Final Report - Base Period

Affordable Silicon Based Visible/Near Infrared Missile Warning Sensor

Contract Number N00014-08-C-0121

Prepared for :
Office of Naval Research
One Liberty Center
875 N. Randolph Street
Arlington, VA 22203-1995

Submitted by :
Wayne E. Rodgers, Principal Investigator
(760) 961- 8457, wayner@eddyco.com
Lawrence S. Ring
(760) 961- 8457, lring@eddyco.com

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1 Introduction

In accordance with the Office of Naval Research STTR Topic Number N03-T020, Contract N00014-08-C-0121, the development activities presented within this report were undertaken as part of a collaboration between the Eddy Company and The Johns Hopkins University Applied Physics Laboratory (JHUAPL) to develop an affordable missile warning sensor (AMWS) using a silicon based CCD operating in the visible/near-infrared. This sensor would ultimately be part of a Directed Infrared Counter-Measure (DIRCM) system designed to protect Navy assets from anti-aircraft missiles. Current technology, for example using two color IR sensors, promises to be effective, but also is expensive to implement: Under a Phase I STTR award, we established the feasibility of a missile waning sensor based on a narrow-band magneto-optical filter (MOF) and commercially available silicon CCD detectors. Under a previous Phase II award, we developed a functional prototype AMWS system that was successfully field tested. The development reported here has taken the necessary steps to produce an improved prototype of the sensor portion of the system for testing under Mil Spec 810E/F requirements. The development effort also achieved control over the manufacturing processes necessary to produce consistent pre-production units. Laboratory and field-tests in appropriate environments were undertaken to verify performance capabilities.

The AMWS design uses affordable, robust and well-characterized silicon based CCD focal plane technology that has several advantages over infrared detectors traditionally used in missile-warning systems. Silicon based CCD's are readily available, inexpensive compared to the alternatives, and do not require expensive cooling systems to perform optimally.
The potential drawback of using a detector in the visible/near infrared is that background and clutter observed during typical daytime operations can make it difficult to accurately detect an incoming missile or prevent false positives. To overcome this problem, the AMWS uses a narrow-band magneto-optical filter (MOF), with a pass-band of approximately 0.005 nm, centered on a missile plume emission line. The MOF has a high background rejection (a few parts in 10^5) and its pass-band falls within a solar Fraunhofer line, further reducing potential image clutter. The AMWS is therefore capable of effectively detecting plume emissions while rejecting both the solar and manmade background.

2 Technical Objective

The primary objective of this effort is to produce a flight ready affordable visible/near-infrared missile warning sensor (AMWS) that uses conventional silicon based commercial charge couple device (CCD) detector technology. These sensors will ultimately form part of a Directed Infrared Counter-Measure system designed to protect naval aircraft from anti-aircraft missiles.

After demonstrating the feasibility of an MOF based missile-warning sensor under a Phase I STTR award, and a prototype AMWS under a Phase II STTR award, it was the purpose of this phase of the development of the AMWS system to demonstrate an improved prototype compact AMWS system sensor that could be field tested in a relevant test environment and that would survive Mil Spec. 810E/F testing for ruggedness and reliability. A second purpose of this phase was the development of improved manufacturability of the AMWS system sensor including improved manufacturing tooling and facilities. This prototype sensor's performance is intended to be representative of the performance achievable in a mass-produced final system. The system as a whole has not yet been designed to meet the physical requirements of a mil-spec production product. The design of a complete mil-spec pre-production AMWS system is under concurrent development by a Prime Contractor.

The prototype sensor was designed to have a 100° square field-of-view and a CCD array 1000x1000 pixels square, giving an instantaneous field-of-view of 0.1° to 0.2°. The Base Period prototype sensors now have mass, volume and power consumption demonstrating an operational AMWS sensor head within the original target specifications mass of 5lb, volume of 5" x 5" x 6" (actual volume is 4" x 4" x 7") and complete system power consumption of less than 35W.

3 Base Period Tasks

3.1 Magneto-optical filter Performance Optimization

These tasks will result in a better understanding of the design parameters affecting the Magneto-optical filter (MOF).

The bulk of the work undertaken under the 2nd Phase II STTR award was in the re-design of the compact magneto-optical filter (MOF). The design process included the design of the MOF cell, heaters, heater controller, and vacuum enclosure.

