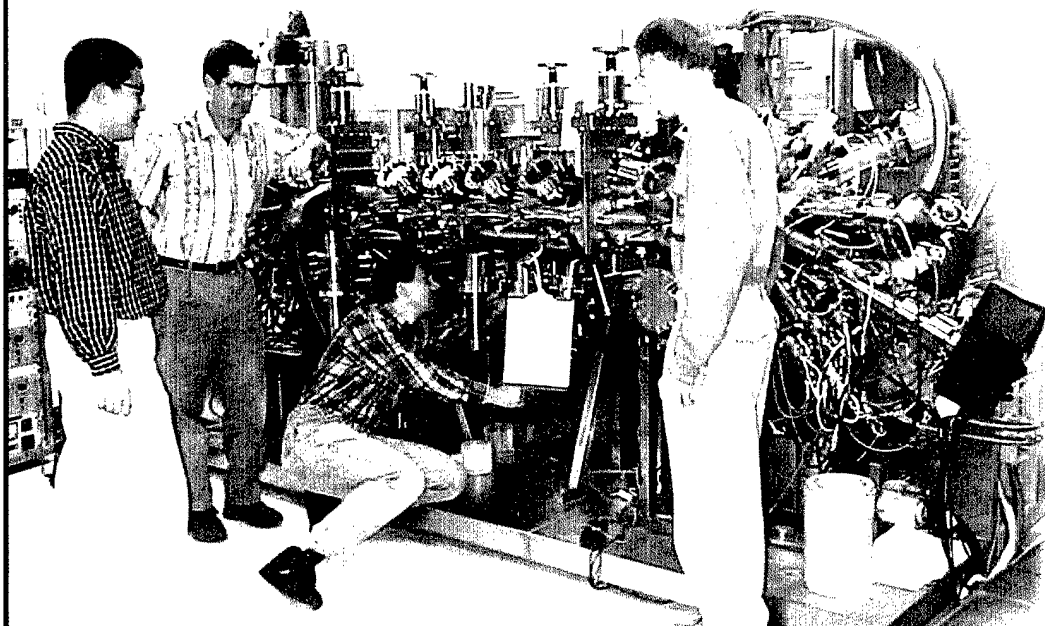
AFOSR Program Manager
Receives Prestigious Award

Dr. Michael R. Berman Honored
With Arthur S. Flemming Award

Dr. Michael R. Berman is a recipient of the 1999 Arthur S. Flemming Award for the year 1999. The Award, recognized by the President of the United States, U.S. Agency Administrators and the private sector, honors exemplary contributions of outstanding men and women serving the Federal Government. The winners for this prestigious award are selected from all areas of federal service in three main categories: basic science, applied science and executive/administrative.

The Arthur S. Flemming Award was established at George Washington University in 1948 and past Flemming honorees include Senator Daniel P. Moynihan, Elizabeth Hanford Dole and Dr. Anthony Fauci, director of the National Institute for Allergies and Infectious Diseases.

Dr. Berman, who works at AFOSR and manages Molecular *story continued on page 3...*



The molecular beam epitaxy (MBE) machine used to grow quantum dots. Left to right: Guangtian Liu, Prof. Kevin Malloy, Dr. Andreas Stintz and Dr. Tim Newell

Breakthroughs In Infrared Technology Using Semiconductor Quantum Dots

The FAST Center and the Air Force Research Laboratory

One of the goals of the FAST Center program is to provide students with exposure to Air Force research needs through ties with the Air Force Research Laboratory (AFRL). Because of the proximity of the University of New Mexico FAST Center to the directed energy directorate (AFRL/DE) and the space vehicles directorate (AFRL/VS) at Kirtland Air Force Base, these opportunities have flourished. In particular, FAST Center students have conducted research in AFRL laboratories using unique facilities for the characterization of infrared countermeasure materials. Former students have become researchers at AFRL developing advanced space-based sensors. Finally, AFRL scientists also leverage the unique facilities established at the FAST Center to grow and fabricate IR devices. By directly involving the students of today in Air Force research, the people and the technology the Air Force needs tomorrow will be ready.

