RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE June 2001
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Materials and Electronics Technology PE 0602712E, R-1 #20

COST *(In Millions)*	FY 2000	FY2001	FY2002	FY2003	FY2004	FY2005	FY2006	FY2007	Cost To Complete	Total Cost
Total Program Element (PE) Cost	239.526	261.883	358.254	298.875	302.200	335.300	338.000	333.200	Continuing	Continuing
Materials Processing Technology MPT-01	129.488	147.455	175.531	145.017	136.985	169.744	172.444	173.684	Continuing	Continuing
Microelectronic Device Technologies MPT-02	83.248	92.550	92.229	59.858	70.215	80.556	85.556	85.556	Continuing	Continuing
Cryogenic Electronics MPT-06	26.790	21.878	9.994	0.000	0.000	0.000	0.000	0.000	0.000	N/A
Beyond Silicon MPT-08	0.000	0.000	80.500	94.000	95.000	85.000	80.000	73.960	Continuing	Continuing

(U) <u>Mission Description:</u>

(U) This program element is budgeted in the Applied Research Budget Activity because its objective is to develop technologies related to those materials, electronics, and biological systems that make possible a wide range of new military capabilities.

(U) The Materials Processing Technology project (MPT-0l) concentrates on the development of novel materials, materials processing techniques, mathematical models and fabrication strategies for advanced structural and functional materials and components which will lower the cost, increase the performance, and enable new missions for military platforms and systems as well as to increase human performance. Areas of concentration include exploitation of emerging processing approaches to tailor the properties and performance of structural materials and devices. This emphasis includes lightweight personnel protection, mesoscale machines for miniature devices, and ultra lightweight and amorphous materials. Approaches for materials risk reduction will also be explored. The project also focuses on smart materials, sensors and actuators, functional materials and devices, advanced magnetic materials for non-volatile, radiation hardened magnetic memories, and electroactive polymers for sensing and actuating. Other areas of concentration include new materials concepts for portable power, development of bio-interface materials and methods, energy harvesting concepts, and frequency agile materials based on ferrite and ferroelectric oxides. This project also includes a biological systems

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thrust. The unique characteristics of biologically derived functional materials and devices will be exploited through the understanding and control of the structure and chemistry of the interface between man-made and biotic materials. In addition, emulation and/or control of biological functionality (i.e., sensing and mobility) will be explored for enhanced DoD applications (sensor, robotic, etc.). Electronics Textiles will develop new technologies and manufacturing techniques for economic manufacture of large-area, flexible conformable information systems

(U) The Microelectronics Device Technologies project (MPT-02) develops advanced electronic and optoelectronic devices, semiconductor process tools and methodologies, materials for optoelectronics and infrared devices. Areas of emphasis include high-performance analog-to-digital converters, military optical processors, novel integrated optoelectronic devices and components, high temperature electronic devices, and high power electronics. Additionally, this project will focus on advanced microelectronics technologies such as digital radar receivers and acoustic-electronic components; optical signal processing of military RF waveforms; and high frequency/high power wide band gap semiconductor technologies. The project also includes a significant effort to develop advanced materials and device technology beyond the classical scaling limits of silicon device technology. A major initiative to explore the feasibility, design and development of information technology devices and systems utilizing non-silicon based materials and techniques has been initiated in FY 2001; these efforts transfer to project MPT-08 in FY 2002.

(U) The Cryogenic Electronics project (MPT-06) funds specific applications of thin-film electromagnetic materials in electronic devices and circuitry for military applications. Thin-film high temperature superconducting components packaged with cryogenic devices are being applied to radars, electronic warfare suites, and communications systems to enhance performance while reducing size and power requirements. Highly dependable and inexpensive cryocoolers (including thermoelectric coolers) are being developed for these applications, and expanded efforts will explore techniques to improve the performance of all solid-state thermoelectric coolers as well as the overall cryogenic performance in applications ranging from communications to computing.

(U) The Beyond Silicon project (MPT-08) will investigate the feasibility, design, and development of powerful information technology devices and systems using approaches to electronic device designs that extend beyond traditional Complementary Metal Oxide Semiconductor (CMOS) scaling, including non-silicon based materials technologies, to achieve low cost, reliable, fast, and secure computing, communication, and storage systems. This investigation is aimed at developing new capabilities; from promising directions in the design of information processing components using both inorganic and organic substrates, designs of components and systems leveraging quantum effects and chaos, and innovative approaches to computing designs incorporating these components for such applications as low cost seamless pervasive computing, ultra-fast computing, and sensing and actuation devices.

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(U) **Program Change Summary:** (*In Millions*)

	FY2000	FY 2001	FY 2002
Previous President's Budget	242.267	249.812	230.267
Current Budget	239.526	261.883	358.254

(U) **Change Summary Explanation:**

FY 2000 Decrease reflects program repricings and SBIR reprogramming.

FY 2001 Increase reflects the net effect of congressional adds for 3-D Microelectronics; Strategic Materials Manufacturing; Materials in Sensors and Actuator Technology; partially offset by the Section 8086 reduction and the government-wide rescission.

FY 2002 Increase reflects expansion of the Materials Processing Technology project (MPT-01) for the following areas: electronic textiles, warfighter performance enhancements, risk reduction for new materials, and new approaches for water purification in the field and deriving power from the environment. The Microelectronic Device Technologies project (MPT-02) includes new initiatives for mixed signal microsystems and high frequency/high power wide band gap semiconductor electronics. The PE also reflects increased emphasis of the Beyond Silicon project (MPT-08), a planned follow-on to the FY 2001 project previously budgeted in MPT-02.

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APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research					R-1 ITEM NOMENCLATURE Materials and Electronics Technology PE 0602712E, Project MPT-01					
COST *(In Millions)*	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	Cost to Complete	Total Cost
Materials Processing Technology MPT-01	129.488	147.455	175.531	145.017	136.985	169.744	172.444	173.684	Continuing	Continuing

(U) **Mission Description:**

(U) The major goal of this project is to develop novel materials, materials processing techniques, mathematical models and fabrication strategies for advanced structural and functional materials and components that will lower the cost, increase the performance, and/or enable new missions for military platforms and systems.

