The USAF Manufacturing Technology

Status Report

Air Force Research Laboratory / Materials & Manufacturing Directorate /
Manufacturing Technology Division / Wright-Patterson AFB, Ohio
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In this issue:

Air Force
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Defense Production Act Title III Program Awards Contracts For Silicon Carbide (SiC) Substrates

In collaboration with the Air Force Research Laboratory (AFRL), the Army Research Laboratory, and the Naval Research Laboratory, the Defense Production Act Title III Office at Wright-Patterson Air Force Base recently awarded three cost-shared contracts exceeding $17 million in value in support of the 75mm Silicon Carbide (SiC) Substrate Program.

Cree Research will receive $2 million from Title III over 24 months while Litton Airtron and Sterling Semiconductor will receive $3 million and $3.5 million respectively over 36 months.

High quality silicon carbide (SiC) substrates can provide revolutionary improvements in the cost, size, weight and performance of a broad range of military systems including radar, communications, electronic warfare, and vehicle and aircraft power conditioning. This material is also of growing importance in a variety of commercial applications including blue light-emitting diodes and lasers and power switching applications. Title III will provide the incentive to establish cost efficient production capacities needed to ensure the U.S. military's access to this critical technology.

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Title III of the Defense Production Act (DPA) is a unique program which occupies a central role in the Department of Defense's mission to maintain U.S. technological leadership in defense production. The DPA of 1950 authorizes the use of government purchases and purchase commitments to encourage private efforts to establish or expand industrial capacity, develop technical processes, and produce essential materials needed for national security.

The Air Force serves as executive agent for the Title III Program by authority of the Deputy Under Secretary of Defense for Commercial and International Programs. The DPA Title III Program Office (AFRL/MLMP) located within the AFRL Materials and Manufacturing Directorate Manufacturing Technology Division, has program management responsibility.

North Carolina-based Cree Research, Inc. is the world leader in developing and manufacturing semiconductor materials and electronic devices made from silicon carbide. The company uses proprietary technology to make enabling compound semiconductors such as blue and green LEDs, SiC crystals used in the production of unique gemstones, and SiC wafers sold for both production and research applications. Cree has new product initiatives underway based on its expertise in SiC, including microwave transistors for use in wireless base stations and radar, blue laser diodes for optical storage applications, and high power devices for power conditioning and switching. For more information on Cree visit http://www.cree.com.

Litton Airtron is a division of Litton Systems, Inc. of Woodland Hills, CA. Reporting to Litton's Electronic Components and Materials sector, Airtron has been satisfying its customers with quality products and services for over 50 years. The company consists of several groups producing electronic materials for the semiconductor industry; microwave components for defense and commercial applications; and optical materials and components for laser-based medical, industrial and commercial applications. Airtron's headquarters and the manufacturing locations for the Electronic Materials and Microwave Groups are located in Morris Plains, NJ. The Synoptics Group is located in Charlotte, NC. For more information on Airtron visit http://www.airtron.com.

Sterling Semiconductor, a Virginia-based subsidiary of Novecon Technologies Corporation, was established in 1996 to manufacture silicon carbide and advanced electronic device components made from silicon carbide. In the fall of 1998, Sterling gained substantial additional capacity, technology, expertise, and an ISO certified wafer production process, with its acquisition of the silicon carbide wafer production assets of Epitronics, a division of ATMI. Sterling Semiconductor aims to provide customers with a full portfolio of SiC substrates for use in applications such as blue-opto electronics, high temperature and high power electronics, and wireless communications. For more information on Sterling Semiconductor visit http://www.sterling-semiconductor.com.

International Team Discovers Method To Design Materials Via Neurocomputing

How many different potentially useful materials are there? If one were to simply consider the possible number of just two, three or four element combinations of the roughly 100 elements, the number of compounds and solutions is in the billions.

Scientists in the Air Force Research Laboratory Materials and Manufacturing Directorate (ML), interested in seeking a computational approach to predicting the existence of a multi-element compound, sponsored a collaborative research effort which led to a significant breakthrough in using neural networks to help design new materials.

The team discovered that a nonlinear expression involving an elementary material property could be used to predict, with greater than 99 percent accuracy, the existence of a compound for a multi-element materials system. This discovery will result in significant savings in time and resources and will speed the search for future, yet to be realized potentially useful materials.

