| Exhibit R-2, RDT&E Budget Item Justification: PB 2012 Defense Advanced Research Projects Agency | DATE: February 2011 |
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| APPROPRIATION/BUDGET ACTIVITY<br>0400: *Research, Development, Test & Evaluation, Defense-Wide*<br>BA 3: *Advanced Technology Development (ATD)* | R-1 ITEM NOMENCLATURE<br>PE 0603739E: *ADVANCED ELECTRONICS TECHNOLOGIES* |

| COST ($ in Millions) | FY 2010 | FY 2011 | FY 2012 Base | FY 2012 OCO | FY 2012 Total | FY 2013 | FY 2014 | FY 2015 | FY 2016 | Cost To Complete | Total Cost |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Program Element | 192.611 | 197.098 | 160.286 | - | 160.286 | 111.499 | 114.843 | 124.903 | 123.003 | Continuing | Continuing |
| MT-07: *CENTERS OF EXCELLENCE* | 7.000 | - | - | - | - | - | - | - | - | Continuing | Continuing |
| MT-12: *MEMS AND INTEGRATED MICROSYSTEMS TECHNOLOGY* | 72.301 | 85.835 | 70.053 | - | 70.053 | 44.466 | 44.355 | 46.642 | 46.642 | Continuing | Continuing |
| MT-15: *MIXED TECHNOLOGY INTEGRATION* | 113.310 | 111.263 | 90.233 | - | 90.233 | 67.033 | 70.488 | 78.261 | 76.361 | Continuing | Continuing |

**A. Mission Description and Budget Item Justification**

The Advanced Electronics Technology program element is budgeted in the Advanced Technology Development Budget Activity because it seeks to design and demonstrate state-of-the-art manufacturing and processing technologies for the production of various electronics and microelectronic devices, sensor systems, actuators and gear drives that have military applications and potential commercial utility. Introduction of advanced product design capability and flexible, scalable manufacturing techniques will enable the commercial sector to rapidly and cost-effectively satisfy military requirements.

The MicroElectroMechanical Systems (MEMS) and Integrated Microsystems Technology project is a broad, cross-disciplinary initiative to merge computation and power generation with sensing and actuation to realize a new technology for both perceiving and controlling weapons systems and battlefield environments. MEMS applies the advantages of miniaturization, multiple components and integrated microelectronics to the design and construction of integrated electromechanical and electro-chemical-mechanical systems to address issues ranging from the scaling of devices and physical forces to new organization and control strategies for distributed, high-density arrays of sensor and actuator elements. The project will also address thermal management, navigation and positioning technology challenges.

The goal of the Mixed Technology Integration project is to leverage advanced microelectronics manufacturing infrastructure and DARPA component technologies developed in other projects to produce mixed-technology microsystems. These 'wristwatch size', low-cost, lightweight and low power microsystems will improve the battlefield awareness and security of the warfighter and the operational performance of military platforms. The chip assembly and packaging processes currently in use produce a high cost, high power, large volume and lower performance system. This program is focused on the monolithic integration of mixed technologies to form batch-fabricated, mixed technology microsystems 'on-a-single-chip' or an integrated and interconnected 'stack-of-chips'. The ability to integrate mixed technologies onto a single substrate will increase performance and reliability, while driving down size, weight, volume and cost.

The Centers of Excellence project provided funding to finance the demonstration, training and deployment of advanced manufacturing technology at Marshall University.

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| B. Program Change Summary ($ in Millions) | FY 2010 | FY 2011 | FY 2012 Base | FY 2012 OCO | FY 2012 Total |
|---|---|---|---|---|---|
| Previous President's Budget | 194.094 | 197.098 | 151.274 | - | 151.274 |
| Current President's Budget | 192.611 | 197.098 | 160.286 | - | 160.286 |
| Total Adjustments | -1.483 | - | 9.012 | - | 9.012 |
| • Congressional General Reductions | | - | | | |
| • Congressional Directed Reductions | | - | | | |
| • Congressional Rescissions | - | - | | | |
| • Congressional Adds | | - | | | |
| • Congressional Directed Transfers | | - | | | |
| • Reprogrammings | 3.665 | - | | | |
| • SBIR/STTR Transfer | -5.148 | - | | | |
| • TotalOtherAdjustments | - | - | 9.012 | - | 9.012 |

| Congressional Add Details ($ in Millions, and Includes General Reductions) | FY 2010 | FY 2011 |
|---|---|---|
| **Project:** MT-07: *CENTERS OF EXCELLENCE* | | |
| Congressional Add: *Advanced Flexible Manufacturing* | 7.000 | - |
| Congressional Add Subtotals for Project: MT-07 | 7.000 | - |
| Congressional Add Totals for all Projects | 7.000 | - |

**Change Summary Explanation**

FY 2010: Decrease reflects internal below threshold reprogrammings and the SBIR/STTR transfer.

FY 2012: Increase reflects repricing, offset by a reduction for Defense Efficiencies for contractor staff support.

| Exhibit R-2A, RDT&E Project Justification: PB 2012 Defense Advanced Research Projects Agency | | | DATE: February 2011 |
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| APPROPRIATION/BUDGET ACTIVITY<br>0400: *Research, Development, Test & Evaluation, Defense-Wide*<br>BA 3: *Advanced Technology Development (ATD)* | R-1 ITEM NOMENCLATURE<br>PE 0603739E: *ADVANCED ELECTRONICS TECHNOLOGIES* | PROJECT<br>MT-07: *CENTERS OF EXCELLENCE* | |

| COST ($ in Millions) | FY 2010 | FY 2011 | FY 2012 Base | FY 2012 OCO | FY 2012 Total | FY 2013 | FY 2014 | FY 2015 | FY 2016 | Cost To Complete | Total Cost |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MT-07: *CENTERS OF EXCELLENCE* | 7.000 | - | - | - | - | - | - | - | - | Continuing | Continuing |

**A. Mission Description and Budget Item Justification**

This project provides funding for the Robert C. Byrd Institute for Advanced Flexible Manufacturing at Marshall University. The Byrd Institute provides both a teaching facility and initiatives to local area industries to utilize computer-integrated manufacturing technologies and managerial techniques to improve manufacturing productivity and competitiveness. Training emphasizes technologies to significantly reduce unit production and life cycle costs and to improve product quality.