(U) One important area of concentration is the exploitation of emerging processing approaches to tailor the properties and performance of structural materials and devices. Thrusts in this area include new concepts for lightweight personnel protection as well as ultra lightweight materials, amorphous and multi-functional materials for lowering the weight and increasing the performance of aircraft, ground vehicles, and spacecraft structures. Approaches are also being developed for reducing the risk of using new materials in defense acquisitions and maintaining them in the field. Techniques are being established for assessing damage evolution and predicting future performance of the structural materials in defense platforms/systems through physics-based models and advanced interrogation tools.

(U) The mesoscopic size range ("sugar cube to fist") offers significant advantages in devices for defense. Efforts include mesopumps for battlefield sensors and mesocoolers for the individual soldier. Technology for the mask-less, direct-write of mesoscopic integrated conformal electronics will enable the three-dimensional integration of both active and passive components, significantly reducing the size, weight and cost of integrated electronics functions (circuits, batteries, antennae, etc.). Mesoscale materials technologies will also be employed in novel approaches for obtaining and purifying water in the field.

(U) Smart materials, sensors and actuators for the control of the aerodynamic and hydrodynamic behavior of military systems are being developed and demonstrated to increase performance and lower detectability of aircraft, helicopters, and submarines as well as to increase human performance. "Intrinsically smart" materials that provide self-diagnosis and/or self-repair will be developed as well. Machines are being developed that would increase soldiers physical capabilities augmenting speed, strength, and endurance. Advanced materials, devices, and structural architectures are being investigated that would allow military platforms to morph or change shape, thus adapting optimally to mission requirements.

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(U) Another major thrust is the development of functional materials and devices. This includes advanced magnetic materials for high sensitivity, magnetic field sensors; non-volatile, radiation hardened magnetic memories with very high density, short access time, infinite cycleability and low power; novel materials and device structures for high frequency acoustic imaging; and electroactive polymers for sensing, actuating, and analog processing. Frequency-agile materials based on ferrite and ferroelectric oxides are being developed for tuned filters, oscillators, and antennas. New permanent magnetic materials with significantly higher magnetic strength and higher operating temperature for motors, generators, flywheels, bearings, and actuators are also being explored. Unique fabrics that can change their porosity or display information will be investigated. Finally, engineered materials (metamaterials) are being developed that provide improvements in electromagnetic behavior across the complete array of defense applications.

(U) The unique characteristics of biologically inspired and biologically derived materials and devices will be exploited through the understanding, control, and emulation of the structure and chemistry of the interface between man-made and biotic materials, and hybrid bioelectronics that electronically control biological organisms or use biological intelligence for smart materials. The direct utilization of biological systems for the production of unique, bioderived materials will be investigated. Structure and function emulated from biological systems will result in new biomimetic systems that capture unique locomotion and sensing schemes. New techniques to determine structure and function of biomolecules and novel biomaterials to enhance the capabilities of the warfighter will be investigated..

(U) New materials and concepts for increasing the availability of portable power to the soldier are being investigated, as are approaches for deriving power from the environment for soldiers and sensors.

(U) Finally, Electronics Textiles program will develop new technologies and manufacturing techniques for economic manufacture of large-area, flexible conformable information systems. This will be achieved through the combination of: textile science and manufacturing technology; novel materials (polymers, piezo and electrostrictive ceramics, shape memory alloys, fiber optics, etc); microsystems, architecture and algorithm technologies. A new community of electronic, computer, material, and textile scientists from industry universities and government will be formed to support this revolutionary new field.

(U) <u>Program Accomplishments and Plans:</u>

(U) <u>FY 2000 Accomplishments:</u>

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- Structural Materials and Devices. ($ 20.761 Million)
  - Integrated material concepts and materials systems into ultra-lightweight armor providing 100 percent improvement in personnel protection for the soldier.
  - Developed analytical, experimental, and simulation technologies for predicting the cost, performance, and life of advanced materials, decreasing the risk of and accelerating the time for insertion of new materials in Defense acquisitions.
  - Investigated concepts for the use of multifunctional materials in Defense applications (e.g., blast protection, thermal control) based on successes in ultra-lightweight metals and other structural materials programs.
  - Developed approaches for rapid design, optimization and assembly of small structures based upon solid freeform and rapid prototyping technologies.

- Mesoscopic Structures and Devices. ($ 9.487 Million)
  - Demonstrated the operation of a mesoscopic pump array with flow rates of several liters/min. in approximately one cubic inch.
  - Built and tested an individual integrated mesoscopic cooler.
  - Demonstrated a mesoscopic vacuum pump.
  - Demonstrated the ability to directly write active and passive electronic materials and components at the mesoscale.

- Smart Materials and Actuators. ($ 25.000 Million)
  - Demonstrated improvements in aerodynamic performance through wind tunnel testing of wings with adaptive leading and trailing edge control surfaces.
  - Developed a "smart skin" for the reduction of self-noise and radiated noise in torpedoes.
  - Explored novel actuator schemes for enhancing the performance of soldiers or devices.
  - Demonstrated techniques to grow large (>3 cm) single crystals of relaxor piezoelectrics.
  - Demonstrated the performance of single crystal piezoelectrics in broadband ultrasonic imaging transducers.

- Functional Materials and Devices. ($ 43.904 Million)
  - Demonstrated very fast (<20 nsec access time), high density, radiation hardened magnetic memory circuits utilizing both giant magneto-resistance (GMR) multilayers and spin dependent tunneling devices; established understanding of the micromagnetics of magnetic domain rotation in these devices.

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- Demonstrated very small, low power, high sensitivity magnetic gradiometers for the localization and identification of small ferrous objects.
- Demonstrated permanent magnet materials with 50 percent higher magnetic strength (energy product) and the ability to preserve magnetic properties to temperatures over 500?C.
- Demonstrated a loss tangent less than 0.002 in hybrid ferroelectric/ferrite (meta-material) devices.
- Demonstrated a broadband 360-degree phase shifter with very low loss for antenna feed applications.
- Demonstrated polymeric actuators that emulate the mechanical response and performance of human muscles.
- Demonstrated green light-emitting diodes (LEDs) fabricated from electroactive polymers with a half-life >5,000 hours; demonstrated blue and red LEDs with >1,000 hours half-life.
- Selected appropriate polymeric materials with electronic characteristics for field-effect transistor (FET) development.
- Demonstrated the growth of AlGaSb-InAs thin-films on GaAs substrates using the lateral epitaxial overgrowth technique.
- Demonstrated lattice mismatched epitaxial growth of dislocation free compound semiconductors using strain-absorbing layers.