There are about 5,000 binary (composed of two elements), 162,000 ternary (three element), and roughly four million quaternary (four element) materials systems possible," according to Dr. Steven R. LeClair, materials scientists and chief of ML's Materials Process Design Branch. "Of course, many of these combinations do not form compounds, and of those that do, data exists for only 80 percent of the binary systems, five percent of the ternary systems, and less than one percent of the quaternary systems."

Dr. LeClair's Branch, together with the Air Force Office of Scientific Research (AFOSR), provided funding to Dr. Pierre Villars, of Switzerland, to establish an international research project, which addressed strategies for accelerating materials design. Dr. Villars is a world-renowned expert in crystallography and a source for many of the world's materials data handbooks. The project took advantage of Dr. Villars' access to quality materials data and leveraged an existing AFOSR initiative referred to as Electronic Prototyping, involving basic research in recursive linear regression and adaptive stochastic optimization as applied to function approximation.

"Electronic Prototyping is a research effort wherein the goal is for all devised artifacts to be prototyped electronically to simulate shape, processing and operation in an intended environment," Dr. LeClair explained. "The objectives of this initiative are to develop new computational methods to model and relate materials-product-process designs; to integrate, synthesize, and generalize new knowledge; and to automate knowledge discovery for use in improving productivity."

By combining their expertise, and leveraging resources, in April 1999, Dr. Villars and the Electronic Prototyping research team made a significant breakthrough. They discovered that a nonlinear expression involving an elemental property could be used to predict the occurrence of a compound for a multi-element (binary, ternary, etc.) materials system. The material property, referred to as the Mendeleev Number, was originally conceived by D.G. Pettifor (Oxford University, England) to group binary compounds by structure type.

"This discovery will save a tremendous amount of time and resources in the exploration of future, yet-to-be-re-

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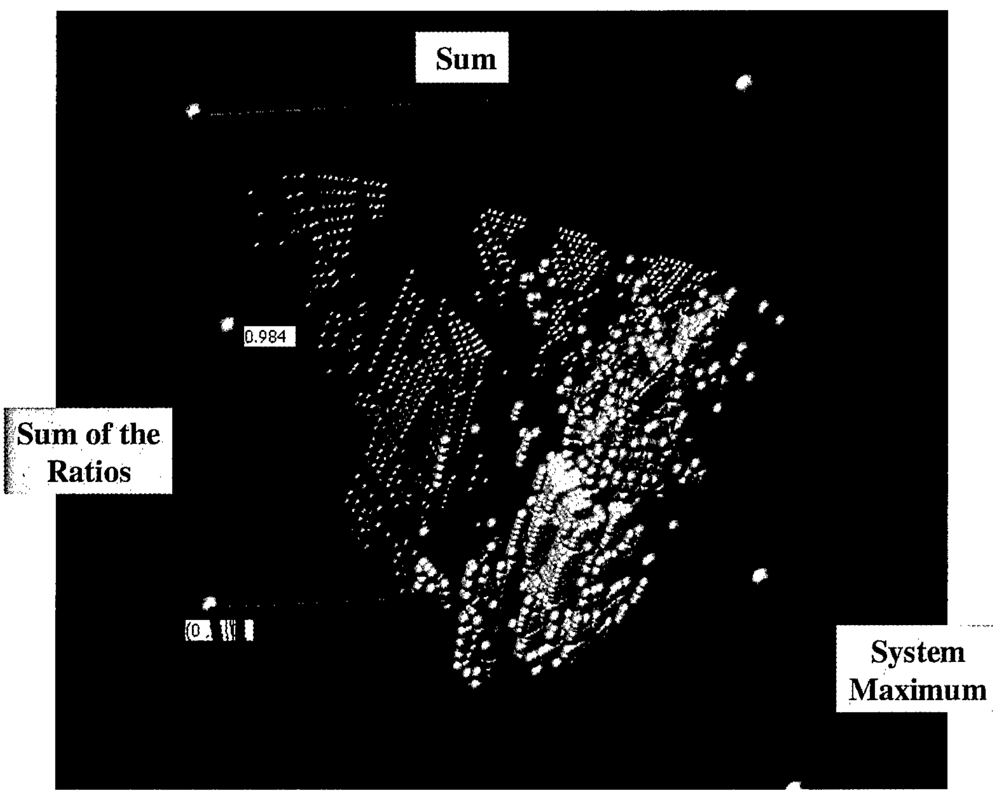
alized, materials systems, particularly the four million quaternary systems on which there is little data," Dr. LeClair said. "These quaternary systems include high temperature superconductors (e.g., YBaCuO), photonics/optical semiconductors (e.g., InGaAsP), and piezoelectrics (e.g., $PbZrTiO^3$), and a host of other compounds exhibiting unique combinations of properties which will enable new, more advanced technologies for tomorrow's Aerospace Force. We now have a computational approach to determining which combinations of elements will yield compounds that may lead to potentially useful materials. Longer term, this ability to computationally predict compound formation will motivate continued research of methods to predict specific combinations of properties, which ultimately will enable an end-user to select a material or material alternatives by simply specifying operational requirements."