| B. Accomplishments/Planned Programs ($ in Millions) | FY 2010 | FY 2011 |
|---|---|---|
| ***Congressional Add:*** Advanced Flexible Manufacturing | 7.000 | - |
| ***FY 2010 Accomplishments:*** - Modernized and increased the availability of shared manufacturing equipment at the four RCBI (Robert C. Byrd Institute) facilities, with selection of equipment based on focus group discussions and studies of manufacturers in the serviced region.<br>- Expanded the electronic procurement and bidding network, the RCBI 21st Century Manufacturing Network, to include procurement counseling assistance.<br>- Provided technical training to 600 people that represent 110 companies, including group and individual training formats.<br>- Continued semi-annual publication of the manufacturing report 'Capacity.' | | |
| **Congressional Adds Subtotals** | 7.000 | - |

**C. Other Program Funding Summary ($ in Millions)**

N/A

**D. Acquisition Strategy**

N/A

**E. Performance Metrics**

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

| Exhibit R-2A, RDT&E Project Justification: PB 2012 Defense Advanced Research Projects Agency | | | DATE: February 2011 |
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| APPROPRIATION/BUDGET ACTIVITY<br>0400: *Research, Development, Test & Evaluation, Defense-Wide*<br>BA 3: *Advanced Technology Development (ATD)* | R-1 ITEM NOMENCLATURE<br>PE 0603739E: *ADVANCED ELECTRONICS TECHNOLOGIES* | PROJECT<br>MT-12: *MEMS AND INTEGRATED MICROSYSTEMS TECHNOLOGY* | |

| COST ($ in Millions) | FY 2010 | FY 2011 | FY 2012 Base | FY 2012 OCO | FY 2012 Total | FY 2013 | FY 2014 | FY 2015 | FY 2016 | Cost To Complete | Total Cost |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MT-12: *MEMS AND INTEGRATED MICROSYSTEMS TECHNOLOGY* | 72.301 | 85.835 | 70.053 | - | 70.053 | 44.466 | 44.355 | 46.642 | 46.642 | Continuing | Continuing |

**A. Mission Description and Budget Item Justification**

The MicroElectroMechanical Systems (MEMS) and Integrated Microsystems Technology program is a broad, cross-disciplinary initiative to merge computation and power generation with sensing and actuation to realize a new technology for both perceiving and controlling weapons systems and battlefield environments. Using fabrication processes and materials similar to those used to make microelectronic devices, MEMS applies the advantages of miniaturization, multiple components and integrated microelectronics to the design and construction of integrated electromechanical and electro-chemical-mechanical systems. The MEMS program addresses issues ranging from the scaling of devices and physical forces to new organization and control strategies for distributed, high-density arrays of sensor and actuator elements. These issues include microscale power and actuation systems as well as microscale components that survive harsh environments. The microfluidic molecular systems effort will develop automated microsystems that integrate biochemical fluid handling capability along with electronics, optoelectronics and chip-based reaction and detection modules for tailored sequence analysis to monitor environmental conditions, health hazards and physiological states. Thermal management technologies will develop heat resistant thermal layers to provide efficient operation for cooling electronic devices. Another focus in micro technologies is to improve navigation, position and timing capabilities for uncompromised navigation and positioning in today's dynamic military field of operations.

The major technical focus areas of the MEMS and Integrated Microsystems programs contained in this project are: 1) inertial measurement; 2) fluid sensing and control; 3) electromagnetic and optical beam steering; 4) chemical reactions on chip; 5) electromechanical signal processing; 6) analytical instruments; 7) thermal management; and 8) navigation and positioning technologies.

| B. Accomplishments/Planned Programs ($ in Millions) | FY 2010 | FY 2011 | FY 2012 |
|---|---|---|---|
| ***Title:*** Chip-Scale Technology* | 7.759 | 9.776 | 3.199 |
| ***Description:*** *Previously Chip-Scale Micro-Gas Analyzers.<br><br>The goal of the Chip-Scale Technology effort is to enhance Microsystems performance. The current focus of the program is to develop an efficient fluid distribution capability for on-chip vacuum pumps that meet the stress application requirements. Additionally, this program will refine microresonator capabilities to accept very narrow radio spectrum channels while canceling out or eliminating others. The Chip-Scale Technologies have the potential to improve the critical performance of Microsystems such as micro mass spectrometers, nanoscale detectors, RF resonators, and vacuum microelectronic components. There is a pressing need to significantly improve chip-scale micropump performance (capable of operating at ~10^-6 Torr in a volume smaller than 1 CM^3) and this program will develop a high-performance integrated low-power microscale pumping capability. Additionally, the microresonator effort has the potential to provide a universal communications receiver that is able to reconfigure and operate | | | |

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| B. Accomplishments/Planned Programs ($ in Millions) | FY 2010 | FY 2011 | FY 2012 |
|---|---|---|---|
| under any communication standard, anywhere from an urban setting to an outer space environment. The program will transition via industrial performers.<br><br>***FY 2010 Accomplishments:***<br>- Demonstrated a deep reactive ion-etched silicon turbo-molecular vacuum micropump with rotational frequency greater than 70 KHz.<br>- Demonstrated micromechanical vacuum on a chip operating at pressures less than 1 Torr.<br>- Demonstrated micromechanical resonator structures with quality factor Q > 100,000; separate demonstration of operating frequency greater than 3 GHz.<br>- Developed a new micromechanical resonator concept combining both capacitive and piezoelectric structural approaches to simultaneously achieve for high Q and low impedance.<br>***FY 2011 Plans:***<br>- Develop MEMS-based component capability with multiple stages to achieve vacuum pressures less than 1 mTorr.<br>- Continue to develop resonators with simultaneous high quality factor (>100,000), high frequency (> 3 GHz), and low impedance (< 50 Ohms).<br>***FY 2012 Plans:***<br>- Demonstrate the concept of a micromechanical signal processor directly coupled to a receive antenna. | | | |
| ***Title:*** Nano-Electro-Mechanical Computers (NEMS)<br><br>***Description:*** The goal of the Nano-Electro-Mechanical Computers (NEMS) program is to develop nanoscale mechanical switches and gain elements integrated intimately with complementary metal-oxide semiconductor switches. One mechanical switch per transistor will enable the transistor to operate at near zero leakage powers, enabling pico or femtowatt standby operation. The program will also develop mechanical gain elements using physical effects such as giant magnetoresistance, buckling, electromechanical phase transitions, van der Waals forces, and Casimir forces to enable very low-noise, high-frequency amplifiers for low-power, low-noise analog signal processing. Mechanical power supplies and mechanical vibrating clocks could facilitate production of electronics that are less susceptible to electromagnetic pulse attacks. Integrating nanomechanical elements in direct bandgap materials will circumvent problems of gate oxide stability, allowing fast logic with optics functionality. This program will transition into DoD systems via industrial program performers.<br><br>***FY 2010 Accomplishments:***<br>- Demonstrated NEMS devices and technologies for microcontroller building blocks - adders, counters, | 3.653 | 7.170 | 2.000 |