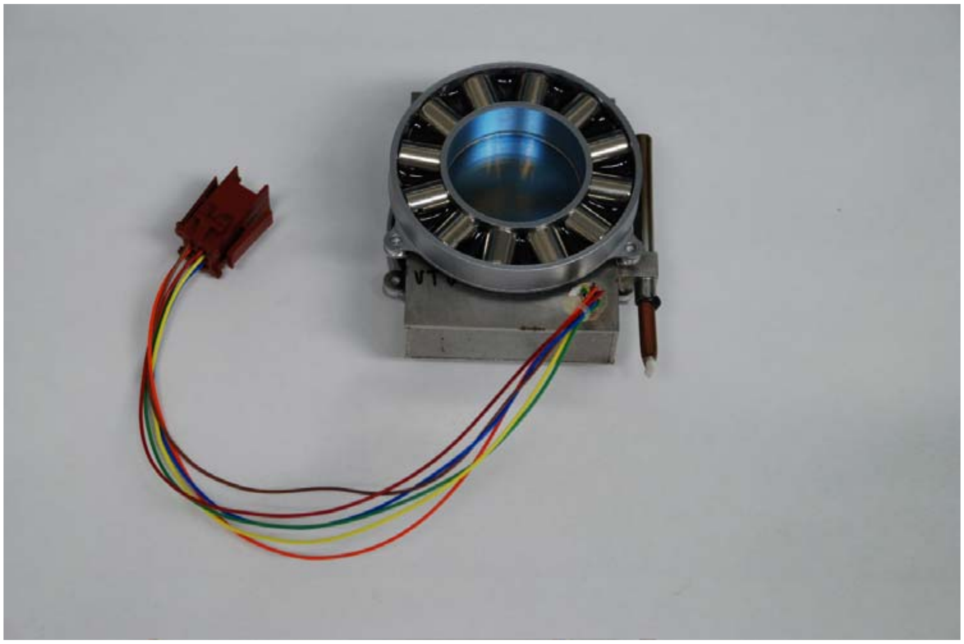

Figure 1 Pre-production Magneto-optical Filter assembly

The re-designed MOF is shown in Figure 1. The filter consists of a cell containing potassium vapor, inside in a vacuum enclosure. Both the cell and enclosure have optical windows and two crossed linear polarizers are mounted inside the vacuum enclosure windows.   A significant amount of development work was required from the previous design to produce a reliable prototype unit. Development of the various filter components is detailed below. A complete AMWS attached to thermal controller's data log downloading software is shown in Figure 2.

Figure 2 Complete AMWS (foreground) with power supply and Data Log download setup

3.1.1   High Performance CCD Camera

The contractor shall acquire, install and test a high performance CCD camera system to measure performance changes in the magneto-optical filter (MOF).

An Andor Technology Inc. electron multiplying high performance Commercial Off-the-Shelf (COTS) CCD camera was acquired to measure the performance of MOF based sensors. Specifications for the camera are attached in Appendix 1. Boulder Imaging Inc. software was acquired to provide camera control, image capture, and image processing capabilities. This camera and related control electronics were installed in a custom built enclosure to provide for both field and flight-testing (see Figure 3 and Figure 4). The enclosure provides a complete portable self-contained (except power) module for performance evaluations. It includes mechanisms for adjusting the tracking and alignment of the camera system. The enclosure was modified twice during the base period to improve its capabilities. The first modification increased the range of tracking and alignment available. The second modification still in progress is being made to install the latest large (1.5") aperture MOF on the high performance camera (see Figure 5).

The enclosure system was installed at the Tonopah, Nevada test range early in March of 2008. A series of live fire tests during both daylight and night conditions were captured using the sensor systems. The test results and an analysis by the Johns Hopkins University Applied Physics Laboratory are attached in Appendix 2. The results were favorable but mixed due to a variety of minor logistical and design issues. These issues were resolved during the Base Period. A second field test opportunity has been requested but has not yet been scheduled by the Navy.

Additional testing was performed using smaller, lower cost PhotonFocus CCD cameras. AMWS systems using this lower cost camera were also fabricated as shown in Figure 2 and Figure 5.

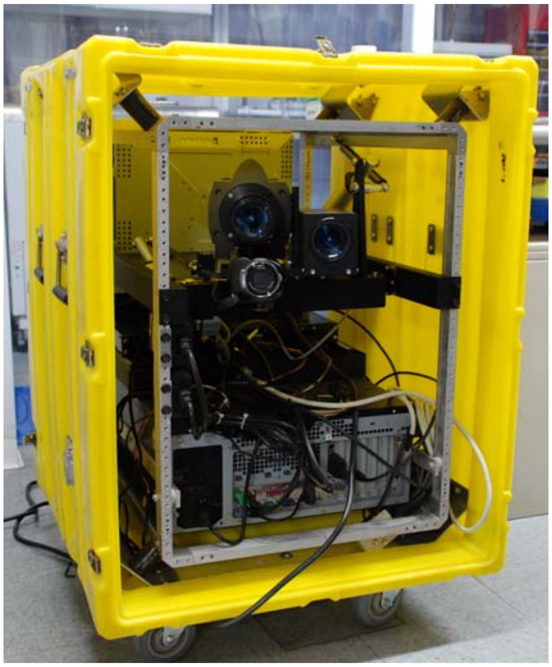

Figure 3 Enclosure Front (MOF and Camera)

Figure 4 Enclosure Back (Electronics)

Figure 5 Andor AMWS (left), PhotonFocus AMWS (right), handheld Camcorder (bottom)

3.1.2 100 Degree Field of View Optics

The contractor shall acquire and install a 100 degree Field Of View (FOV) optical system. These optics, in conjunction with the High Performance Camera will allow the contractor to measure and track performance changes in the MOF related to design, manufacturing and process improvements.

Custom wide angle optics were designed and acquired thru Custom Optics Inc. A manufacturing process error that aggravated detrimental light scatter was discovered during testing and corrected. These optics were installed and tested in a live fire test at Tonopah, Nevada in March of 2008. Please see Appendix 2 for the JHU/APL report on this field testing.

The 100 Degree Field of View optics assemblies were examined both on the Eddy Company's internal calibration system and with a small model rocket sled system located at the Eddy Company's facilities. The camera and optics were found to operate properly on the calibration system. The model rocket test sled was destroyed during the first test run which was not formally documented. Additional test runs are pending completion of an upgraded model rocket sled, currently in progress.