- Bioinspired Materials and Devices. ($ 2.400 Million)
  - Explored sensormotory and navigational control schemes for biological systems through microelectronic interfaces.
  - Evaluated chemical, visual and acoustic cues used by biological systems for controlled locomotion, behavior and distribution.

- Advanced Energy Technologies. ($ 15.436 Million)
  - Demonstrated and field tested compact portable power systems in soldier applications.
  - Developed high efficiency direct thermal to electric energy conversion devices (in the laboratory).
  - Demonstrated (in the laboratory) power generation from the environment capable of operating unattended ground sensors.
  - Investigated novel concepts for small-scale, near ambient temperature, chemical power generation.

- Materials in Sensors. ($ 9.500 Million)
  - Continued work in materials and processing, including investigation of novel polymer and inorganic sensor and sensor protection schemes.

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- Biodegradable Plastics. ($ 1.000 Million)
  - Initiated an effort to examine biodegradable plastics for Defense applications.

- Strategic Material Manufacturing. ($ 2.000 Million)
  - Continued the effort to develop new manufacturing approaches for cutting tools used for Defense strategic materials.

(U) <u>FY 2001 Plans:</u>

- Structural Materials and Devices. ($ 26.435 Million)
  - Demonstrate ultra-lightweight armor with 100 percent improvement over current materials and begin transition of manufacturing/design capabilities to the Army.
  - Demonstrate the use of multifunctional materials to provide significant improvement in the capabilities of defense systems by providing additional functions (e.g., self-healing, thermal control, blast protection, power) to load bearing structures.
  - Continue the optimization of analytical, experimental and simulation technologies for determining the properties and processing of advanced polycrystalline, nanocrystalline and amorphous materials.
  - Select specific material(s) of high value to a DoD system for demonstration of accelerated insertion concepts.

- Mesoscopic Structures and Devices. ($ 14.200 Million)
  - Demonstrate initial, one-dimensional mesoscopic gyroscope operation that has drift rates <1.0?/hr.
  - Demonstrate fully functional integrated mesoscopic coolers that exhibit a coefficient of performance >3.
  - Demonstrate that direct-write mesoscale active and passive components have functionality close to discrete surface mount components.
  - Demonstrate the ability to direct-write mesoscale passive components (resistors, capacitors) and antennas on conformal surfaces.
  - Explore energetic machines and devices that aid the soldier in urban terrain.

- Smart Materials and Actuators. ($ 25.800 Million)
  - Completed wind tunnel test verification of an active aircraft engine inlet enabling a 20 percent increase in aircraft mission radius compared to a conventional fixed geometry inlet design.

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- Complete water tunnel test of a subscale submarine propulsor with active control to reduce acoustic radiation levels.
- Explore techniques that use the intrinsic response of a material to its operating environment to provide diagnosis of the performance life of the material.
- Develop approaches for integrating actuators, power systems and control methods to affect lightweight, energy efficient actuators for enhancing the performance of soldiers or devices.
- Investigate artificial materials and membranes that can be integrated into controllable variable porosity fabric.
- Demonstrate methods to fabricate multilayer actuators made from single crystals of relaxor piezoelectrics.
- Demonstrate the performance of single crystal piezoelectrics in an advanced Navy sonar transducer.

• Functional Materials and Devices. ($ 41.212 Million)
  - Demonstrate a prototype, very high effective density (>16 Mbit), high speed (<10 nsec access time) magnetic memory circuit based on giant magneto-resistance (GMR) or spin-dependent tunneling utilizing very low power and low voltage (<2.5 volts).
  - Demonstrate a steerable, ferroelectric lens for phased array radar.
  - Demonstrate a conformal, frequency agile antenna that is 100 times cheaper than conventional technology.
  - Explore applications of meta-materials for advanced electromagnetic devices (e.g., antennas).
  - Demonstrate advantages of polymer-based actuators in specific Defense applications (e.g., robotics, sonar).
  - Demonstrate the use of electroactive polymers as thin-film spatial filters for quasi-real-time multispectral image analysis for enhancing target detectability.
  - Investigate various multi-chromal fabrics that can be integrated along with conventional fabrics and be used to display information to a soldier on the uniform.

• Bioinspired Materials and Devices. ($ 5.408 Million)
  - Identify candidates for advanced sensor systems that incorporate biologically inspired concepts including self-calibration, self-healing, variable temperature operation, functional responsiveness and mobility.
  - Construct prototype microelectronic interfaces for control of biological systems.

• Advanced Energy Technologies. ($ 16.900 Million)
  - Demonstrate energy harvesting from the environment for unattended sensor and soldier applications.

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- Demonstrate (in the laboratory) high efficiency direct thermal to electric energy conversion operating on a liquid hydrocarbon fuel.
- Develop specific approaches for small, chemical power generation that operates at near ambient temperatures.
- Investigate novel ultra-high energy density power source concepts.

- Bio:Info: Physical Systems Interface. ($ 5.000 Million)
  - Create new families of catalysts and pathways for synthesizing compounds and materials biomimetically.
  - Explore new architectural components and assembling principles of biological systems; develop new artificial matrices and assembling processes.
  - Develop new materials and matrices for sensing, actuation and computation via biologically inspired routes to material synthesis.

- Materials in Sensors. ($ 9.500 Million)
  - Continue work in materials and processing, including investigation of novel polymer and inorganic sensor and sensor protection schemes based on electroactive polymer and carbon nanotubes.

- Strategic Material Manufacturing. ($ 3.000 Million)
  - Continue the effort to develop new manufacturing approaches for cutting tools and other ceramics used for Defense applications.

(U) **<u>FY 2002 Plans:</u>**

- Structural Materials and Devices. ($ 32.500 Million)
  - Full demonstration of ultra-lightweight armor materials in a system with 100 percent improvement over currently fielded systems and complete transition to Army.
  - Identify models and mathematical techniques for capturing the physics of failure and behavior prediction in materials suitable for providing information on the degree of in-situ damage accumulation.
  - Demonstrate solutions to critical technical issues for the accelerated insertion of materials, quantifying potential payoff (time and resources) of each. Begin the integration of these technologies into a methodology that will allow designers to cut the insertion time of new materials by over 50 percent.