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| B. Accomplishments/Planned Programs ($ in Millions) | FY 2010 | FY 2011 | FY 2012 |
|---|---|---|---|
| memories that can operate at very high temperatures.<br>***FY 2011 Plans:***<br>- Demonstrate capability to produce mixed signal mechanical components such as operational amplifiers, analog to digital converts and digital to analog converters.<br>***FY 2012 Plans:***<br>- Demonstrate capability to produce microcontrollers consisting of analog and digital building blocks based on NEMS devices. | | | |
| ***Title:*** Thermal Management Technologies (TMT)<br>***Description:*** The goal of the Thermal Management Technologies (TMT) program is to explore and optimize new nanostructured materials and other recent advances for use in thermal management systems. Innovative research is underway to go beyond evolutionary thermal management systems. Modern, high-performance heat spreaders, which use two-phase cooling, are being developed to replace the copper alloy spreaders in conventional systems. Enhancing air-cooled exchangers by reducing the thermal resistance through the heat sink to the ambient, increasing convection through the system, improving heat sink fin thermal conductivity, optimizing and/or redesigning the complimentary heat sink blower, and increasing the overall system (heat sink and blower) coefficient of performance is another thrust of this program. Another element of this effort is focused on novel materials and structures that can provide significant reductions in the thermal resistance of the thermal interface layer between the backside of an electronic device and the next layer of the package, which might be a spreader or a heat sink. The TMT program is an aggregation of: Thermal Ground Plane (TGP), Microtechnologies for Air-Cooled Exchangers (MACE), Nano Thermal Interfaces (NTI) and Active Cooling Modules (ACM) technology research. Technology will be inserted through DoD industrial firms into future DoD systems.<br>***FY 2010 Accomplishments:***<br>- Investigated active cooling of electronic devices using techniques such as thermoelectric coolers, sterling engines, etc.<br>- Demonstrated a full-performance high-thermal conductivity substrate with enhanced thermal conductivity, hermeticity, and lifetime in a scaled-up 3 cm x 3 cm < 2mm sample.<br>- Scaled up prototype air-cooled exchangers to a large, full-format heat sink.<br>- Developed prototype reworkable nanostructured thermal interfaces that exhibit better thermal conduction than conventional epoxy-based materials.<br>***FY 2011 Plans:***<br>- Deliver sample high thermal conductivity substrates to DoD labs (ARL, NSWC, AFRL) for testing against DoD application needs.<br>- Design customized substrates for customer-selected insertion opportunities.<br>- Design and build prototype active cooling module elements that demonstrate active cooler benefits. | 35.866 | 29.951 | 20.737 |

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| B. Accomplishments/Planned Programs ($ in Millions) | FY 2010 | FY 2011 | FY 2012 |
|---|---|---|---|
| - Initiate efforts to reduce thermal resistance within the first 10 micrometers near a high-power electronic junction.<br>- Deliver enhanced heat exchangers for insertion demonstrations on mobile platforms.<br>- Demonstrate reliable, reworkable nanostructured thermal interface materials based on nanotubes, nanoplates and nanosprings with reduced thermal resistance.<br>***FY 2012 Plans:***<br>- Insert TGP substrates to demonstrate improvements in GaN Power amplifiers, High-Power T/R modules, high-density electronic systems, composite projectile casings, airborne radar modules, and other opportunities enabled by lightweight, flexible, highly-conductive heat spreaders.<br>- Complete insertion demonstrations for enhanced heat exchangers, and initiate transitions to platforms.<br>- Demonstrate 10x improvements over state of the art (SOA) for reworkable thermal interface materials.<br>- Demonstrate high active cooling modules for efficient operation of cooled electronic devices.<br>- Fabricate and demonstrate significant reductions in near-junction thermal resistance for manufacturable GaN power devices.<br>- Overall goal of TMT program: Insert breakthrough materials and structures at all layers of DoD systems, and enable higher power densities, increased performance, and improved efficiency. | | | |
| ***Title:*** Micro-Technology for Positioning, Navigation, and Timing (Micro PN&T) | 20.911 | 37.838 | 44.117 |
| ***Description:*** The Micro-Technology for Positioning, Navigation, and Timing (Micro PN&T) program is developing technology for self-contained chip-scale inertial navigation and precision guidance. This technology promises to effectively mitigate dependence on Global Positioning System (GPS) or any other external signals, and enable uncompromised navigation and guidance capabilities. The program will enable positioning, navigation and timing functions without the need for external information updates by employing on-chip calibration, thereby overcoming vulnerabilities which arise in environments where external updates are not available such as caves, tunnels, or dense urban locations. The technologies developed will enable small, low-power, micro-gyroscopes capable of operating in both moderate and challenging dynamic environments; chip-scale primary atomic clock standards; and on-chip calibration systems for error correction. Advance micro-fabrication techniques allow a single package containing all the necessary devices (clocks, accelerometers, gyroscopes and calibration) to be incorporated into a volume the size of a sugar cube. The small size, weight and power of these technologies and their integration into a single package responds to the needs of guided munitions, unmanned aerial vehicles and individual soldiers. The Micro PN&T program is an aggregation of Integrated Primary Atomic Clock, Information Tethered Microscale Autonomous Rotary Stages, Microsystem Integrated Navigation and Precision Navigation and Positioning Technologies. The technology is expected to transition through industry.<br>***FY 2010 Accomplishments:***<br>- Demonstrated navigation grade low-power gyroscope (20mW) in a small package (10 cubic centimeters). | | | |