Figure 6 100 Degree Field of View optics

3.1.3 Reduced F-ratio Configurations

The contractor shall fabricate a series of MOF filters with varying thickness to diameter ratios and varying outer diameters. The tasks associated with these configurations include:

3.1.3.1 Fabricate new assembly

3.1.3.2 Assemble new thin cells

3.1.3.3 Operational test new thin cells

3.1.3.4 Fabricate new large cell grinding and assembly jigs

3.1.3.5 Design larger outer enclosure and magnet assembly
3.1.3.6 Fabricate larger diameter polarizers
3.1.3.7 Fabricate larger diameter cell body and windows
3.1.3.8 Assemble new larger diameter cells
3.1.3.9 Operational test new larger diameter cells
3.1.3.10 Document tools, assemblies, test results and probable performance relationships

Vapor cells of varying thickness and diameters were evaluated for MOF use. It proved to be infeasible to make the cells significantly thinner than 1cm because they had to run much hotter to perform properly. Running hotter increased the power consumption, reduces lifetime, and creates other issues. A vapor path 0.95cm thick was determined to be as thin as is feasible for an MOF vapor cell with a stem type reservoir at this time. Larger diameters were found to be practical and the 1.5" design has performed well. All Eddy Company Magneto-optical filters are now fabricated in the "thin cell" configuration due to the improved performance obtained.

Figure 7 Thin Cell Vapor cells

In the course of this work numerous assembly jigs were fabricated including tools for final alignment and tack welding of the polarizers, vapor cell flanges, and housing components. Test final alignment tooling further incorporates apparatus for measurement of the extinction ratio achieved with the polarizers.

A total of 35 vapor cells were fabricated during the base year with 4 each 1" and 4 each 1.5" completed to specifications. The yield for this latest run of 4 and 4 thin cells was 100%. Several have been built into completed MOF's. The operational performance of these MOF's has been confirmed on the test benches at the Eddy Company. One completed and tested MOF was delivered to the Prime Contractor during the Base Period for confirmation of its performance and for incorporation into their optical systems.

As mentioned previously logistical delays were encountered in scheduling additional field tests at the Tonopah Test Range. To expedite evaluations a Model Rocket powered test sled was designed, fabricated, and tested at the Eddy Company's facilities. The initial test run destroyed the sled but yielded information needed for a revised design.

All components, assembly processes and tools used in the fabrication of Eddy Company MOF's have been outlined. Sequence Software by FFD Inc. is being used to document each tool, process, and assembly. We have estimated that 2 man-years of labor will be required to complete all documentation. The Prime Contractor has reviewed and is supporting the current documentation methods.

Final filter acceptance testing is currently collected using a custom Labview program and Excel spreadsheet software. Testing is performed using a sweeping diode laser, a Lock-in amplifier, a Photomultiplier Tube, and a custom Eddy Company MOF control module. The Prime Contractor previously purchased a duplicate of the Eddy Company final acceptance test station for their internal use (see Figure 9 below).

3.2 Calibration

The contractor shall design, build and document a MOF calibration facility to test the center wavelength, bandwidth, throughput and field of view of each MOF. The tasks associated with this task include:
3.2.1 Develop standardized and stable light source
3.2.2 Develop standardized and calibrated image sensor
3.2.3 Establish uniform test procedures
3.2.4 Document procedures and facility.

To calibrate the final performance test station an NBS traceable lamp was acquired and set-up. A 6.5 digit Fluke current meter was used to monitor the current supplied to the lamp during testing. The lamp is used to supply a known light intensity at a known distance to the final test station. This calibration is used to determine the sensitivity of the PMT. The sweeping diode laser is then calibrated against the PMT. Finally; each MOF is then tested according to Eddy Company Procedure FE2011 using the frequency sweeping diode laser and the PMT to determine its calibrated transmission response curve (Figure 8). A sample of the final test reporting form is attached as Appendix 3.