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quantum dots. Semiconductor quantum dots confine electron motion in three dimensions, rather than in only one dimension as in a quantum well by embedding nanometer-sized islands of narrow bandgap semiconductor inside a different semiconductor with a larger bandgap. In this case indium arsenide (InAs) dots are embedded in gallium arsenide (GaAs).

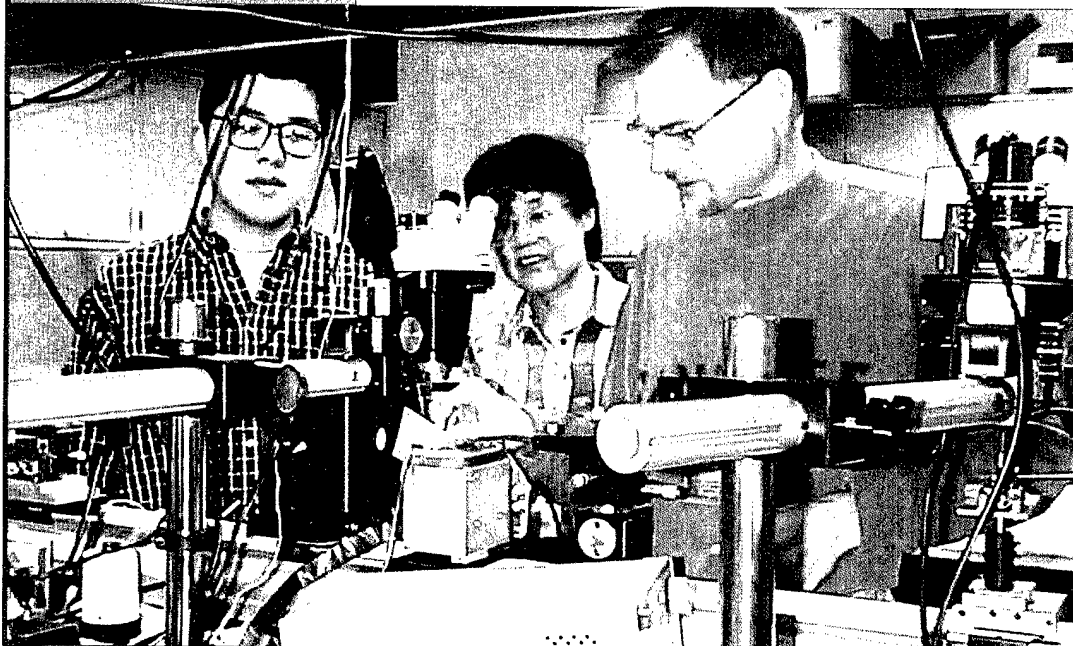
These dots mimic the quantum mechanical behavior of isolated atoms with two important differences. First, because they are embedded in a semiconductor, it is easy to excite electrons bound to the quantum dots by simply passing current through the semiconductor. The second difference is that these dots are active in the infrared portion of the spectrum instead of in the visible or ultraviolet portion where isolated atoms show activity. Electrons in quantum dots have very well defined energy levels, similar to isolated atoms, in contrast to

the range of energy levels found in quantum wells. As a result, light that is released when an electron makes a transition from a high energy level to a lower energy level in a quantum dot has a very sharply defined wavelength that can be tuned to the infrared by the size of the dot. This makes semiconductor quantum dots ideal candidates for discriminating between different targets with hyperspectral imaging.