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| B. Accomplishments/Planned Programs ($ in Millions) | FY 2010 | FY 2011 | FY 2012 |
|---|---|---|---|
| - Independently tested MEMS gyros and experimentally verified low bias drift of the angular rate response 0.05 degrees/hour and Angle Random Walk 0.01 [o/vhr].<br>- Demonstrated cold atom micro-primary standard physics package of 16 cubic centimeters.<br>- Demonstrated 10m @ 0.5hrs navigation accuracy during walking.<br>- Developed and demonstrated micro-fabrication technologies for creating new classes of MEMS navigation instruments that can be used for achieving high accuracy, GPS free navigation using zero-velocity updating.<br>- Initiated technology development efforts for demonstrating a complete physics package for an advanced miniaturizable atomic clock that can interrogate gaseous atoms and does not suffer from light shifts and buffer gas shifts that usually limit the use of hyperfine transition frequencies for applications to clocks.<br>***FY 2011 Plans:***<br>- Develop design architecture for low-cost, small size rate integrating gyroscopes to provide direct measurement of orientation and angular velocity.<br>- Demonstrate three-dimensional microfabrication techniques for rate integrating gyroscopes that are compatible with large scale manufacturing.<br>- Identify fabrication method to co-fabricate clocks and inertial sensors into a single low power package for navigation microsystems.<br>- Identify self-calibration techniques to compensate for long-term drift.<br>***FY 2012 Plans:***<br>- Demonstrate a microsystem rate integrating gyroscope to provide directly measured orientation and angular velocity.<br>- Demonstrate a microsystem that combines a functional timing and inertial measurement unit.<br>- Demonstrate the co-fabrication of an inertial sensor and a calibration stage to enable integration of error correction technologies on the same stage. | | | |
| ***Title:*** MEMS Exchange<br><br>***Description:*** The MEMS Exchange program seeks to provide flexible access to complex MicroElectroMechanical systems (MEMS) fabrication technology in a wide variety of materials and to a broad, multi-disciplinary user base via the MEMS Exchange service. A major goal of the effort is to ensure self-sustained operation of MEMS Exchange after the end of the program by adding several process modules to the existing repertoire and increasing the number of processes run per year to raise revenues to the point of self-sufficiency. Among the future payoffs of this program is the establishment of an accessible infrastructure for low or medium volume production of MEMS-enabled products for DoD applications. The goal of the MEMS Exchange program is to provide MEMS fabrication services to all levels of industry and academia in support of Army, Navy, Air Force, and other DoD requirements without further DARPA sponsorship. | 1.459 | 1.100 | - |

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| B. Accomplishments/Planned Programs ($ in Millions) | FY 2010 | FY 2011 | FY 2012 |
|---|---|---|---|
| ***FY 2010 Accomplishments:***<br>- Implemented new state-of-the-art technical unit process capabilities to achieve greater effectiveness for creating MEMS devices, including electron-beam lithography, mixed transistor and MEMS process modules, and general purpose MEMS hermetic packaging.<br>- Initiated new quality control efforts to achieve higher reliability in manufacturing.<br>***FY 2011 Plans:***<br>- Optimize process cost efficiencies by increased marketing of MEMS Exchange capability.<br>- Improve self-sufficiency by providing a higher value to program users by improved yield and lower manufacturing costs. | | | |
| ***Title:*** Harsh Environment Robust Micromechanical Technology (HERMIT)<br>***Description:*** The Harsh Environment Robust Micromechanical Technology (HERMIT) program developed micromechanical devices that operate under harsh conditions (e.g., under large temperature excursions, large power throughputs, high g-forces, corrosive substances) while maintaining unprecedented performance, stability, and lifetime. Micromechanical RF switches were of particular interest, where sizable power throughputs and impacting operation constitute harsh operational environments. Other applications such as vibrating resonator reference tanks, gyroscopes, and accelerometers were also addressed. Among the HERMIT implementation approaches pursued were: 1) wafer-level encapsulation or packaging strategies based on MicroElectroMechanical systems (MEMS) technology that isolates a micromechanical device from its surroundings while maintaining a desired environment via passive or active control; and 2) material and design engineering strategies that render a micromechanical device impervious to its environment with or without a package (if possible). The technology transitioned through Industry.<br>***FY 2010 Accomplishments:***<br>- Demonstrated hermetic packaging technology for advanced MEMS inertial gyroscopes and accelerometers. | 0.525 | - | - |
| ***Title:*** Low Power Micro Cryogenic Coolers (MCC)<br>***Description:*** The Low Power Micro Cryogenic Coolers (MCC) program achieved superior performance in micro-scale devices (e.g. Low Noise Amplifier (LNA's) IR detectors, RF front-ends, superconducting circuits) by cooling selected portions to cryogenic temperatures. The key approach in this program was to selectively cool. Such an approach benefits a large number of applications where performance is determined predominately by only a few devices in a system, e.g., communications where the front-end filter and LNA often set the noise figure; and sensors, where the transducer and input transistor in the sense amplifier often set the resolution. The technology transitioned through industry. | 2.128 | - | - |

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| B. Accomplishments/Planned Programs ($ in Millions) | FY 2010 | FY 2011 | FY 2012 |
|---|---|---|---|
| ***FY 2010 Accomplishments:***<br>- Demonstrated fully integrated Joule-Thompson micro-cooler capable of cooling from room temperature to 145 K.<br>- Combined hybrid integration of an integrated micro cryogenic cooler with a 3-5 micron HgCdTe infrared focal plane detector array.<br>- Designed a new low cost infrared focal plane detector architecture exploiting the full power of silicon microfabrication and direct MEMS materials integration. | | | |
| **Accomplishments/Planned Programs Subtotals** | 72.301 | 85.835 | 70.053 |

**C. Other Program Funding Summary ($ in Millions)**

N/A

**D. Acquisition Strategy**

N/A

**E. Performance Metrics**

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

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| COST ($ in Millions) | FY 2010 | FY 2011 | FY 2012 Base | FY 2012 OCO | FY 2012 Total | FY 2013 | FY 2014 | FY 2015 | FY 2016 | Cost To Complete | Total Cost |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MT-15: *MIXED TECHNOLOGY INTEGRATION* | 113.310 | 111.263 | 90.233 | - | 90.233 | 67.033 | 70.488 | 78.261 | 76.361 | Continuing | Continuing |

**A. Mission Description and Budget Item Justification**

The goal of the Mixed Technology Integration project is to leverage advanced microelectronics manufacturing infrastructure and DARPA component technologies developed in other projects to produce mixed-technology microsystems. These 'wristwatch size', low-cost, lightweight and low power microsystems will improve the battlefield awareness, security of the warfighter and the operational performance of military platforms. At the present time, systems are fabricated by assembling a number of mixed-technology components: microelectromechanical systems (MEMS), microphotonics, microfluidics and millimeterwave/microwave. Each technology usually requires a different level of integration, occupies a separate silicon chip and requires off-chip wiring, and requires fastening and packaging to form a module. The chip assembly and packaging processes produce a high cost, high power, large volume and lower performance system. This program is focused on the monolithic integration of mixed technologies to form batch-fabricated, mixed technology microsystems 'on-a-single-chip' or an integrated and interconnected 'stack-of-chips'.