In addition to Drs. Villars and LeClair, the team members included: Dr. Al Jackson, Technical Management Concepts Incorporated; Professor Yoh-Han Pao, Case Western University; Dr. Boris Igelnik, Case Western university; Professor Mark Oxley, Air Force Institute of Technology; Professor Mike Kirby, Colorado State University; Professor Bhavik Bakshi, Ohio State University; and Professor Phillip Chen, Wright State University.



Graphic: This is a 3-D graphic involving three expressions of the Mendeleev number which clearly depicts the hyperspace separation of over 4,000 ternary (three element) compounds.

ManTech For Affordable Space Systems Initiative Attacks Cost Drivers

In an effort to reduce the cost and improve the capabilities of electronics, structures and operations for military space systems, the Air Force Research Laboratory has initiated a major effort to attack the real cost drivers in space systems.

The Materials and Manufacturing Directorate's Manufacturing Technology Division (ManTech) is leading this $26 million program, which is called the ManTech for Affordable Space Systems (MASS) Initiative.

The initiative will look at using advanced industrial practices in all aspects of acquisition and development of spacecraft, payload and launch vehicle systems. While most of the cost of a conventional aircraft system comes in its operation and support, most of the cost of a typical space system comes in production and testing. The MASS Initiative seeks to reduce this cost and acquisition cycle time, improve mission responsiveness, and improve supplier collaboration.

Four MASS contracts were recently started in areas where analysis indicates ManTech can make the biggest impact in space. The Affordable Millimeter Wave Units project is a cooperative agreement with TRW which will develop and demonstrate low-cost radio frequency process technologies for the Advanced Extremely High Frequency (EHF) program. Researchers will develop metrics for board and module cost, select the board and module approach with the least cost, develop an automatic tuning method, design modules and boards for the EHF receiver array, and conduct a production demonstration against the metrics. These researchers are aiming at an 80 percent reduction in tune and test costs, a 90 percent reduction in board assembly costs, and a 30 percent reduction in the cost of module/board parts.

The Flexible Space Vehicle Production Line project is another cooperative agreement with TRW. Its objective is to establish a flexible, multiple-mission, lean production line to integrate diverse payloads with a standard modular spacecraft architecture for any mission or any orbit. In this effort, researchers will develop modular, mission-adaptable spacecraft bus configurations and develop robust, standardized structural designs and interfaces. They anticipate that insertion of materials and manufacturing technologies into bus structure and avionics packaging designs will provide performance benefits while reducing operations costs. They will use lean manufacturing principles to establish efficient operation sequence flows and optimize space and resource use, which will reduce recurring costs and shorten the cycle for new designs. Standardized mechanical integration and test procedures will be used to facilitate a flexible manufacturing environment for the new design architecture. Flexible manufacturing cells will be employed to increase production efficiencies while improving quality for the new design architecture. The project is expected to result in a 50 percent reduction in costs and a 50 percent reduction in cycle time.