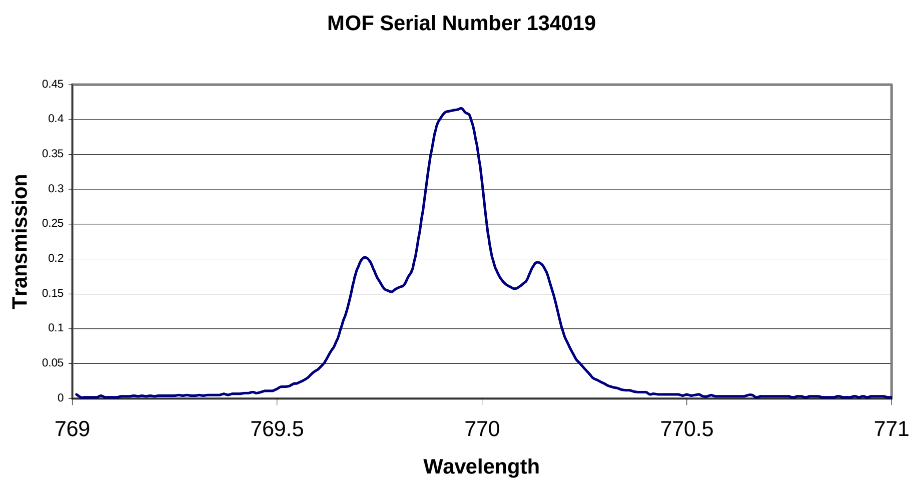

Figure 8 MOF Final Acceptance Transmission Response Curve

The development of a standardized and calibrated image sensor has been deferred to the Option Period due to logistical issues. In the interim a THORLabs photodetector is being used in place of the standardized sensor. The standardized and calibrated image sensor task is to be performed by JHU/APL following the collection of suitable data at a live fire field test. Insufficient data was collected at the March ’08 test series due to the issues mentioned previously and as described in the report in Appendix 2. These issues have been resolved. The next suitable live fire field test will not be conducted until a date in the Option Period. A standardized and calibrated image sensor will be implemented at that time.

Final acceptance testing data for Eddy Company MOF’s is currently collected using a custom Labview program and Excel spreadsheet software. This testing is performed using a sweeping diode laser, a Lock-in amplifier, a Photomultiplier Tube (PMT), and an Eddy Company fabricated MS-418 MOF control module and power supply. The manual for the MS-418 is attached as Appendix 4. The Prime Contractor previously purchased a duplicate of the Eddy Company final acceptance test station for their internal use and incoming filter quality inspection. An MS-418 Data Logger & Control module with Power Supply has been supplied to them as well. The prime contractor has reviewed and is supporting the current documentation methods.

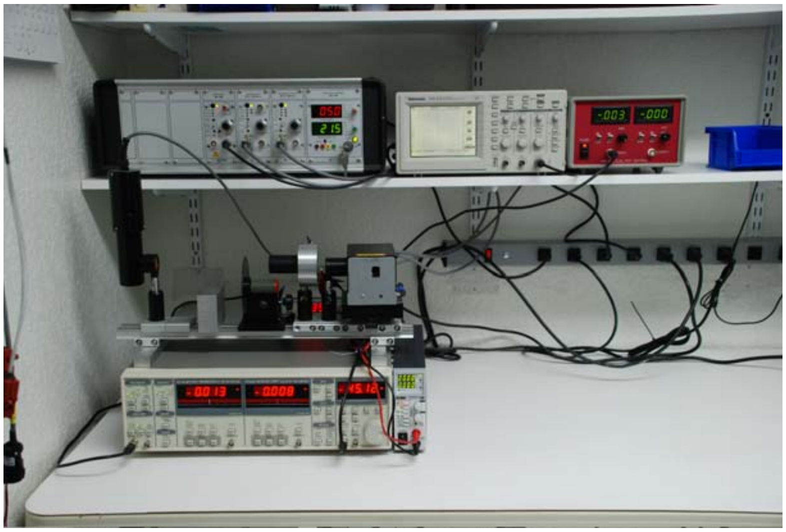

Figure 9 Final Acceptance Test Station

3.3 Vapor Cavity Leakage Reduction

The tasks associated with this task include:
3.3.1 Development and evaluation of molecular bonded vapor cell windows
3.3.2 Fabrication of new reactor elements to fit new vapor cell stems
3.3.3 Retrofit of the cell filling system for molecular bonded window
3.3.4 Upgrade of the vacuum system to a higher performance turbo-molecular vacuum pump

The purpose of the vapor cavity leakage reduction task was to identify and reduce causes of leakage that result in limitations to the lifetime of MOFs. Two approaches were taken to vapor cavity leakage reduction during the Base Period. The first was the development and evaluation of molecular bonded vapor cell windows. 6 each 1” and 4 each 1.5” cells were fabricated and one 1” cell was processed to completion for testing. 4 of each size remain in storage pending successful completion of the existing final filter assembly testing thru field testing. The results to date for this cell are shown in Figure 14 below.

The second approach was improvement of adhesive bonding methods for cell fabrication. It was discovered during testing that reactivity of the adhesive with the vapor inside the cell was an issue. New adhesives were evaluated and improved results have been obtained.

The design of both the adhesive and molecular bonded vapor cells was revised to improve the mounting system from stem held to tab mounted as shown in Figure 10. Adhesive bonded and molecular bonded cells have now successfully demonstrated extended lifetimes with the longest running cell currently at 6,720 hours (280 days) and continuing.

Figure 10 Vapor Cell showing flange posts for tab mounting

This development effort required modification of the vapor filling system for the vapor cells. New reactor elements were fabricated to fit the smaller stems of the thin cell configuration. The filling system was retrofitted to accommodate the molecular bonded window cell’s configuration as well. The filling system vacuum pump was upgraded to a higher performance turbo-molecular pump in conjunction with these retrofits.

Figure 11 Eddy Company Vapor Filling Station

3.4 Reactive Gas Scavenger Enhancements

The tasks associated with this task include:
3.4.1 Redesign of a new getter material. The contractor shall modify the getter side tube configuration for improved thermal isolation during activation. An improved getter material has been identified and will be implemented in a one-piece custom insert configuration. A more precisely temperature controlled heating technique will be developed for activation of the new getter material. The tasks associated with the Reactive Gas Scavenger enhancements include:
3.4.1.1 Redesign of the getter tube
3.4.1.2 Implementation of a new getter material
3.4.1.3 Fabrication of new getter tubes
3.4.1.4 Fabrication of a new getter activation oven.
The tasks associated with this tasks include:
3.4.1.4.1 Design, fabricate and instrument a custom getter activation station
3.4.1.4.2 Purchase and install mechanical and turbo-molecular vacuum pumps on the station

The getter side tube of the MOF assembly was redesigned to provide better thermal isolation during activation. The new design can be seen in Figure 12 below. Both type 172 and type 175 getter materials were ordered in the custom configurations necessary for testing in the MOF. Testing to date has been of insufficient duration to determine whether there is a benefit to using these types and is continuing. The fabrication of new getter side tube assemblies is in progress. Final fabrication will not occur until the conclusion of the materials evaluation.