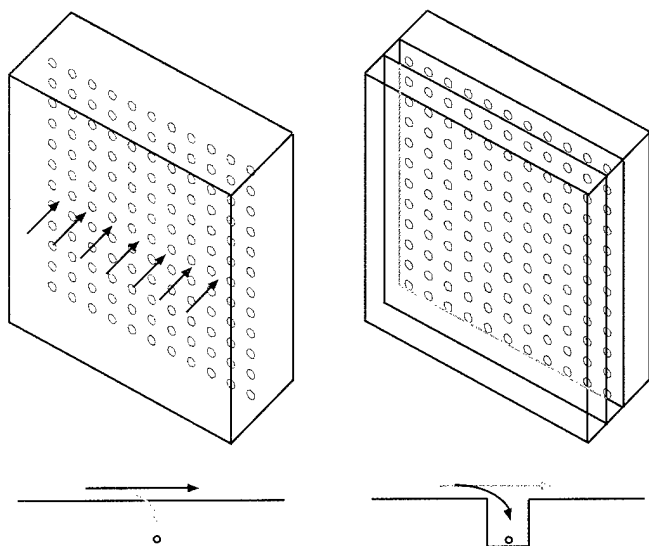
During investigation of the possible use of semiconductor quantum dots for strategic sensors and detectors, an important insight was made into how to maintain the dot's activity as far into the infrared (IR) region as possible. The goal was to do everything possible to keep the indium concentration in the dot high to ensure IR activity. This insight was implemented by sandwiching the dots inside a separate indium-rich layer inside the GaAs semiconductor. This layer, called a quantum well, provided extra indium for the dot after its formation and

made the dot active far into the IR.

Using this "dots-in-a-well" (DWELL) configuration, the UNM-AFRL team made two important discoveries. The first was lasers using DWELL configuration had the world's lowest threshold current density, which is a measure of how much current it takes to turn on the laser. The FAST Center team presently has the current density down to 16 amperes per square centimeter, a 68 percent reduction over the previous best. Previously, the record stood at 50 amperes per square centimeter in another type of semiconductor laser. This should translate directly to the efficiency of operation of infrared systems and reduce the supporting hardware weight and power by a similar percentage. The second important discovery was that these quantum dot lasers behave very differently from other semiconductor lasers and perhaps not too surprisingly, behave like atomic lasers in some ways. This has very important consequences for the high power semiconductor lasers needed for infrared countermeasures. Previously, conventional semiconductor lasers have exhibited instabilities when highly excited to produce high power. This occurred because flooding the semiconductor with current changed the optical properties, causing the lasing characteristics to fluctuate. This phenomenon is described by the "alpha parameter," also called the linewidth enhancement factor. Typical values are around 3 with about 0.5 being the lowest ever reported.



2 ABOVE: From left to right: Guanghan Lin, Dr. Hua Li and Dr. Tim Newell study a quantum dot laser diode.



HOW DOTS-IN-A-WELL (DWELL) LASERS WORK:

Previous semiconductor quantum dot lasers used the configuration on the left. Because the indium arsenide dots only occupy about 4% of the area, current collection by the dots is inefficient. The energy diagram underneath shows that most carriers bypass the dots. DWELL lasers are depicted on the right. Introducing a low energy indium gallium arsenide well layer around the dots has two important effects. The first is to provide a reservoir of indium for the dots, ensuring the proper wavelength for infrared countermeasures or eyesafe laser radar. The second effect is to capture and direct the carriers toward the dots. As shown in the bottom diagram on the right, the well acts to funnel carriers toward the dots, significantly increasing the current collection by the dots, and subsequent power output.

However, when the DWELL lasers were tested at AFRL, the linewidth enhancement factor was 0.1, a significant improvement and another indication of the atomic-like properties of semiconductor quantum dots. This reflects the payoff expected from the quantum dot's sharper transitions, compared to quantum well lasers without embedded quantum dots. Further improvements are expected from improving the size uniformity of the quantum dots. Using the insights already gained from studying InAs/GaAs quantum dots, Dr. Ron Kaspi of AFRL is leading an effort at the UNM FAST Center to extend these results to quantum dots in the semiconductor gallium antimonide

(GaSb). Dr. Kaspi previously has made extensive progress in more conventional GaSb lasers using advanced growth techniques coupled with direct monitoring of the growth process. This has led to the FAST Center/AFRL team demonstrating GaSb semiconductor lasers in the IR at two micrometers and four micrometers, and to providing these lasers to Air Force and DoD contractors for incorporation into working IR countermeasure systems. The increased spectral purity and power output will allow longer range defense against IR guided missiles. Initial results on extending quantum dots to the GaSb system are encouraging.