A third project being undertaken with Lockheed Martin is called Affordable Space Systems Intelligent Synthesis Technology (ASSIST) for Manufacturing. ASSIST will develop and

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demonstrate an intelligent knowledge management system to reduce the cycle time, cost, and risk of design, production and systems check out of satellite subsystems. To achieve this, researchers will use a spiral development methodology, develop an integrated product and process development infrastructure and tools, and demonstrate the technology and tools on a satellite propulsion subsystem.

Satellite systems are typically low volume, and low volume production is expensive, time-consuming and risk laden. This is due to the inability to adequately predict, monitor and control the product development and sustainment process. ASSIST will resolve this problem by employing an internet-based, intelligent knowledge management system that: incorporates proven technologies; seamlessly integrates needed information needed across the product cycle; disseminates that information to managers, designers, suppliers, the shop floor, and the launch site; and validates the benefits. This project aims at: a 50 percent reduction in design cycle time, a 10-15 percent reduction in procurement costs, a 50 percent reduction in manhours for test, a 50 percent reduction in exposure to hazardous operations, a reduction in rework hours to five percent of total manufacturing hours, and a 50 percent reduction in launch site test support hours.

The fourth project in the MASS Initiative is Enterprise Synchronous Manufacturing and Investments (ESMI), a cooperative agreement with Boeing which targets top level space enterprise and manufacturing processes to reduce cost and cycle times and improve quality. ESMI will develop a virtual corporation to create and distribute breakthroughs in design and manufacturing for space systems.

This portion of the initiative consists of eight projects which look at a broad coverage of space systems test and manufacturing areas: lower cost optics; standard readout integrated circuit for infrared-focal plane arrays; improved focal plane array to optics alignment; supply chain integrated manufacturing; reduced satellite testing; low-cost reusable composite propellant tanks; engine duct cell synchronous manufacturing demonstration; and factory layout, simulation and visualization. Anticipated benefits from this program include: reduced cost, cycle time, quality defects and waste; increased supplier and customer collaboration; and reduced time to market leading to improved responsiveness.

ManTech Initiative Seeks Ways To Manage Electronic Parts Obsolescence

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Military aircraft are experiencing ever increasing electronics obsolescence problems. Leading edge integrated circuit manufacturing processes change every 12 to 18 months. Commercial parts are usually manufactured for a period of two to four years, and the manufacturing processes are available for five to six years. Meanwhile, military weapon systems' life cycles have been extended for decades. With long weapon system development cycles, new weapon systems are experiencing parts obsolescence during development and production.

The services are becoming more reliant on Commercial Off The Shelf (COTS) technology, but using COTS has the associated problem of ever-increasing technology turnover rates. The military market for manufactured electronics is dwarfed when compared with the commercial market. Low military market volume has resulted in the military having virtually no influence on the electronics market place or on electronic parts availability. Electronic parts obsolescence is a major issue for all weapon systems and it's a problem that will not go away. So the question is how to predict and proactively manage this problem in the most affordable manner.

The Air Force Research Laboratory Materials and Manufacturing Directorate recently implemented a five-year $21 million initiative to seek ways to answer this question by managing parts obsolescence. Contractors are providing another $11 million in cost share for the Air Force Initiative, which is being led by the Directorate's Manufacturing Technology (ManTech) Division.

Parts obsolescence problems are prevalent in systems where the service life or developmental cycle is longer than the manufacturing life of one or more of its components. With the typical manufacturing life of most electronic components today being two to four years, it is expected that most defense systems will have obsolescence problems before fielding, and certainly experience obsolescence during service life.

Until now, parts obsolescence has been handled piece by piece. A person trying to repair a unit runs out of a specific part. The logistics engineer attempts to order a replacement part, but discovers the part is no longer in production and stockpiles have been depleted. So another unit must be cannibalized for the part, or extremely high prices must be paid to have the part remanufactured (emulated) or purchased from an after market vendor.

The eight different projects in this ManTech initiative intend to demonstrate the cost effectiveness of managing obsolescence through a systematic proactive corporate management approach. These projects will cover three key areas: parts obsolescence management and reengineering tools; the Application of Commercially Manufactured Electronics (ACME); and pilot demonstration programs.