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- Quantify the performance of multifunctional structures that combine structure with additional functions, significantly reducing the parasitic weight of the structure in defense systems. Specific functions to be demonstrated include: self-healing, power generation, and self-sensing.
- Develop and verify models that predict bulk amorphous metal formation; describe the deformation behavior of structural amorphous metals. Use these models to produce bulk amorphous materials with superior properties as compared to crystalline materials, including increased fracture toughness and high strain rate behavior.
- Investigate novel, cost effective processing routes for structural materials of interest to Defense (e. g., Ti).

- Mesoscopic Structures and Devices. ($ 23.200 Million)
  - Demonstrate the ability to "dial-in" any passive component with at least 5 percent tolerances with direct-write electronics manufacturing tool.
  - Fabricate direct-write batteries on complex geometries.
  - Demonstrate two-dimensional patterning of two cell types with the associated microelectrode array using direct-write.
  - Fabricate high efficiency direct-write antennae on low-temperature substrates.
  - Investigate concepts for highly power-dense, portable mesoscale machines and devices that aid the soldier in urban terrain.
  - Evaluate concepts for obtaining water from non-traditional sources.
  - Model and evaluate concepts to desalt brackish water with low-energy.

- Smart Materials and Actuators. ($ 32.992 Million)
  - Demonstrate the utility of smart materials and adaptive structures in military platforms.
  - Complete flight test of a rotorcraft with blades containing integral actuators and flaps for control of noise and vibration.
  - Develop concepts that exploit smart materials to create new high power actuators for a variety of military platforms.
  - Demonstrate energy efficient electronics for smart actuator systems.
  - Demonstrate integrated power and actuation systems that exploit energy dense fuels.
  - Develop models that describe the dynamic performance required from actuators to augment soldiers in a variety of mission scenarios.
  - Explore systems architectures for enhancing soldier physical performance including lower extremities for locomotion augmentation and upper extremities for strength augmentation.

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- Demonstrate pilot production technology for piezocrystals in quantities and at cost suitable for prototype devices.
- Demonstrate, on laboratory scale, targeted Naval sonar device/system performance using piezocrystals.
- Investigate advantages and enabling capabilities created by allowing shape change to occur in military platforms.

• Functional Materials and Devices. ($ 43.030 Million)
- Demonstrate prototype frequency and phase agile antennas and filters for transition to radar and communication systems.
- Demonstrate embedded magnetoresistive non-volatile radiation hard memory for reconfigurable processors.
- Investigate the electronic capabilities (sensors, transistors, etc) of electronic polymers in Defense applications.
- Demonstrate use of electroactive polymers in color displays, including flat panel and real 3D displays.
- Demonstrate exchange-biased ferromagnetism in a bulk material.
- Develop processing approaches for low-cost manufacturing of high-performance printed optics (e.g., gradient index lenses).
- Demonstrate/validate "left-handed" wave propagation at microwave frequencies.
- Demonstrate low-power, compact, acoustic imaging beamformer technology with a large number of channels (>1024).
- Demonstrate 1.5 dimension acoustic imaging array technology with a large number of elements (>1024).
- Develop mathematical methodology for predicting macroscopic material characteristics from unit cell properties.

• Bioinspired and Bioderived Materials and Devices. ($ 14.251 Million)
- Demonstrate new capabilities in functionalizing magnetic nanoparticles for integration with biological hosts.
- Evaluate alternative biological energy sources for driving biomolecular motors.
- Explore soft materials (e.g., actuators, adhesives) in biological systems for potential Defense applications.
- Define new materials for coordinated appendage function in land and air platforms that utilize biomimetic principles of locomotion and actuation.
- Demonstrate biomimetic sensory prototypes that collect electromagnetic, olfactory and visual inputs.
- Identify genes that are responsible for stable biomaterials from organisms that survive environmental extremes.
- Explore multifunctional materials from organisms that survive environmental extremes and define design principles for biomimetic materials development.
- Explore new methods for determining structure and function of bio-molecules.
- Identify gene and gene related materials that are associated with stress reduction and extended performance.

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- Advanced Energy Technologies. ($ 20.558 Million)
  - Fully integrate and demonstrate energy harvesting technologies with military applications.
  - Explore novel approaches for power generation based on sonoluminescence and related technologies.
  - Fabricate and test new direct methanol membrane electrode assemblies based on materials breakthroughs in membranes and catalysts.
  - Design a second-generation portable direct methanol fuel cell with 50 percent higher performance than the first generation.
  - Demonstrate direct electrochemical oxidation of hydrocarbon fuels at moderate temperatures in a single cell solid oxide fuel cell suitable for a hand-held system.
  - Develop concepts for hand-held hydrocarbon-fueled portable power sources in the 20-watt power range for advanced soldier systems.
  - Demonstrate high performance thermoelectric or thermionic power generation and/or cooling devices for military and commercial applications.
  - Evaluate undersea energy sources for in-situ harvesting, processing, and use in undersea platforms and vehicles.

- Electronic Textiles. ($ 9.000 Million)
  - Design, fabricate and test novel fiber based active and passive components.
  - Weave, knit and/or braid components into test structures and develop electrical interconnection and physical mounting schemes
  - Analyze performance characteristics of the components, structural and subsystem integrity including routing, buss structures and interconnection schemes to demonstrate the feasibility of incorporating the components into woven circuitry.
  - Evaluate requirements and implementation characteristics for large area applications comprised of novel materials and micro-systems.

(U) Other Program Funding Summary Cost:

- Not Applicable.

(U) Schedule Profile:

- Not Applicable.

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APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research					R-1 ITEM NOMENCLATURE Materials and Electronics Technology PE 0602712E, Project MPT-02					
COST *(In Millions)*	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	Cost to Complete	Total Cost
Microelectronic Device Technologies MPT-02	83.248	92.550	92.229	59.858	70.215	80.556	85.556	85.556	Continuing	Continuing

(U) <u>Mission Description:</u>

(U) This project develops advanced electronic and optoelectronic devices, semiconductor process tools and methodologies, materials for optoelectronics, and infrared devices. Areas of emphasis include high performance Analog-to-Digital (A/D) converters, military optical processors, novel integrated optoelectronic devices and components, photonics technologies, high temperature electronic devices, and high power electronics. In addition, this project develops and demonstrates advanced microelectronics technology for DoD critical needs including digital radar receivers and acoustic-electronic components. Technologies developed in this project are performance driven and exceed commercial capabilities.