The field of microelectronics incorporates micrometer/nanometer scale integration and is the most highly integrated, low-cost and high-impact technology to date. Microelectronics technology has produced the microcomputer-chip that enabled or supported the revolutions in computers, networking and communication. This program extends the microelectronics paradigm to include the integration of heterogeneous or mixed technologies. This new paradigm will create a new class of 'matchbook-size', highly integrated device and microsystem architectures. Examples of component-microsystems include low-power, small-volume, lightweight, microsensors, microrobots and microcommunication systems that will improve and expand the performance of the warfighter, military platforms, munitions and Unmanned Air Vehicles (UAVs).

The program includes the integration of mixed materials on generic substrates including glass, polymers and silicon. The program is design and process intensive, using 'standard' processes and developing new semiconductor-like processes and technologies that support the integration of mixed-technologies at the micrometer/ nanometer scale. The program includes the development of micrometer/nanometer scale isolation, contacts, interconnects and 'multiple-chip-scale' packaging for electronic, mechanical, fluidic, photonic and rf/mmwave/microwave technologies. For example, a mixed-technology microsystem using integrated microfluidics, MEMS, microphotonics, microelectronics and microwave components could provide a highly integrated, portable analytical instrument to monitor the battlefield environment, the physical condition of a warfighter, the identity of warfighters (friend or foe) or the combat readiness of equipment. The ability to integrate mixed technologies onto a single substrate will drive down the size, weight, volume, and cost of weapon systems while increasing their performance and reliability.

| B. Accomplishments/Planned Programs ($ in Millions) | FY 2010 | FY 2011 | FY 2012 |
|---|---|---|---|
| ***Title:*** COmpact Ultra-stable Gyro for Absolute Reference (COUGAR) | 7.256 | 17.601 | 8.987 |
| ***Description:*** The COmpact Ultra-stable Gyro for Absolute Reference (COUGAR) program goal is to realize the fundamental performance potential of the resonant fiber optic gyro in combination with bandgap optical fiber (BGOF), ultra-stable compact lasers, phase conjugate elements, and silicon optical benches: a compact ultra-stable gyro for absolute reference applications. | | | |

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| APPROPRIATION/BUDGET ACTIVITY<br>0400: *Research, Development, Test & Evaluation, Defense-Wide*<br>BA 3: *Advanced Technology Development (ATD)* | R-1 ITEM NOMENCLATURE<br>PE 0603739E: *ADVANCED ELECTRONICS TECHNOLOGIES* | PROJECT<br>MT-15: *MIXED TECHNOLOGY INTEGRATION* |

| B. Accomplishments/Planned Programs ($ in Millions) | FY 2010 | FY 2011 | FY 2012 |
|---|---|---|---|
| The COUGAR gyro will have a practical and typical size (~ 4 inch diameter) featuring bias stability and sensitivity (or angle random walk), which is more than 100 times better than state-of-the-art gyroscopes. This program will transition via industry.<br><br>***FY 2010 Accomplishments:***<br>- Initiated development of optical bench interface technology for the air-to-bandgap fiber to then be exploited for a gyroscope with reasonable bias performance levels and consistent with military needs.<br><br>***FY 2011 Plans:***<br>- Reduce loss in BGOF to 0.5dB/km.<br>- Integrated laser noise suppression electronics with laser devices.<br>- Demonstrate full gyroscope with integrated electronics and performance exceeding 10 micro-degrees/hr drift.<br><br>***FY 2012 Plans:***<br>- Demonstrate full gyro with performance of 1 micro-degree/hr bias drift in integrated 4" diameter package. | | | |
| ***Title:*** Gratings of Regular Arrays and Trim Exposures (GRATE) | 6.522 | 10.995 | 11.000 |
| ***Description:*** The Gratings of Regular Arrays and Trim Exposures (GRATE) program will develop revolutionary circuit design methodologies combined with hybrid lithography tools to enable cost-effective low volume nanofabrication for DoD applications. Moore's law has driven the silicon industry for several decades with the minimum feature size on an integrated circuit (IC) reduced to 45 nm for today's commercial products. Due to challenging patterning requirements and complex circuit designs, costs of lithography tools and masks have become unaffordable for low-volume manufacture, i.e., military electronics or application specific integrated circuit (ASICs). Similarly, the circuit design, verification, and testing costs have also grown exponentially further preventing military electronics from using advanced silicon technology nodes. Military electronics capabilities are currently limited by the high cost of nanofabrication. To solve this important problem, DARPA has invested in a variety of maskless patterning technologies including parallel e-beam arrays, parallel scanning probe arrays, and an innovative e-beam lithography tool. This program will develop revolutionary circuit design methodologies coupled with innovative hybrid maskless patterning tools to realize cost-effective nanofabrication for low-volume defense or commercial ASICs. Such an approach can also address the nanofabrication requirements of other low-volume DoD technologies such as photonics and micro-electro-mechanical systems. This program will transition via industry.<br><br>***FY 2010 Accomplishments:***<br>- Initiated development of 1-D fabrication demonstrations.<br>- Began development of 1-D standard cell library for digital designs at < 32 nm node. 1-D computer aided design tool development.<br>- Commenced 1-D fabrication demos including various circuit elements making use of 1-D specific process extensions. | | | |