The goal in the area of parts obsolescence management and reengineering tools is to provide the defense industry and Air Force logistics centers with common, commercially available obsolescence management decision and reengineering tools. The initiative seeks to determine which is the most cost-effective approach for obsolescence problems with a particular system and to develop a structured approach for decision making associated with obsolete-parts management. Several contracts have been awarded to study cost tradeoffs, parts redesign, predictive data elements, and a preplanned periodic improvement strategy.

The ACME portion of the initiative addresses technologies essential to using COTS parts in military environment. The goal is to show defense system decision-makers how to adapt to changing commercial processes and device operating characteristics. The effort includes developing validated reliability prediction tools, improving packaging and life cycle prediction of commercial application specific integrated circuits (ASICs), and improving access to commercial ASIC vendors.

The initiative will use pilot programs to demonstrate technology insertion in systems. These pilot demonstrations will ensure reliable application of commercial electronics in military systems, while documenting the cost savings of using COTS parts and the corporate obsolescence management approach.

Parts obsolescence management should be considered an important corporate function and demonstrating software tools and processes through these pilot programs will accelerate the transition of effective business practices and technology to industry. Past Air Force solutions to obsolescence management have shown a positive return on investment, but with the number of defense systems currently experiencing parts obsolescence, the electronics parts obsolescence initiative has the potential to deliver a 100 to 1 return on investment. Though this initiative is directed towards electronics, the results of these efforts can apply to nonelectronics obsolescence issues.

Casting Supplier Initiative Speeds Manufacturing Technology Improvements

The Engine Supplier Base Initiative (ESBI), also known as the Casting Supplier Initiative, is a major effort to identify, implement and deploy manufacturing technology that will improve the U.S. industrial base and enhance international competitiveness in the man-rated gas turbine engine industry.

The Air Force Research Laboratory is represented in this initiative by the Materials and Manufacturing Directorate's Manufacturing Technology Division (ManTech). The initiative is composed of many projects designed to enhance the productivity of gas turbine engine airfoil and structural casting products. These projects are being conducted at Precision Castparts Corporation (PCC) and Howmet Corporation.

The main objective of the ESBI is to reduce the cost of cast airfoil and large structural components for gas turbine engines. Four recent projects successfully completed by PCC as part of this initiative offer strong evidence that the ESBI program approach is significantly shortening the time to implement Air Force-sponsored ManTech improvements.

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Wax patterns used in investment castings influence product quality further downstream in the processing. The Wax Standardization Project replaced "old technology" waxes with new waxes with improved performance characteristics in an attempt to improve dimensional stability, pattern surface quality and dewaxability of molds. By balancing the requirements for the various characteristics needed for different parts, the number of waxes required was reduced from five to three. Equipment maintenance was reduced, improved surface quality caused a significant reduction in wax repair, and cost savings in excess of $130,000 were calculated for the trial parts alone. The new waxes significantly improved surface finish of the patterns and this translates into less finishing of waxes and castings and better first time yields. These waxes have been extended beyond the test set to approximately 70 additional parts and are being used on new parts.

Ceramic cores used in traditional airfoil castings go through a very labor-intensive and often inaccurate hand-finishing operation after firing to remove parting line flash and to add fine details. Computerized Numerical Control (CNC) had been used for limited machining of casting airflow features on cores but had not been extended over larger areas. The Finishing Reduction Process Project extended this CNC process to finish most of the core. This project accomplished its two primary objectives of showing that CNC techniques were capable of reducing finishing labor by 50 percent while improving dimensional accuracy significantly on critical features. As a result, new CNC enabled processes have been introduced into production at PCC-Airfoils foundries.

The Mold Improvement Project focused on the mold-making operation which impacts surface quality of castings and also influences product yield and repair costs of castings. In the particular instance involved, the castings were requiring excessive repair for rough surfaces. A detailed breakdown of the process was made, the needed process changes were developed on one part number, and these were extended over the total product line.

As much as one-third of the price of a structural casting is due to rework associated with the weld repair of defects in the casting. These defects are often due to the presence of flakes of ceramic shell that erode into the molten metal during pouring and to microporosity associated with solidification. PCC-Structurals developed a new shell system that will significantly reduce the amount of rework required for large structural turbine engine castings such as turbine rear and spoke frames, diffusers, tangential on-board injectors and combustor cases. The new shell incorporates an engineered formula for the ceramic slurry as well as many enhancements to the production process, which result in a shell will improved erosion resistance. Based on this success, all new parts and other select current production parts are being tooled to use the new shell.