(U) The phenomenal progress in current electronics and computer chips will face the fundamental limits of silicon technology in the early 21st century, a barrier that must be overcome in order for progress to continue. The Beyond Silicon initiative explores alternatives to silicon based electronics in the areas of new electronic devices, new architectures to use them, new software to program the systems, and new methods to fabricate the chips. Approaches include nanotechnology, nanoelectronics, molecular electronics, spin-based electronics, quantum computing, new circuit designs, and other approaches to electronic device designs that extend beyond traditional Complementary Metal Oxide Semiconductor (CMOS) scaling to non-silicon based materials technologies. Given DoD emphasis in this area, the Beyond Silicon programs are funded in a new project, MPT-08, within this program element in FY 2002 and beyond.

(U) The Reconfigurable Aperture (RECAP) program provides revolutionary antenna technology for future military needs in high capacity communication and sensors. Technologies being advanced include; artificial magnetic conductors, RF MEM switches, photonic band gap ground planes, high-density multi-layer interconnects, and fragmented antennas. These will be integrated into applications demonstrations that will show substantial new capabilities. These capabilities include multi-beam arrays for satellite-based communication links, which geometrically reconfigure to provide hemispherical coverage. Applications such as Future Combat System need such battlefield links. Techniques being developed will also allow soldier communication with wearable antennas and have application to Personal Communications System (PCS) in the commercial market. Wideband antenna technologies will allow simultaneous Electronic Support Measures (ESM) and radar functions from a single aperture. Finally, this technology will also allow the number of antennas on aircraft and ships to be reduced by a factor of 5-10.

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(U) The Acoustic Micro-Sensors program goal is to demonstrate a miniature acoustic sensor system based on MEMS transducers and advanced non-linear signal processing techniques for three-dimensional detection, capture, and tracking of sound sources in noisy environments with optimum sensitivity. The Materials Integration on Silicon program will demonstrate technologies and applications of direct integration of advanced materials and devices, such as high-speed logic and RF transistors with semiconductor integrated circuits. The Photonic Wavelength and Spatial Signal Processing (Photonic WASSP) program goal is to develop photonic device technologies that allow the dynamic manipulation of both the spectral and spatial attributes of light for sensing, image pre-processing, bio-chemical sensing and general spectral signature analysis.

(U) Included within this project are several new initiatives starting in FY 2002 – Analog Optical Signal Processing (AOSP) will significantly enhance the performance of, and enable entirely new capabilities/architectures for, tactical and strategic RF systems by expanding the dynamic range-bandwith and time-bandwidth limits by a factor of 1000 through the introduction of analog optical signal processing components into the system front ends.

(U) Technology for Efficient, Agile Mixed Signal Microsystems (TEAM) is the fabrication of high performance mixed signal systems-on-chip (SoC) that will be the core of the embedded electronics in new platforms that are constrained by size and on-board power.

(U) The Chip Scale Atomic Clock will demonstrate a low-power chip scale atomic-resonance-based time-reference unit with stability better than 1 part per billion in 1 second. Application examples of this program will include the time reference unit used for GPS signal locking.

(U) High Frequency Wide Band Gap Semiconductor Electronics Technology will develop wide band gap semiconductor technology and demonstrate high performance, cost effective high power electronic devices that exploit the unique properties of wide band gap semiconductors. This program will develop low defect epitaxial films, high yield fabrication processes, and device structures for integrated electronic devices for emitting and detecting high power radio frequency/microwave radiation, and high power delivery and control.

(U) An initiative in High Power Wide Band Gap Semiconductor Electronics Technology will develop components and electronic integration technologies for high power; high frequency microsystem applications based on wide band gap semiconductors.

(U) <u>Program Accomplishments and Plans:</u>

(U) <u>FY 2000 Accomplishments:</u>

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APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Materials and Electronics Technology PE 0602712E, Project MPT-02

- Reconfigurable Aperture (RECAP). ($ 8.327 Million)
  - Completed technology investigation, preliminary design and limited bread boarding of wideband antenna components.
  - Distributed Picasso modeling beta code to RECAP contractors to initiate user interaction and obtain requirements for next version.
  - Analyzed, modeled, and measured key technologies such as MEM switches, multi-layer substrates and configurable radiators.
  - Completed trade-offs of radiating elements and ground plane configurations.
  - Used genetic algorithms to develop a fragmented ground plane to meet 8:1 decade bandwidth requirements.
  - Completed Ultra thin lightweight designs of low frequency artificial magnetic conductors and progressed in material testing.

- Digital Receiver Technology. ($ 3.887 Million)
  - Demonstrated a very high performance analog-to-digital (A/D) converter with 14 effective bits, 60 MHz instantaneous bandwidth, and >86 dB spurious free dynamic range (SFDR) with potential for multiple military applications.

- High Powered Solid State Electronics. ($ 2.934 Million)
  - Demonstrated high-current density (>100 A/cm^2) 2500-V class switch from silicon carbide (SiC); demonstrated 2500-V rectifier diode from gallium-nitride (GaN).

- Sonoelectronics. ($ 6.561 Million)
  - Completed sonoelectronic camera prototype fabrication; carried out laboratory characterization and test-tank evaluation.
  - Demonstrated the lab-proven imager in a very-shallow-water (VSW) field setting.

- Acoustic Micro-Sensors. ($ 2.555 Million)
  - Initiated air-coupled acoustic micro sensor project to demonstrate chip-scale sensor system capable to locate, track and identify a sound source or a voice in a noisy environment.

- HERETIC. ($ 9.438 Million)
  - Completed integration of Heterostructure Integrated Thermoelectronic (HIT) device arrays with bias and control circuitry on GaAs substrates; completed integration of micro-jet, micro-nozzle or micro-thermionic arrays with bias and control circuitry over Si substrates.

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- Advanced Microelectronics (AME). ($ 9.444 Million)
  - Demonstrated circuit and modeling of a full-scale system (e.g. image processing system) featuring terascaled-compatible devices and associate technology far beyond the existing industry roadmap.

- VLSI Photonics. ($ 18.545 Million)
  - Developed VLSI heterogeneous integration technology and integrate micro-opto-mechanical components with VLSI chips; developed system-level CAD tools.

- Materials Integration on Silicon. ($ 10.875 Million)
  - Initiated an integration program that develops a tool kit of materials and processes for integration of multiple materials onto a single silicon substrate.