Figure 12 MOF with getter side tube visible on left

A new getter activation oven was built to provide improved vacuum outgassing of the MOF housing assembly and getter. The new activation oven further provides improved time and temperature control of the activation cycle. New mechanical and turbo-molecular pumps were installed as part of this installation. This oven is used for initial outgassing, burn-in, and activation of each MOF housing assembly.

The getter activation oven provides computer controlled sequencing of the vacuum and thermal conditioning cycles for multiple MOF housings. It is programmed in Labview and records the process parameters for tracking. Multi-station capability is important for this processing, as it is several weeks in duration.

A second new portable getter activation station was also developed during the Base Period. The purpose of this project was not initial burn of the MOFs, but instead to determine whether it was possible to build a field activation oven capable of restoring Eddy Company MOFs after the conclusion of their original useful life.

Figure 13 Portable Getter Activation Station

The portable getter activation station was designed, fabricated and tested. It provides temperature and cycle time control of a precision heating sleeve. The heating sleeve adapter fits snuggly over the getter side tube of the MOF assembly for reactivation. The reactivation process can be completed in approximately 1 hour.

3.5 Hermetic Housing Elimination of Adhesive Bonding

The tasks associated with task include:

3.5.1 The contractor shall revise the mounting method for attachment of the polarizers. New methods for mounting of the polarizers will be evaluated.

3.5.2 The contractor shall revise the mounting method for securing the vapor cell's stem. New methods for mounting the vapor cell's stem will be evaluated.

3.5.3 The contractor shall develop Indium soldering techniques for attachment of the hermetic housing's windows.

The specific tasks associated with this process development include:

3.5.3.1 Design and fabrication of a custom cell window and hermetic housing sputtering system

3.5.3.2 Design and fabrication of a custom servo controlled parts holder inside the sputtering system.

3.5.3.3 The contractor shall design and fabricate an induction heating fixture for melting of the Indium-Tin soldering rings.

The limitation on MOF lifetime was experimentally determined to be related to the time period for which the MOF housing can maintain a strong vacuum. One source of pressure increases was identified as outgassing of the adhesive used for mounting components inside the MOF housing. This task focused on the elimination of these adhesives. The results were favorable as shown in Figure 14. The elimination of adhesives for mounting of most internal components has significantly extended the initial lifetime of MOF assemblies. It has also enabled the return of MOF assemblies to operational condition with a quick re-activation.

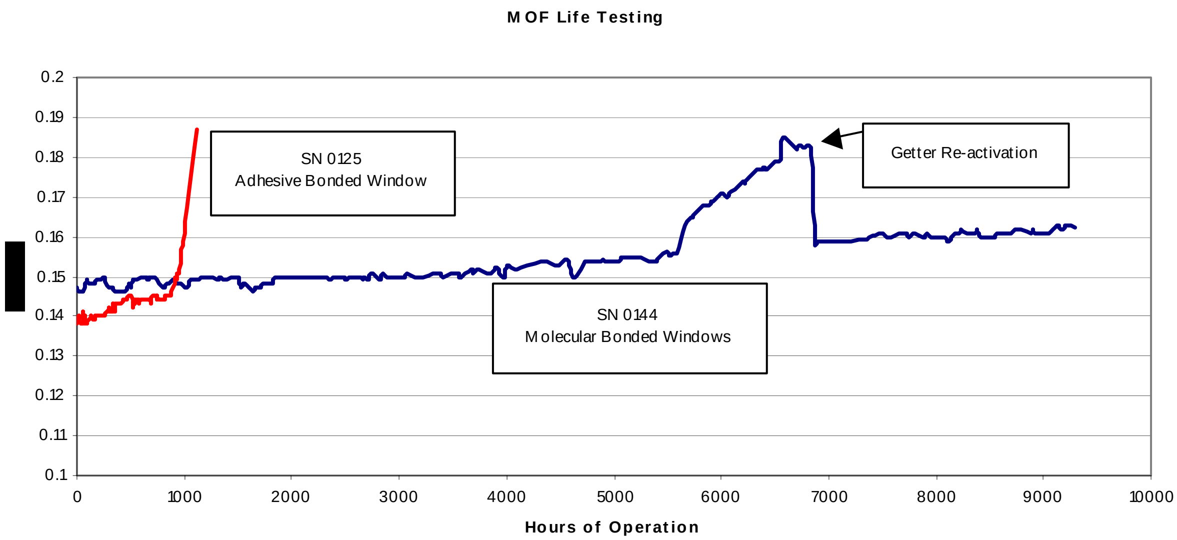

Figure 14 MOF Life Testing Chart

The polarizer mounting was redesigned to permit mounting by a combination of soldering and spot welding. This eliminated adhesives from the polarizer assembly. In conjunction with this change polarizer mounting was moved from the outsides of the vapor cell to the insides of the MOF housing. In addition to eliminating adhesives, this produced a more rugged assembly, reduced the thermal mass of the vapor cell, and reduced thermal cycling of the polarizer mounting connections. All MOFs now use this polarizer configuration.