The cost reductions achieved through product and process improvements and cycle time reductions are extremely important measures of the success of this initiative. These benefits hinge largely on advances, implementation, and if appropriate, multi-site deployment of manufacturing technology along proprietary lines. These projects are positive examples of what can be achieved by factory based execution and advanced planning. Sixty-five separate technical activities have been initiated in support of the ESBI at 12 Howmet and PCC sites.

ManTech Year 2000 Project Book Now Available

The latest issue of the book which describes the projects of the Manufacturing Technology Division is now in print. The **ManTech Year 2000 Project Book** was recently published and should be on its way to people who are on the mailing list for this Status Report. It will also be available soon on the Materials and Manufacturing Directorate website at: **http://www.afrl.af.mil**

Anyone not on the mailing list or who cannot access this homepage should contact the division's Technology Information Center, at (937) 256-0194, to obtain a copy.

END OF CONTRACT FORECAST

DATE	PROJECT TITLE CONTRACT NO.	PRIME CONTRACTOR	POINT OF CONTACT
November 1999	Conformable Multichip Assembly Technology F33615-98-C-5149	Epic Technologies Incorporated Woburn, MA	Charles Wagner (937) 904-4591
November 1999	Field Level Repair/Joining of Composite Structures F33615-97-C-5125	Foster-Miller Incorporated Waltham, MA	Joy Morrison (937) 904-4381
November 1999	Infrared Focal Plane Array/Flexible Manufacturing F33615-93-C-4320	Texas Instruments Incorporated Dallas, TX	Virginia McMillan (937) 904-4364
December 1999	Materials Process Design Web Site N/A	Imagination Engines Incorporated Saint Louis, MO	Steven LeClair (937) 255-8786
December 1999	Enhanced Pultruded Composite Materials F33615-96-C-5629	Rust College Holly Springs, MS	Frances Abrams (937) 904-4380
December 1999	Robust Design Computational System F33615-96-2-5618	Rockwell International Corporation Canoga Park, CA	Daniel Lewallen (937) 904-4343
December 1999	Behavior Analog Fault Modeling F33615-96-1-5603	University of Iowa Iowa City, IA	William Russell (937) 904-4583
December 1999	Titanium Matrix Composite Turbine Engine Component Consortium F33615-94-2-4439	United Technologies Corporation West Palm Beach, FL	Kevin Spitzer (937) 904-4599
December 1999	Simulation Assessment Validation Environments (SAVE) F33615-95-C-5538	Lockheed Martin Corporation Fort Worth, TX	James Poindexter (937) 904-4351
January 2000	Advanced Resin System for RTM/VARTM Processing F33615-99-C-5311	Applied Poleramic Incorporated Benicia, CA	Frances Abrams (937) 904-4380
January 2000	Advanced Resin System for RTM/VARTM Processing F33615-99-C-5308	Shade Incorporated Lincoln, NE	Frances Abrams (937) 904-4380
January 2000	WEBADE: The Web-Enabled Agent-Based Design Environment F33615-99-C-5903	Wizdom Systems Incorporated Naperville, IL	Steve Medeiros (937) 255-8787
January 2000	Web-Based Collaborative Environment with Knowledge Driven Agents F33615-99-C-5705	TechnoSoft Incorporated Cincinnati, OH	Steve Medeiros (937) 255-8787
January 2000	Intergation of On-Line Sensors with the CVD Fiber-Coating F33615-99-C-5210	Advanced Technology Materials Danbury, CT	John Jones (937) 255-8786
January 2000	An Adaptable Environment for Parts Obsolescence Management F33615-98-2-5148	The Analytical Sciences Corporation Reading, MA	Ronald Stogdill (937) 904-4350