- Photonic Wavelength and Spatial Signal Processing (Photonic WASSP). ($ 8.682 Million)
  - Initiated program to begin a major development in photonics, using both wavelengths – wavelength optics – as well as spatial attributes of light – bulk optics.

- 3-D Microelectronics. ($ 2.000 Million)
  - Continued development of key technologies behind a packaging concept using a stacked MCM approach to reduce interconnect length and increase physical connectivity between layers of electronics.

(U) <u>FY 2001 Plans:</u>

- Reconfigurable Aperture (RECAP). ($ 14.246 Million)
  - Demonstrate fabrication and reconfigurability of fragmented antennas for wideband communication.
  - Construct wearable antennas with zero phase ground planes, switchable elements, and polyimide materials for low cost component fabrication.

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- Continue successful core technologies and initiate efforts for integrated system application demonstrations concentrating on battlefield communications through low profile satellite communications and wearable low frequency communication antennas, and space/air/surface/submarine-based electronic intelligence (ELINT), signal intelligence (SIGINT) and radar systems.
- Validate RENOIR modeling and simulation tool with experimental data.
- Demonstrate dual polarization conformal wideband antenna technology.

• Acoustic Micro-Sensors. ($ 5.911 Million)
  - Demonstrate MEMs-based 3-D acoustic transducers and/or transducer arrays with superior sensitivity, signal-to-noise ratio, and bandwidth that are current state-of-the-practice.

• HERETIC. ($ 7.884 Million)
  - Demonstrate HIT devices on GaAs having better specific heat-removal capacity as the best commercial-off-the-shelf TE coolers; demonstrate micro-jets, micro-nozzles, or micro-thermionic emitters on Si having much better heat-removal capacity as the best convective air or liquid cooling systems.

• 3-D Microelectronics. ($ 1.986 Million)
  - Continue development of key technologies behind a packaging concept that uses a stacked MCM approach to reduce interconnect length and increase physical connectivity between layers of electronics.

• VLSI Photonics. ($ 7.859 Million)
  - Demonstrate Synthetic Aperture Radar (SAR) processor using VLSI Photonics technologies; showcase reconfigurable cross-connect switching. Demonstrate rapid parallel access to memory using optical interconnection.

• Materials Integration on Silicon. ($ 8.959 Million)
  - Continue integration of new material and processes into a single silicon substrate that will drive system performance.
  - Demonstrate logic circuits and power amplifiers on silicon substrates.

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- Photonic Wavelength and Spatial Signal Processing (Photonic WASSP). ($ 10.843 Million)
  - Continue component development, integration, algorithms, architectures and sub-system functionality demonstrations.
  - Demonstrate emitters and detectors in the spectral band 350-500 nm.

- Beyond Silicon - Antimonide Based Compound Semiconductors (ABCS). ($ 7.944 Million)
  - Demonstrate non-silicon based transistors technologies based on low band gap materials capable of multi-gigahertz operation at bias voltages < 1 volt.
  - Demonstrate nanostructured materials for quantum based electronic and optoelectronic device applications.
  - Demonstrate a three terminal resonant tunneling device operating at several hundred GHz.

- Beyond Silicon - Integrated Mixed Signal (A/D) and Electronic/Photonic Systems (NeoCAD). ($ 3.974 Million)
  - Develop fast algorithms for non-linear analysis of mixed signal systems – analog and photonic devices.
  - Extend algorithm methods to non-linear problems.

- Beyond Silicon - Polymorphous Computing Architecture (PCA). ($ 7.944 Million)
  - Initiate Polymorphous Computing Architecture (PCA) research efforts.
  - Identify and select DoD reactive in-mission and multi-mission applications of interest.
  - Develop PCA hardware abstraction models and stable architecture interfaces.
  - Identify multi-dimensional reactive computing, communication, memory, verification and optimization techniques.

- Beyond Silicon - Quantum Information Science and Technology (QuIST). ($ 15.000 Million)
  - Investigate techniques for building reliable scaleable quantum bits out of devices potentially subject to failures and decoherence, via efficient fault tolerant mechanisms.
  - Initiate investigation of new problem classes, beyond factorization and unsorted search, which are solvable with dramatic efficiency on a quantum computer.
  - Initiate theory and algorithm research for secure quantum communication; investigate techniques amenable for implementation in existing networks and fiber optic backbone.

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(U) **FY 2002 Plans:**

- Acoustic Micro-Sensors. ($ 4.753 Million)
  - Integrate MEMs-based 3-D acoustic transducer array with read-out electronics.
  - Demonstrate acoustic microsystem for remote detection and tracking of voices or sound sources in noisy outdoor environments.

- Materials Integration on Silicon. ($ 7.604 Million)
  - Complete technology development and demonstrations.
  - Demonstrate heterogenous fabrication processes and technologies for integrating disparate semiconductor devices and materials.
  - Complete fabrication of composite microcircuits that demonstrate advanced capabilities through the incorporation of devices from multiple materials.
  - Evaluate feasibility of flexible, mobile, high resolution display components for wireless communications.

- Photonic Wavelength and Spatial Signal Processing (Photonic WASSP). ($ 11.406 Million)
  - Develop micro-machined optical elements for spectral bands 300 to 500 nm and 3 to 15 microns.
  - Initiate integration of the passive elements into beam conditioners.

- Reconfigurable Aperture (RECAP). ($ 8.120 Million)
  - Integrate and assemble component technologies into single sub arrays, which replace multiple antenna systems.
  - Develop and demonstrate low cost fabrication processes to support technology transition.
  - Initiate demonstrations with application to low band and satellite communications, ELINT/SIGINT, and radar.
  - Validated modeling and simulation software will be completed.

- Analog Optical Signal Processing (AOSP). ($ 8.346 Million)
  - Perform analysis of analog signal characteristics of military RF systems.
  - Create, model and simulate new photonic-based optical signal processing techniques of ultra-high bandwidth analog signals.
  - Evaluate anticipated system performance improvements due to novel signal processing algorithms and determine the resulting photonic component performance requirements.

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- Test signal processing techniques of analog signals.
- Evaluate signal-processing algorithms.
- Evaluate photonic component performance requirements.

• Technology for Efficient Agile Mixed Signal Microsystems (TEAM). ($ 6.000 Million)
- Develop and demonstrate nanoscale silicon-based structures and associated fabrication processes to achieve high-speed analog/RF functions.
- Optimize device and process parameters for high speed mixed signal circuits.
- Produce test devices for analog/RF parameter extraction.
- Demonstrate CMOS compatible fabrication processes that can yield integration levels > 10,000 nanoscale devices.