Redesign of the polarizer mounting necessitated design and fabrication of a new polarizer alignment fixture. The new fixture was designed, built, and tested. It includes instrumentation for measuring the extinction coefficient of the polarizer assembly prior to final welding.

A new heating system was designed and built to reflow solder Indium-Tin for attachment of the polarizers. Induction heating was found to be less controllable than resistance heating for this process. A resistance heating was used for the new heating system to improve process control.

A new sputtering system was also designed and built to accommodate sputter coating of the polarizers as well as the vapor cells and hermetic housing windows. Jigs and tooling were fabricated to fixture the polarizers and other components in the sputtering system. A servo controlled parts holder was implemented for turning of the vapor cell windows during coating (See Figure 15 below).

The vapor cell mounting was redesigned to permit mounting by spring brackets and spot welding. This eliminated adhesives from the vapor cell mounting assembly. In conjunction with this change vapor cell mounting was moved from the vapor cell stem to a three flange cylinder edge configuration. In addition to eliminating adhesives, this produced a more rugged assembly and reduced the thermal mass of the vapor cell stem. All MOFs now use this vapor cell mounting configuration.

Redesign of the vapor cell mounting necessitated the design and fabrication of new vapor cell alignment and mounting jigs. The new fixtures were designed, built, and tested in conjunction with the polarizer mounting fixture above. Each vapor cell is quality tested while on the fixture for specified heater resistances prior to final MOF housing assembly.

The hermetic housing window mounting was redesigned to permit mounting by Indium-Tin soldering. This eliminated a significant quantity of adhesive from the hermetic housing. It was found that a combination of Indium-Tin soldering and laser welding produced the most reliable results. All MOFs now use this housing window mounting technique.

A new induction heating fixture was built to reflow Indium solder for sealing of the hermetic housing windows. A separate laser welding step is used to mount the housing window bracket to the hermetic housing.

Completed final filter assemblies are now entirely free of adhesives with the exception of a very small quantity used for the mounting of temperature sensors. All units built to date have been subjected to thermal cycle, humidity, and shock exposures prior to performance evaluation. The lifetime operational capability and the lifetime operational capability with periodic regeneration of these filter assemblies has not yet been determined, though initial results indicate a minimum of 5,000 operational hours can be expected from the molecular bonded vapor cell configuration. It also remains to be determined as well whether the gradual increase in vacuum housing pressure is an initial burn in phenomenon that can be factory treated or a longer term issue requiring field re-activation.

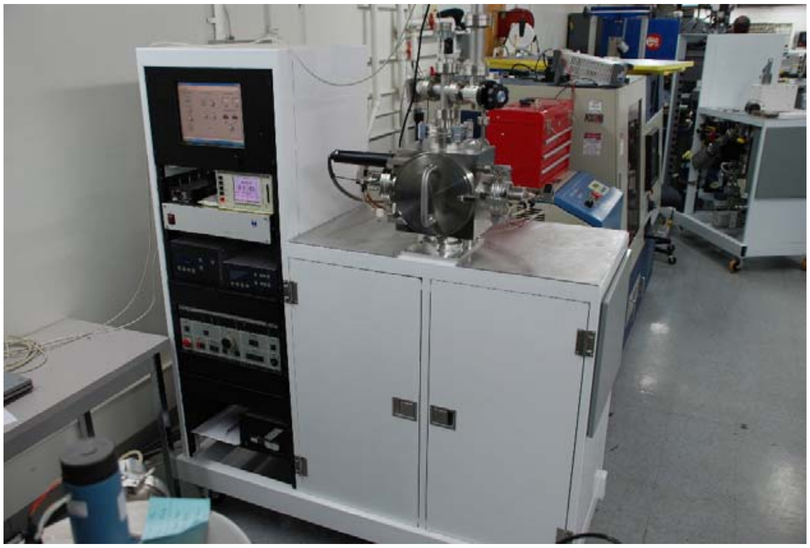

Figure 15 Eddy Company Custom Sputter Coating System

3.6 Improved Heating Film Deposition System

The tasks for the heating element deposition development include:
3.6.1 Design and fabrication of additional jigs and fixtures for the sputtering system of the Indium soldering development effort.

The new sputtering system built to coat components used for the adhesive elimination task was also tooled for sputtering of the Vapor Cell heating elements. Three elements are coated on each vapor cell; the stem heater, the entrance window heater, and the camera window heater. The servo-controlled actuator mechanism of the sputter coating systems is used for coating of the window heaters. Several configurations for each of these heaters were evaluated during the Base Period. Difficulties with coating adhesion, coating location, and surface preparation were encountered and overcome. The final configuration of the coating system is illustrated in Figure 15 and Figure 16.

Recent heater coatings have demonstrated less than 4% variance between the front window and the back window electrical resistance. This provides for excellent temperature consistency of the assembled MOF.