End of Contract Forecast

DATE	PROJECT TITLE CONTRACT NO.	PRIME CONTRACTOR	POINT OF CONTACT
January 2000	Semi-Insulating (SI) Indium Phosphide (InP) Wafers F33733-97-C-1022	American Xtal Technology Fremont, CA	John Blevins (937) 255-3701
January 2000	Semi-Insulating (SI) Indium Phosphide (InP) Wafers F33733-97-C-1023	MA Com Incorporated Lowell, MA	John Blevins (937) 255-3701
January 2000	Flexible Environment for Conceptual Design F33615-96-C-5617	Rockwell International Corporation Palo Alto, CA	Daniel Lewallen (937) 904-4343
January 2000	Integrated Knowledge Environment - Integrated Product Management F33615-96-C-5109	Knowledge Base Engineering Incorporated Centerville, OH	David Judson (937) 904-4590
January 2000	MEREOS - A Product Definition Management System for Enterprise F33615-95-C-5519	Ontek Corporation Laguna Hills, CA	Daniel Lewallen (937) 904-4343
February 2000	Flow Optimized Repair Cycle (FORCE) F33615-99-C-5307	Southwest Research Institute San Antonio, TX	Laura Leising (937) 904-4388
February 2000	Memory Techniques for Software Design N/A	TechnoSoft Incorporated	Steven LeClair (937) 255-8786
February 2000	Acoustic Wave Inspection of SOI Substrates F33615-98-C-5111	IBIS Technology Corporation Danvers, MA	Donald Knapke (937) 904-4596
February 2000	Automated Data Acquisition for In-Situ Material Process Modeling F33615-97-C-5841	Infoscribe Technologies LTD Beavercreek, OH	John Jones (937) 255-8786
March 2000	Systems Engineering Using Key Characteristics F33615-98-C-5158	Schwalb Consulting Irvine, CA	George Orzel (937) 904-4338
March 2000	Interactive Simulation System for Design of Multi-Stage Manufacturing Processes F33615-98-C-5114	Austral Engineering Athens, OH	Garth Frazier (937) 255-8786
March 2000	Manufacturing Technology for Multifunctional Radomes F33615-93-C-4312	Lockheed Martin Corporation Palmdale, CA	Michael Urig (937) 904-4384
April 2000	Microwave Curing for Reversible Bonding of Composites F33615-98-C-5115	Aerotech Engineering & Research Co. Lawrence, KS	Frances Abrams (937) 904-4380
April 2000	Create a Process Analysis Tool Kit for Affordability Supporting the R&D Process F33615-97-C-5141	James Gregory Associates Pickerington, OH	David Judson (937) 904-4590

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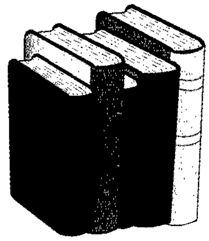
Reports



System Design Advisor Baseline Enhancement

Alog Number: 4219
Contract Number: F33615-96-2-5612
Technical Report Number:
AFRL-ML-WP-TR-1998-4181
Distribution: LIMITED

Wafer Level Known Good Die

Alog Number: 4222
Contract Number: MDA972-95-0001
Technical Report Number:
AFRL-ML-WP-TR-1998-4190
Distribution: LIMITED

Metal Forming Simulation

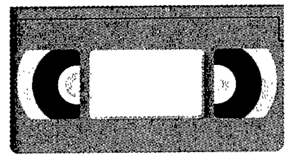
Alog Number: 4209
Contract Number: F33615-93-C-5318
Technical Report Number:
AFRL-ML-WP-TR-1998-4073
Distribution: LIMITED

Advanced Collaborative Open Resource Network (ACORN)

Alog Number: 4217
Contract Number: F33615-94-C-4450
Technical Report Number:
AFRL-ML-WP-TR-1998-4182
Distribution: LIMITED

Spare Part Production & Reprocurement Support System (SPARES)

Alog Number: 4218
Contract Number: F33615-90-C-5002
Technical Report Number:
AFRL-ML-WP-TR-1998-4176
Distribution: LIMITED



Videos

Robotic Plastic Bead Paint Stripping Demonstration

Alog Number: 114
Length: 3:22:07
Distribution: LIMITED

Automated Manufacturing Research Facility

Alog Number: 115
Length: 19:40
Distribution: LIMITED

Flexible Assembly Subsystems

Alog Number: 117
Length: 13:30
Distribution: LIMITED

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Winter 1999

The USAF Manufacturing Technology

PROGRAM STATUS REPORT

Winter 1999

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