• Chip Scale Atomic Clock. ($ 5.000 Million)
- Demonstrate feasibility and theoretical limits of miniaturization of cesium clock.

• High Frequency Wide Band Gap Semiconductor Electronics Technology. ($ 11.000 Million)
- Demonstrate uniform growth of epitaxial wide band gap semiconductor films on substrates.
- Develop bulk and surface process technologies for reducing, or mitigating crystallographic defects in wide band gap materials.
- Develop coupled electro thermal and physical models for design of high power device structures.

• High Power Wide Band Gap Semiconductor Electronics Technology. ($30.000 Million)
- Develop electro thermal models for analyzing high power high frequency enclosures.
- Develop thermal management technologies for high power high temperature devices.
- Identify military system requirements and platform heat-management constraints.
- Develop electro thermal models for analyzing high power, high frequency enclosures.
- Evaluate maximum thermal load capacity at the integrated circuit level.
- Demonstrate effective high temperature adhesives and high power interconnect techniques.
- Develop high frequency, high temperature passive components for integration with high power devices.
- Develop thermal management concept for high power, high temperature devices.

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(U) **Other Program Funding Summary Cost:**

- Not Applicable.

(U) **Schedule Profile:**

- Not Applicable.

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APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research					R-1 ITEM NOMENCLATURE Materials and Electronics Technology PE 0602712E, Project MPT-06					
COST *(In Millions)*	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	Cost to Complete	Total Cost
Cryogenic Electronics MPT-06	26.790	21.878	9.994	0.000	0.000	0.000	0.000	0.000	0.000	N/A

(U) Mission Description:

(U) Thin-film electromagnetic materials have reached a stage of development where specific applications can be identified in electronic devices and circuitry for military systems. Films may be deposited and patterned to form electromagnetic components in ways that are similar to, and compatible with, the processes of conventional semiconductor manufacturing. Such electromagnetic components, as well as complementary metal oxide semiconductors (CMOS), work best at lower temperatures, so that cryogenic packaging generally will be required for optimum performance. Thin-film high temperature superconducting (HTS) components packaged with cryogenic devices are being applied to radars, electronic warfare suites, and communications systems to enhance performance by more than an order of magnitude while reducing size and power requirements. Particular demonstrations include detection and geolocation of targets of high interest based upon low-level characteristic emissions and communications receivers with greater immunity to interference. Highly dependable and inexpensive cryocoolers are also being developed for these applications. These latter development efforts include the exploration of techniques to improve the performance of solid-state thermoelectric materials and devices in applications ranging from communications to power generation. The project concludes in FY 2002.

(U) Program Accomplishments and Plans:

(U) FY 2000 Accomplishments:

- Cryogenic Technologies. ($ 22.463 Million)
  - Developed devices and components, based upon superconducting and other electromagnetic materials that in a cryogenic environment would provide a 5-10 times-range improvement over conventional means for detection of low-level signals.
  - Completed adaptation of cryocoolers in microelectronics packages for communications transceivers.
  - Expanded efforts in mixed-mode electronics technology development to include tunable high temperature superconducting filters that preserve high-Q, with 10 percent tunability.

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- Thermoelectric Materials and Devices. ($ 4.327 Million)
  - Demonstrated thermoelectric cooling materials that can achieve 100°C cooling in two stages or less.
  - Demonstrated a thermoelectric converter with a factor of two improvement in power generation per unit size.

(U) <u>FY 2001 Plans:</u>

- Totally Agile Sensor Systems (TASS). ($ 21.878 Million)
  - Fabricate a cryogenic module, operating as a front-end pre-selector, to enhance the sensitivity of a receiver to detect low-level emitters in the presence of multiple interferors.
  - Design a complete cryogenic receiver module, incorporating tunable high temperature superconducting (HTS) antenna/pre-selector and digital microelectronics (with HTS embedded passives), displaying unsurpassed sensitivity and interference rejection.

(U) <u>FY 2002 Plans:</u>

- Totally Agile Sensor Systems (TASS). ($ 9.994 Million)
  - Incorporate agile front-end pre-selector modules on aircraft and ships, utilizing tunable high-Q HTS filters.
  - Demonstrate totally agile sensor systems with 10X SIGINT and COMINT capability.
  - Fabricate Thermoelectric (TE) modules that can be integrated with receiver front ends to provide cooling and/or thermal management as required for enhanced performance.

(U) <u>Other Program Funding Summary Cost:</u>

- Not Applicable.

(U) <u>Schedule Profile:</u>

- Not Applicable.

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APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research					**R-1 ITEM NOMENCLATURE** Materials and Electronics Technology PE 0602712E, Project MPT-08					
COST *(In Millions)*	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	Cost to Complete	Total Cost
Beyond Silicon MPT-08	0.000	0.000	80.500	94.000	95.000	85.000	80.000	73.960	Continuing	Continuing

(U) <u>Mission Description:</u>

(U) The phenomenal progress in current electronics and computer chips will face the fundamental limits of silicon technology in the early 21st century, a barrier that must be overcome in order for progress to continue. The Beyond Silicon project will explore alternatives to silicon based electronics in the areas of new electronic devices, new architectures to use them, new software to program the systems, and new methods to fabricate the chips. Approaches include nanotechnology, nanoelectronics, molecular electronics, spin-based electronics, quantum computing, new circuit architectures optimizing these new devices, and new computer and electronic systems architectures.

(U) The Beyond Silicon project will investigate the feasibility, design, and development of powerful information technology devices and systems using approaches to electronic device designs that extend beyond traditional Complementary Metal Oxide Semiconductor (CMOS) scaling, including non-silicon based materials technologies, to achieve low cost, reliable, fast, and secure computing, communication, and storage systems. This investigation is aimed at developing new capabilities; from promising directions in the design of information processing components using both inorganic and organic substrates, designs of components and systems leveraging quantum effects and chaos, and innovative approaches to computing designs incorporating these components for such applications as low cost seamless pervasive computing, ultra-fast computing, and sensing and actuation devices. The programs within this project were initially budgeted in PE 0601101E, Project MS-01 and PE 0602712E, Project MPT-02 in FY 2001.