Figure 16 Eddy Company Sputter Coating System - Open

3.7 Integration of the Base Plate Feedthrough

The tasks associated with the base plate feedthrough integration include:
3.7.1 Design and fabrication of new base plate feedthroughs
3.7.2 Laser welder installation, programming, and training

Commercial hermetic vacuum feedthroughs were evaluated for use in the MOF housing. None was found to be satisfactory for the specifications of the system. Custom multi-channel electrical feedthroughs were then designed and contracted for fabrication. They can be seen in part in the lower right hand corners of Figure 1 and Figure 12

The custom feedthroughs were laser welded into the MOF hermetic housings and successfully tested. The laser welder is shown in Figure 17. Weld schedules were generated for each laser weld performed on the MOF assembly, including the base plate feedthrough attachment.

Satisfactory test results were obtained for hermeticity, humidity, shock and vibration of the Base Plate Feedthrough as described further in Section 3.8. Each MOF is Helium Leak tested for hermeticity at several stages of assembly.

Figure 17 Eddy Company Laser Welder

3.8 Base Year Performance Evaluation

The contractor shall prepare a Performance Evaluation and Report at the conclusion of the Base Year. The Performance Evaluation will include:

3.8.1 Measurement of the total out of band rejection over the sensitivity spectrum of the silicon detector.

3.8.2 Measurement of the in band sensitivity and its bandwidth relative to Potassium's emission spectrum.

3.8.3 Development of a predictive test method for measurement of the anticipated life of the MOF filter.

3.8.4 Measurement of the anticipated storage life of the pre-production MOF filters.

3.8.5 Measurement of the anticipated operational life of the pre-production MOF filters.

3.8.6 An analysis on the use of the predictive test method as an end of life indicator in installed systems.

3.8.7 Pass / Fail humidity testing of the pre-production MOF filters.

3.8.8 Performance (sensitivity) measurement of pre-production MOF's at elevated and reduced temperatures, and following thermal cycling.

3.8.9 Pass / Fail mechanical shock testing of pre-production MOF filters at up to 30g and up to 2khz.

3.8.10 Measurement ofthe temperature control accuracy of the MOF thermal controller.

The total out of band rejection and in band sensitivity for each Magneto-optical filter is checked across the sensitivity spectrum of the detector at the final acceptance test station. An example result from this test is shown in Appendix 3. The final acceptance test station is described above in section 3.2 and is shown in Figure 9.

During the Hermetic Housing Adhesive investigation above (Section 3.5) it was determined that limitations on the life of some MOF's was caused not by deterioration of the vapor cell, but instead by a gradual loss of vacuum in the MOF vacuum housing. This loss appears to currently limit the life of MOF's to near 6,000 hours of running time. The slope of the electrical current required to maintain vapor cell heater temperature vs. time is shown in Figure 14. This slope can be used to predict the operational life of an MOF before regeneration is required, the overall operational life of an MOF, and the shelf life of an MOF.

It was determined during this development task that it is possible to re-evacuate MOF housings and restore full operational functionality by re-activation of their getter alone. No additional equipment or disassembly of the MOF itself is required. The re-activation process takes roughly 1 hour. The MOF must be removed from the sensor optics and camera assembly for getter re-activation to avoid heat damage to other components.

Results of the long term performance for a molecular bonded vapor cell MOF housing and an adhesive bonded vapor cell MOF housing including reactivation are shown in Figure 14 above. Each cell was tested on the final acceptance test station prior to starting the long term testing. The heater controller is mated to the MOF at this time and serialized. Performance of the cells is monitored by its heater controller and periodically verified. Figure 14 shows the current (power) required to maintain the cells at operating temperature. As gases slowly leak or outgas into the vacuum housing of the MOF the power required to heat the vapor cell increases. When the capacity of the getter tube is reached, the vacuum pressure and power required for temperature control increase rapidly compromising the performance of the MOF. As seen in the chart the threshold for this rise is detected by tracking the slope of the operating current over time. When the slope rises abruptly, a warning light is triggered by the MOF's controller indicating that service is required.

Testing to date has demonstrated at least 6700 hours for one molecular bonded cell and somewhat less than 1000 hours so far for an adhesive bonded cell. Monitoring and determination of MOF operation lifetimes is an ongoing activity. Note: the operational times suggested are for the operating time from initial use to first recommended regeneration. The total operational and shelf life capability of these MOFs remains to be determined but may be quite long.

The new Heater Controller was developed with built in datalogging capability to provide programmable measurement and storage of critical parameters for the cells. The controller provides periodic monitoring and reliable warning indicators to the user of pending "out of specification". These warnings include a hard wired warning light, an external warning signal output, and trend charting interface software.

At end of operation regeneration has been demonstrated to be an effective means of restoring full operational status. The datalogging capability of the MOF heater controller is being used to build a database on the long term performance of each cell produced. The heater controller manual (MS-418) is attached as Appendix 4. The MOF heater controller has demonstrated vapor cell reservoir and vapor cell body temperature control to within at least 1 degree F over an external ambient temperature range of 0C to 40C.

In preparation for later Mil Spec 810E/F testing the MOF cells were all successfully subjected to thermal shock (7 one hour cycles of -40C to 60C), mechanical shock (30g), vibration (up to 2khz), and humidity (24 hour immersion) prior to final acceptance testing. The test equipment is shown in Figure 18. The Heater Controller, camera, and lens assemblies have not been built or tested to meet these environmental requirements. Design and assembly of Mil Spec compliant electronics and optics is a task designated for the Prime Contractor.