Maj. Dan Johnstone
Program Manager, AFOSR/NE
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Dr. Michael R. Berman Honored With Arthur S. Fleming Award



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Dynamics and Theoretical Chemistry Programs and basic research team, was selected for his outstanding contributions in the executive/administrative category. Dr. Berman is a winner of several other awards and was previously selected as an AFOSR Senior Fellow in 1995.

Dr. Berman won the Fleming Award for his meritorious and effective leadership in managing multidisciplinary Air Force laboratory, university and industry



research partnerships. His management of projects and research teams has advanced the understanding of basic mechanisms involved in chemical reaction dynamics and energy transfer. Many of his projects have rapidly addressed Air Force operational issues in the areas of rocket propellants, aircraft and spacecraft signatures and surveillance, chemical lasers and new materials.

He has guided both Air Force and university laboratory researchers in developing and applying predictive tools to design new materials and improve materials processing and chemical synthesis. He coordinated an interagency atmospheric chemistry program — NASA, the National Science Foundation and the AFRL's KAFB site laboratory — that significantly supported the mission of Air Force Space Command. As the AFOSR technology coordinator for High Energy Density Materials, he assembled a Laboratory/university team that has earned the Air Force an international reputation as a scientific leader in providing affordable, safe access to space.

He nurtures research teams, serves as mentor and inspires a commitment to scientific excellence. Four of his six Air Force laboratory programs have earned recognition as AFOSR Star Teams for performing world-class research. He also serves as the Air Force representative for the Chemistry Scientific Planning Group for DoD's Science and Technology Reliance Basic Research Panel. He frequently participates in government review panels and advisory boards, and has served as session chair at national and international meetings.

Dr. Berman has more than two decades of experience in scientific research and management in academia, industry and government. He is the author of 35 published scientific papers and is a member of the American Chemical Society, American Physical Society and Sigma Xi.

Dr. Berman is the Program Manager at AFOSR/NL. He can be reached at (703) 696-7781.

The DoD Engineer and Scientists Exchange Program, or ESEP, supports science and technology through international cooperation in military research, development, and acquisition through the exchange of defense scientists and engineers. ESEP provides on-site assignments for U.S. military and civilian scientists and engineers in foreign government organizations and reciprocal assignments of foreign scientists and engineers in U.S. government organizations. ESEP supports current USAF science and technology requirements by seeking specific foreign technologies. It provides insight into the technology and project management techniques of foreign laboratories and centers and opens areas of possible technical cooperation.

John D. Corley

Air Force Research Laboratory
Munitions Directorate

Education:

MS in Civil Engineering,
University of South Florida
BS in Chemical Engineering,
University of Missouri

Current Assignment:

Fraunhofer Institut Kurzzeitdynamik, Ernst-Mach-Institut (EMI),
Freiburg, Germany

Description of Work:

Mr. Corley's research assignment at EMI involves the performance and survivability of high explosives in penetrating munitions. Mr. Corley has evaluated the blast performance of two AFRL/MN developed explosive formulations in EMI's 3-chamber system, including AFX-757 which was recently selected as the explosive fill for the Joint Air-to-Surface Standoff Missile (JASSM). Regarding warhead survivability, Mr. Corley is studying the mechanical properties of high explosives to better understand why high explosives in penetrator munitions sometimes explode prior to reaching their intended targets and how such undesirable reactions can be prevented. This work forms the basis of Mr. Corley's doctoral dissertation at the German University of the Armed Forces which he is preparing during his exchange assignment. During his USAF career, Mr. Corley has managed a variety of projects in technology areas ranging from Insensitive Munitions to Demilitarization to Enhanced Weapons Effects. He has been active in numerous national and international cooperation panels including The Technical Cooperation Program (TTCP) WAG-11 on Energetic Materials and AF Data Exchange Agreement (DEA)-7304-Physics of Explosives. He has served as Chairperson of the Joint Army, Navy, NASA, Air Force (JANNAF) Propulsion Systems Hazards Subcommittee and Chairman of the Four Power Air Senior National Representatives Long Term Technology Project on Insensitive High Explosives for Penetrators.



Research Highlights

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