(U) The Quantum Information Science and Technology (QuIST) program will explore all facets of the research necessary to create a new technology based on quantum information science. Research in this area has the ultimate goal of demonstrating the potentially significant advantages of quantum mechanical effects in communication and computing. Research will include the formulation of new algorithms and protocols for ultra-secure communications, ultra-precise metrology, information-bandwidth enhancements, the limits of quantum computation for speedups over classical computation, and computational applications for which quantum computation offers significant advantage over known classical equivalents. Concurrently with these theoretical advances, QuIST will develop the component technology for secure quantum

* Funding for Beyond Silicon programs funded in PE 0601101E and PE 0602712E in FY 2001 totaled: $44.2 million.

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communication and quantum computation including the development of robust megahertz rate single photon sources and detectors, practical implementations of single and multiple quantum bit logic gates, quantum memory, and systems level constructs such as quantum repeaters. Theoretical and hardware developments will be integrated into demonstrations that may include scalable assemblies of quantum logic and memory, quantum teleportation-based communication, coherent optic quantum communication, ultra-precise clock synchronization and ultra-secure communication over large distances (100 km).

(U) The Polymorphous Computing Architectures program will develop a revolutionary approach to the implementation of embedded computing systems to support reactive multi-mission, multi-sensor, and in-flight retargetable missions and reduce payload adaptation, optimization, and verification from years to days to minutes. The program breaks the current development approach of hardware first and software last by moving beyond conventional silicon to flexible polymorphous computing systems. The key efforts are: 1) define critical reactive computing requirements and critical micro-architectural features; 2) explore, develop and prototype reactive polymorphous computing concepts; 3) explore, develop and prototype multi-dimensional verification and validation techniques for dynamic reactive missions; and 4) provide early experimental testbeds and prototype polymorphous computing systems.

(U) Included within this project is a program to develop low power high frequency electronics circuits and infrared (IR) sources based on the Antimonide family of compound semiconductors (ABCS). Specific IR source goals include operating above thermoelectric cooled temperatures and >10% efficiency with continuous wave (cw) in the Mid-Wave Infrared (MWIR) and single mode cw operation in the Long-Wave Infrared (LWIR).

(U) The Integrated Mixed Signal (A/D) and Electronic/Photonic Systems (NeoCAD) program will develop and demonstrate innovative approaches to Computer Aided Design (CAD) of Mixed Signal (Analog/Digital) and Mixed Electronic/Photonic systems. The goal is to enable the design and prototyping of ultra complex microsystems with a high degree of integration and complexity for both military and commercial applications.

(U) This project continues and expands research in molecular electronics (Moletronics) initially funded in Basic Research (6.1) to demonstrate the integration of multiple molecules, nanotubes, nano-wires, etc., into scalable, functional devices that are interconnected to the outside world with the potential to provide low power, a wide range of operating temperatures and much greater density. This research will also demonstrate the scalability of molecular scale electronics to circuits containing 10^{11} elements and for densities equivalent to $10^{11}/cm^2$ and show that hierarchical self-assembly processes can be employed to build the molecular circuits.

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(U) Program Accomplishments and Plans:

(U) FY 2000 Accomplishments:

- Not Applicable.

(U) FY 2001 Plans:

- Initial funding for the following Beyond Silicon programs is contained in this PE under Project MPT-02:
  - Quantum Information Science and Technology. ($ 15.000 Million)
  - Polymorphous Computing Architectures. ($ 7.944 Million)
  - Antimonide Based Compound Semiconductors. ($ 7.944 Million)
  - Integrated Mixed Signal (A/D) and Electronic/Photonic Systems. ($ 3.974 Million)

- Initial funding for Moletronics is contained in PE 0601101E, Project MS-01. ($ 9.300 Million)

(U) FY 2002 Plans:

- Quantum Information Science and Technology (QuIST). ($ 22.500 Million)
  - Investigate alternative designs and devices for low overhead fault tolerant communication and computation including solid state, quantum bit (qubit) memory and reliable generation of entangled qubits.
  - Demonstrate robust single photon sources and detectors.
  - Determine quantum architecture and design solutions for problems such as graph isomorphism, imaging, and signal processing.
  - Investigate alternative protocols for secure quantum communication, quantum complexity, and control.
  - Explore designs that can be potentially implemented in existing fiber plants and free space, to include high-energy coherent state mechanisms, and polarization compensation.

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- Polymorphous Computing Architectures. ($ 15.000 Million)
  - Characterize and perform functional decomposition of pivotal reactive system algorithms and computing functions.
  - Develop a representative scalable benchmark suite.
  - Develop and evaluate initial polymorphous computing architecture concepts.
  - Develop multi-dimensional reactive computing optimization, verification techniques.
  - Implement early prototyping of reactive concepts, software services.

- Antimonide Based Compound Semiconductors (ABCS). ($ 12.000 Million)
  - Substrate Technology. Accelerate recent breakthroughs in lateral epitaxial overgrowth and thin film delaminating and rebonding to develop a source for ABCS substrates with essentially any desired thermal and/or electronic property.
  - Electronics Integration. Raise levels through a series of demonstrations of analog, digital or mixed signal circuits with increasing device count which have beyond state-of-the-art performance in terms of frequency of operation and low power consumption.
  - Demonstrate robust semi-insulating ABCS substrate material.

- Integrated Mixed Signal (A/D) and Electronic/Photonic Systems (NeoCAD). ($ 12.000 Million)
  - Develop Model Order Reduction methods (for analog and photonic devices) to enable the creation of behavioral models.
  - Develop and demonstrate top-down design capabilities for analog, mixed signal and mixed electronic/photonic systems that match the efficiency currently achieved with digital designs.
  - Develop fast solvers for analog and photonic devices; perform non-linear model order reduction, develop extraction tools, synthesis and layout capabilities for mixed signal and mixed electronic/photonic circuits, develop interfaces with existing digital tools to enable co-simulation.

- Moletronics. ($ 19.000 Million)
  - Characterize and optimize molecular-based devices such as switches, multi-state molecules and molecules exhibiting highly non-linear characteristics such as negative differential resistance.
  - Demonstrate that nano-wires have conductivities near that of bulk metal.
  - Quantify the defect-tolerance required for a molecular-based computer to still function.

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(U) Other Program Funding Summary Cost:

- Not Applicable.

(U) Schedule Profile:

- Not Applicable.