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| B. Accomplishments/Planned Programs ($ in Millions) | FY 2010 | FY 2011 | FY 2012 |
|---|---|---|---|
| - Began development of 1-D circuit patterns using trimmed interference lithography.<br>***FY 2011 Plans:***<br>- Demonstrate grating-based design and fabrication, including experimental verification of desired patterns. The demonstration vehicles will be logic/memory "standard cells" and high speed RF devices in state-of-the-art Complimentary Metal-Oxide Semiconductor (CMOS) technologies.<br>- Develop re-usable grating and trim masks, design methodology, process design kits, and software for layout conversion from standard (2-D) to grating-based (1-D) layout styles.<br>- Demonstrate wafer-scale patterning of gratings, and the customization of these gratings by the "trim/stitch" processes.<br>***FY 2012 Plans:***<br>- Fabricate 1-D digital design at 22 nm node.<br>- Demonstrate > 300 GHz performance for 1-D SiGe transistor circuit. | | | |
| ***Title:*** Maskless Direct-Write Nanolithography for Defense Applications<br>***Description:*** The Maskless Direct-Write Nanolithography for Defense Applications program will develop a maskless, direct-write lithography tool that will address both the DoD's need for affordable, high performance, low volume Integrated Circuits (ICs) and the commercial market's need for highly customized, application-specific ICs. In addition, this program will provide a cost effective manufacturing technology for low volume nanoelectromechanical systems (NEMS) and nanophotonics initiatives within the DoD. Transition will be achieved by maskless lithography tools, installed in the Trusted Foundry and in commercial foundries, which will enable incorporation of state-of-the-art semiconductor devices in new military systems, and allow for the cost-effective upgrade of legacy military systems.<br>***FY 2010 Accomplishments:***<br>- Demonstrated system level lithography performance on a linear stage demonstrator system.<br>- Designed, built, and tested a rotary stage.<br>- Integrated electron beam column and rotary stage demonstrator platform.<br>- Designed, built, and characterized an enhanced electron beam column for system alpha prototype experiments.<br>***FY 2011 Plans:***<br>- Fabricate and test digital pattern generator (DPG) with lenslet structure.<br>- Design, build, and test wafer metrology system.<br>- Design, build, and test DPG, data preparation system, and data path.<br>- Develop and demonstrate a sensitive photoresist with acceptable performance for the 32 nanometer node.<br>***FY 2012 Plans:*** | 32.045 | 25.560 | 16.275 |

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| B. Accomplishments/Planned Programs ($ in Millions) | FY 2010 | FY 2011 | FY 2012 |
|---|---|---|---|
| - Integrate electron optics and new pattern generator onto column prototype.<br>- Demonstrate system level lithography performance on a column prototype. | | | |
| ***Title:*** Advanced Wide FOV Architectures for Image Reconstruction & Exploitation (AWARE) | 26.454 | 27.347 | 18.001 |
| ***Description:*** The Advanced Wide FOV Architectures for Image Reconstruction & Exploitation (AWARE) program primarily addresses the passive imaging needs for multi-band, wide field of view (FOV) and high-resolution imaging for ground and near ground platforms. The AWARE program aims to solve the technological barriers that will enable wide FOV, high resolution and multi-band camera architectures by focusing on four major tasks: High space-bandwidth product (SBP) camera architecture; Small pitch pixel focal plane array architecture; Broadband focal plane array architecture; and Multi-band focal plane array architecture.<br><br>The AWARE program will advance integration of technologies that enable wide field of view and high resolution and multi-band cameras, including the technologies demonstrated in the related AWARE program in PE 0602716E, Project ELT-01. AWARE aggregates the following programs: Nyquist-Limited Infrared Detectors (NIRD), Photon Trap Structures for Quantum Advanced Detectors (P-SQUAD), Dual-Mode Detector Ensemble (DUDE), and Multiscale Optical Array Imaging (MOSAIC). The integration of the technologies will demonstrate subsystems such as focal plane arrays and cameras.<br><br>***FY 2010 Accomplishments:***<br>- Established initial focal plane array (FPA) performance models and projections, iterating flow down analysis that includes material and device specifications for small pixels.<br>- Demonstrated very low (18 microamps/cm2) dark current for 5 µm pitch photodiodes with 0.8 µm via diameter, surpassing requirements.<br>- Completed dual-band read out integrated circuit (ROIC ) design.<br>- Demonstrated Low Wave Infrared (LWIR) microbolometer fabrication with low temperature process.<br>- Developed Visible-Near Short Wave Infrared test chip for InGaAs performance evaluation.<br>- Fabricated pillar nBBn device structures in the photonic structures with dark currents below current nBn devices. Completed p/n junctions in photonics structures.<br>- Fabricated 64x64 arrays with broadband response and tested arrays.<br>- Demonstrated a 640 x 480 array that is fully integrated with readout processor.<br>- Designed and validated broadband integrated detector array.<br>- Demonstrated LWIR detectors, with a size of 5 micrometers, operating at 80K with dark current less than 0.5ma/cm^2.<br>- Achieved 10 x 10 LWIR array with 5 micrometer pixels interconnected to silicon read-out with interconnect resistance less than 5 ohm.<br><br>***FY 2011 Plans:*** | | | |