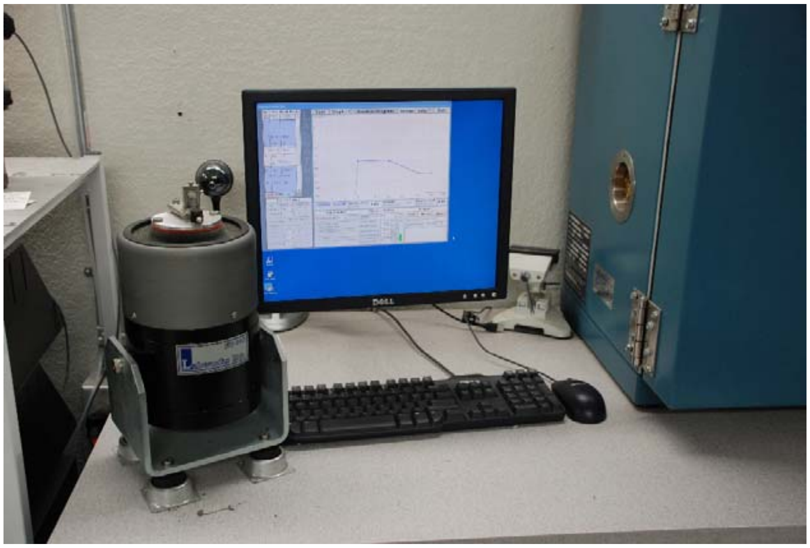

Figure 18 Shock and Vibration Test Station

4 Base Period Deliverables

4.1 Monthly Technical Reports
4.2 Final Reports
4.3 Fully functional Affordable Missile Warning System Sensor, not necessarily in full compliance with Military Specification 81OEIF.

Monthly technical reports and this final report were all completed and delivered in a timely manner. A fully functional Affordable Missile Warning System Sensor was delivered to the prime contractor. At the request of the TPOC, documentation for a second fully functional Affordable Missile Warning System Sensor was delivered to the Navy in lieu of the actual device. Delivery was deferred in order to expedite additional testing at the Eddy Company's facilities.

5 Conclusions

In response to a call from the Navy STTR program, the Eddy Company teamed with JHU/APL to develop a low-cost missile-warning sensor. Under an initial Phase II STTR award, a prototype AMWS system was designed, fabricated and tested in the field. The system was developed with a 100x100 degree field of view and a form factor consistent in size to existing missile warning systems. During the second Phase II STTR award Base Period the manufacturability and durability of the AMWS MOF was addressed. Several manufacturing challenges were overcome and a smaller, more consistently manufacturable, and more durable MOF product is now in place. Several accessories components have also been developed for heater control and regeneration.

The out of band rejection and in band sensitivity of the MOF is consistent with the prior generation. Light scatter that reduced the performance of previous prototypes has been substantial reduced with this generation, though measurement of the improvement is pending live fire field testing.

The Wide-Eye system's MOF design is now complete and has started pre-production fabrication. The Wide-Eye system electronics evaluation design is now complete and ready for both field testing and operation lifetime monitoring.

Investigation of the operation lifetime of the Wide-Eye system demonstrates that extended (>5,000 hours) operational lifetimes are practical and that the critical MOF component can be quickly regenerated in the field for even greater extended lifetime capability. Technical risks for the project are now low as the major feasibility and producibility issues have been resolved. The Base Period Milestones were completed on schedule and within budget.

6 Recommendations

Following successful completion of the STTR phase II Base Period activities we recommend continuation into the Option Period activities. No amendments to the Option Period tasks are requested at this time.

Further discussion about the need for, and possible ramifications of, field re-activation of the AMWS' internal MOF would be helpful in directing the program efforts.

7 Appendices

7.1 Appendix 1: Andor Camera Specification Sheet

7.2 Appendix 2: JHUAPL - Eddy Company Base Period Final Report

7.3 Appendix 3: Eddy Company MOF Final Acceptance Report Form

7.4 Appendix 4: Eddy Company MS-418 MOF Heater Controller Manual

8 References

1. Erlandson, R.E., and Hargis, C.B., JHU/APL STTR Phase II Final Report Affordable Silicon Based Visible/Near Infrared Missile Warning Sensor, June 2006
2. Gibson, D.M., O'Marr, G., Spisz, T., and Mehta, N., Pendine Final Report, 2004.
3. Rodgers, W., Erlandson, R.E., and Hargis, C.B., Affordable Silicon Based Visible/Near Infrared Missile Warning Sensor, Document: STTR Phase I Final Report (N03-T020), 22 January 2004.
4. Hargis, Erlandson, and Rodgers, Low-Cost Missile Warning Sensor, MSS IRCM Conference, April 2005
5. Ring, L., Rodgers, W., Hall, I., Monthly Progress Reports 1-15, February 2008 to February 2009.

9 Abbreviations and Acronyms

AMWS	**Affordable Missile Warning Sensor**
CCD	**Charged Coupled Device**
DIRCM	**Direct Infrared Counter Measure**
MOF	**Magneto Optical Filter**
COTS	**Commercial Off-the-Shelf**

Text in italics was extracted from the N00014-08-0121 contract Base Period Task list.