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| B. Accomplishments/Planned Programs ($ in Millions) | FY 2010 | FY 2011 | FY 2012 |
|---|---|---|---|
| - Demonstrate and fabricate photonic structure in each detector unit cell for broadband response with 80% quantum efficiency across full band.<br>- Develop low cost materials for focal plane arrays and associated optics.<br>- Demonstrate the feasibility of achieving wide angle, near diffraction-limited instantaneous Field of View (iFOV) data capture in moderate size (~10's cm aperture diameter) imaging systems.<br>***FY 2012 Plans:***<br>- Demonstrate 5µmx5µm LWIR photodetector unit cell design with detector ROIC and capacitor 3-D interconnects.<br>- Complete hybrid integration of 1024x1024 FPA with ROIC with < or equal to 30 µm pitch for broadband.<br>- Demonstrate integrated Visible-Near Short Wave Infrared and Long Wave Infrared detectors with noise equivalent temperature difference of 30 milli-Kelvin @ F/1. | | | |
| ***Title:*** Excalibur*<br>***Description:*** * Formerly Adaptive Photonic Phased Locked Elements (APPLE).<br><br>The Excalibur program will develop high-power electronically-steerable optical arrays, with each array element powered by a fiber laser amplifier. These fiber-laser arrays will be sufficiently lightweight, compact, and electrically efficient to be fielded on a variety of platforms with minimal impact on the platform's original mission capabilities. Each array element will possess an adaptive-optic capability to minimize beam divergence in the presence of atmospheric turbulence, together with wide-field-of-view beam steering for target tracking. With each Excalibur array element powered by a high power fiber laser amplifier (at up to 3 kilowatts per amplifier), high power air-to-air and air-to-ground engagements will be enabled that were previously infeasible because of laser system size and weight. In addition, this program will also develop kilowatt-class arrays of diode lasers that will provide the higher spatial and temporal bandwidths needed to correct for the increased air turbulence effects encountered in ground-to-ground engagements. Excalibur arrays will be conformal to aircraft surfaces and scalable in size and power by adding additional elements to the array. By defending airborne platforms such as unmanned aerial vehicles against proliferated, deployed and next-generation man-portable air-defense systems (MANPADS), Excalibur will enable these reconnaissance platforms to fly at lower altitude and obtain truly persistent, all-weather ground reconnaissance despite low-lying cloud cover. Further capabilities include multi-channel laser communications, target identification, tracking, designation, precision defeat with minimal collateral effects as well as other applications. This technology will transition via industry.<br><br>In the Excalibur program, efficient high-power laser amplifier arrays based on coherent or spectral beam-combining will be developed. The potential of these arrays to scale to tactical power levels (100 kW class) will be investigated as well as near-term | 12.942 | 17.000 | 15.970 |

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| B. Accomplishments/Planned Programs ($ in Millions) | FY 2010 | FY 2011 | FY 2012 |
|---|---|---|---|
| options for low-altitude self defense against MANPADS. These laser amplifier arrays will be designed to work in tandem with the core laser components developed under the Excalibur program in PE 0602702E, Project TT-06.<br><br>***FY 2010 Accomplishments:***<br>- Demonstrated atmospheric compensation of laboratory-generated turbulence and turbulence on a 2-km range using a 7-element optical phased array at 1 watt power levels.<br>- Demonstrated high-power stand-off tracking of moving ball bearing using a coherent 7-element, electronically-steerable, fiber laser amplifier array with a conformal beam director.<br>- Demonstrated coherent combination of a 150-W fiber laser amplifier array.<br>***FY 2011 Plans:***<br>- Complete laser lethality testing.<br>- Develop system requirements for low-altitude MANPADS self-defense using fiber-laser arrays.<br>- Demonstrate a phased array of seven 500-W fiber laser amplifiers.<br>***FY 2012 Plans:***<br>- Complete the design, fabricate and procure the components for a coherently or spectrally combinable array of 21 array elements, each fed by a 1 kW fiber laser amplifier.<br>- Demonstrate 7 kW 7-element fiber-amplifier laser array using coherent-combining and spectral-combining technologies. | | | |
| ***Title:*** Low Cost Thermal Imager (LCTI-M)*<br>***Description:*** *Formerly Advanced Imaging Program.<br><br>The Low Cost Thermal Imager (LCTI-M) effort will develop a pocket-sized, manufacturable, and practical thermal imager at a price point allowing them to be provided to large numbers of warfighters. The resulting devices will allow a soldier to have practical thermal imaging capability for locating warm objects (e.g., enemy combatants) in darkness. The small Size, weight and Power (SWaP) thermal camera will be integrated with a handheld device such as a cell phone with network capability for tactical ISR. In order to achieve this goal, breakthroughs will be required in low-cost thermal imagers manufactured using wafer scale integration, vacuum packaging, low cost optics and low-power signal processing. By the end of the program, the imager chips will be fully integrated with a low-cost processor and optics. The camera will have wireless connectivity to integrate video display with cell phones or PDAs.<br><br>***FY 2012 Plans:***<br>- Develop wafer-scale vacuum packaging with infrared-transparent windows.<br>- Develop low cost infrared optics. | - | - | 20.000 |

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| B. Accomplishments/Planned Programs ($ in Millions) | FY 2010 | FY 2011 | FY 2012 |
|---|---|---|---|
| - Demonstrate integrated bolometer-based thermal imager chips with integral packaging.<br>- Initial demonstration of connectivity and display on a handheld device. | | | |
| ***Title:*** Hemispherical Array Detector for Imaging (HARDI)<br><br>***Description:*** The objective of the Hemispherical Array Detector for Imaging (HARDI) program is to exploit the benefits of the hemispherical imaging surface. The basic idea behind the program is that a detector array can be fabricated on a hemispherical substrate using materials such as organic/inorganic semiconductors and that this array can be combined with a single lens to produce a wide field of view, small form factor camera. Organic materials have been shown to have good electronic and optoelectronic properties including light emission and detection. Furthermore, in-plane organic/inorganic transistors can be incorporated for pre-processing of images. This program will transition to DoD systems through a demonstration of an array prototype developed by industrial contractors.<br><br>***FY 2010 Accomplishments:***<br>- Developed novel photodetector materials for the spectral range 400-1900 nanometers (nm).<br>- Demonstrated a 16,000 pixel array on a 2.5 cm radius hemispherical substrate.<br>- Explored manufacturing techniques amenable to producing hemispherical array detectors with high reproducibility.<br>***FY 2011 Plans:***<br>- Demonstrate a prototype 1 megapixel, 1 cm radius hemispherical focal plane array for the spectral range of 400-1900 nm.<br>- Demonstrate a prototype f/1.4 camera with a 120 degree field of view with high reliability. | 3.152 | 3.754 | - |
| ***Title:*** Radio Frequency Photonic Technology (RPT)<br><br>***Description:*** The Radio Frequency Photonics Technology (RPT) program is developing components and microsystems to revolutionize deployed signal intelligence (SIGINT) gathering capabilities. The radio frequency (RF) spectrum contains innumerable friendly and adversarial signals of interest including: voice and data communications, electronic signatures, and navigation information. Conventional electronic systems are challenged in detecting weak signals in the presence of strong ones (low-linearity) across a broad range of frequencies (narrow-band). The RPT program aims to efficiently capture all RF signals of interest by developing broad-band (>10 gigahertz) high-linearity (>70 decibels dynamic-range) optical components and microsystems. The RPT program will reduce susceptibility to electronic attack, increase the probability-of-intercepting (POI) adversaries on their first-pulse transmission, and increase information awareness 1000-fold.<br><br>RPT program integrates optical components such as modulators, photodetectors, lasers, delay elements, and low-noise oscillators with microwave electronics to demonstrate microsystems such as remote links, channelizers, and analog-to-digital converters (ADCs). Components developed under the RPT program in PE 0602716E, Project ELT-01 will be integrated into | 7.969 | 9.006 | - |

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| B. Accomplishments/Planned Programs ($ in Millions) | FY 2010 | FY 2011 | FY 2012 |
|---|---|---|---|
| subsystem demonstration under this program. This program also incorporates photonic components previously addressed in the Photonic-enabled Simultaneous Transmit and Receive (P-STAR) program, Electromagnetic Pulse Tolerant Microwave Receiver Front End (EMPIRE), Integrated Photonic Displays (iPHoD) in ELT-01, Remoted Analog-to-Digital Converter with De-serialization and Reconstruction (RADER) in ELT-01, and the Transmit and Receive Optimized Photonics (TROPHY) program. This technology will transition via industry.<br><br>***FY 2010 Accomplishments:***<br>- Demonstrated 10 GHz, 44 decibel (dB) dynamic-range photonic ADC.<br>- Demonstrated 500 MHz receiver with 61 dB dynamic-range.<br>- Developed and demonstrated low loss lithium niobate optical modulators, which exhibit low switching voltages and incorporate a long effective length for achieving high Transmit/Receive (T/R) isolation.<br>- Developed and demonstrated a power amplifier that when connected to the electro-optic modulator and incorporated into the T/R module package, enables the transmit power goal over a multi-octave frequency range.<br>- Enhanced third-order intercept point of the Transmit link to +65 decibels (dB) relative to a milliwatt of power (dBm).<br>- Enhanced gain of the Receive link to 35 dB.<br>***FY 2011 Plans:***<br>- Develop 10-channel channelizer that extends 10 GHz ADC to 100 GHz bandwidth.<br>- Demonstrate >4 GHz antenna remote link with >30 dB dynamic-range.<br>- Demonstrate 10 GHz, 50 dB dynamic-range remoted ADC. | | | |
| ***Title:*** Visible/Short Wave IR - Photon Counting Arrays<br><br>***Description:*** The Visible/Short Wave IR - Photon Counting Arrays program developed imaging over a broad spectral band at extremely low levels of ambient illumination to provide a unique capability for remote sensing, unattended sensors, and pay-loads for autonomous ground and air platforms. The program leveraged recent innovations in solid state imaging devices, including parallel processing at the pixel level and novel read read-out technology, to develop a new class of sensors, that create images with only a few photons per pixel, exceeding performance of current low light level imagers. The direct conversion of low light level information into an electronic format has provided access to a suite of signal processing, image enhancement and communications techniques not available with current low light level imaging devices. This program transitioned via industry for ultraviolet to infrared imaging applications.<br><br>***FY 2010 Accomplishments:***<br>- Demonstrated real-time processor and interface with an existing photon counting camera. | 2.007 | - | - |
| ***Title:*** Advanced Photonic Switch (APS) | 1.468 | - | - |

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|---|---|---|---|
| ***Description:*** The Advanced Photonic Switch (APS) program developed a technology for creating on-chip, photonic switching devices that can be fabricated in a silicon-compatible process. Most high performance photonic switching devices are fabricated with compound semiconductors, but silicon manufacturing technologies now offer potential advantages due to the great precision being driven by commercial mainstream markets for microelectronics. This program pursued advanced technologies that take full advantage of those commercial capabilities to produce photonic devices that maximize switching speed, minimize device power dissipation and transmission losses, small area, and decreased sensitivity to ambient temperature variations. This technology transitioned via industry.<br><br>***FY 2010 Accomplishments:***<br>- Enhanced APS fabrication technologies and design approaches to improve devices and integrated assemblies. | | | |
| ***Title:*** Compound Semiconductor Materials on Silicon (COSMOS) Multi-Project Wafer (MPW)<br><br>***Description:*** The Compound Semiconductor Materials on Silicon (COSMOS) Multi-Project Wafer (MPW) program has pioneered the intimate integration of high-performance compound semiconductor devices (specifically Indium Phosphide Heterojunction Bipolar Transistors) with advanced, high-density silicon Complementary Metal Oxide Semiconductor devices to realize mixed-signal circuits that exploit the principle of "best junction for the function". The COSMOS MPW program established a foundry capability in order to provide broad access to the DoD and commercial RF/mixed-signal design community. This program introduced early access multiproject wafer effort and will support 4 MPW runs of increasing sophistication. This program is a companion effort to the COSMOS program in PE 0602716E, Project ELT-01, and is budgeted in Budget Activity 3 to initiate foundry activities and prepare for transition. This technology transitioned to industry.<br><br>***FY 2010 Accomplishments:***<br>- Initiated development of a COSMOS foundry technology design kit.<br>- Initiated mask aggregation and support functions for eventual transition to the Trusted Access Program Office (TAPO) or MOSIS (a production service for chip fabrication) to facilitate future regular offerings of the technology following the early access program. | 10.445 | - | - |
| ***Title:*** High Frequency Wide Band Gap Semiconductor<br><br>***Description:*** The High Frequency Wide Band Gap Semiconductor program fully exploited the properties of wide bandgap semiconductors (WBGS) to enhance the capabilities of microwave and millimeter-wave (MMW) monolithic integrated circuits (MMICs) and enable future RF sensor, communication, and multifunction military capabilities. Wide bandgap semiconductors have the ability to deliver very high power and other very favorable high frequency characteristics. Prior efforts have focused on improvements to the basic semiconductor while current efforts are focused on realizing devices and circuits. These technologies led to affordable, high performance, reliable, wide bandgap devices and MMICs with characteristics suitable for enabling new DoD | 3.050 | - | - |

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|---|---|---|---|
| systems and greatly improved performance for fielded platforms. This program was a companion to the effort in PE 0602716E, Project ELT-01.<br><br>***FY 2010 Accomplishments:***<br>- Demonstrated superior thermal management and packaging strategies. | | | |
| **Accomplishments/Planned Programs Subtotals** | 113.310 | 111.263 | 90.233 |

**C. Other Program Funding Summary ($ in Millions)**

N/A

**D. Acquisition Strategy**

N/A

**E. Performance Metrics**

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.