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Opto-Mechanical Assembly Procurement for the National Ignition Facility

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ABSTRACT

A large number of the small optics procurements for the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL) will be in the form of completely assembled, tested, and cleaned subsystems. These subsystems will be integrated into the NIF at LLNL. To accomplish this task, the procurement packages will include, optical and mechanical drawings, acceptance test and cleanliness requirements.

In January 1999, the first such integrated opto-mechanical assembly was received and evaluated at LLNL. With the successful completion of this important trial procurement, we were able to establish the viability of purchasing clean, ready to install, opto-mechanical assemblies from vendors within the optics industry. 32 vendors were chosen from our supplier database for quote, then five were chosen to purchase from. These five vendors represented a cross section of the optics industry. From a "value" catalog supplier (that did the whole job internally) to a partnership between three specialty companies, these vendors demonstrated they have the ingenuity and capability to deliver cost competitive, NIF-ready, opto-mechanical assemblies.

This paper describes the vendor selection for this procurement, technical requirements including packaging, fabrication, coating, and cleanliness specifications, then testing and verification. It also gives real test results gathered from inspections performed at LLNL that show how our vendors scored on the various requirements.

Keywords: Opto-Mechanical, assembly, NIF, packaging, shipping, specifications, procurement**,** MIL-STD-1246C, surface cleanliness

1. INTRODUCTION

The National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL) is a $1.2-billion laser project now under construction. To complete the world class facility, approximately 24,000 small optics are required. 60-80% of the small optics will be supplied as part of assemblies with stringent cleanliness, wavefront, and photometry requirements. The 192 beam laser employs a modular architecture comprised of many Line Replaceable Units (LRU)[1]. One of these LRUs is the Input Sensor Package (ISP) [2], that contains the M1 and M2 mirror assemblies. The M1 mirror serves as a turning mirror that also allows a fraction of the beam to leak, which feeds a signal into the diagnostics side of the ISP. The M2 is a maximum reflector mirror used to turn the beam within the ISP. This paper summarizes the requirements of these assemblies, and compares them with the results. It also details the important requirements, giving someone familiar with optics fabrication and coating a good idea of what is involved in the manufacturing and testing of the units. The technical requirements for these assemblies are specified clearly in several assembly and component drawings, and other procurement documentation. All dimensions and tolerencing for LLNL optics and opto-mechanical components are specified per ASME Y14.5[3] and ISO 10110.[4,5]

1.1 OBJECTIVE OF THIS PROCUREMENT

a) To see if our cleanliness requirements are realistically attainable within our cost target
b) To better understand the cost differences in purchasing clean assemblies versus purchasing the components and integrating them ourselves
c) To prove that weather large or small, the average precision optics company can effectively and efficiently expand their capability, or partner with someone that already has that capability, to provide opto-mechanical assemblies for the NIF
d) To gain a better understanding of the capabilities of the average precision optics company and uncover any stumbling blocks in the process of procuring these precision cleaned, mounted and coated, three inch mirrors in mounts as an assembly

2. VENDOR SELECTION

The vendor selection used for the ISP M1 and M2 mirror assemblies was not typical of the process that will be used to purchase most NIF small optics. A cross sectional approach was used, choosing 32 vendors from our database to solicit for quotation. 18 vendors responded with quotations which were evaluated by LLNL staff before five vendors were selected to purchase from. The group of five vendors are categorized in the following manner: three catalog suppliers, three involved in partnerships (with this procurement), two low cost suppliers, one precision coatings house, and one international partnership. The price range of the 18 bids is extremely broad. We can easily meet our $1100 per unit cost target when purchased in production quantities of 50 or more. We purchased a total of five units, three of the M2 mirror assemblies, and two of the M1 mirror assemblies.

3. TECHNICAL REQUIREMENTS

The physical dimensions of the elements are three inch diameter BK-7 mirrors, one half inch thick, ground edges with the drawing and serial numbers, masked and sandblasted into the edge surface. Laser ablation is another allowable marking technique.

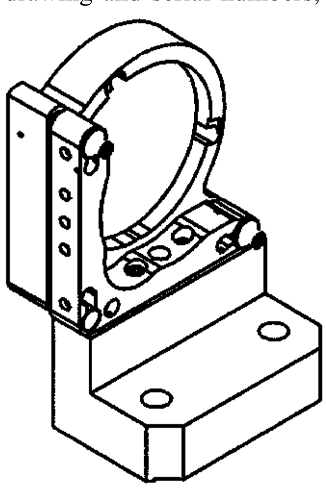
Figure 1

Optical surfaces are to be polished l /50 RMS and l /12 peak-to-valley (P-V) (where l = 633 nm) tested at zero degrees, angle of incidence (AOI). Phase measuring interferograms are required, removal of piston and tilt allowed, but no spatial filtering allowed. Up to 3% of the area may be excluded when testing the P-V surface figure. A key requirement is that all specifications apply after coating, mounting, assembly, and shipping. The goal is to be supplied with an assembly that is tested and ready to install and align.

The coating specifications on both the M1 and M2 mirrors apply at 45∞ AOI, and are to be tested at a wavelength of 1053 nm. Both require a laser damage threshold of greater than 5 joules/square centimeter, with a 3 nano-second gaussian pulse.

The M1 mirror is to have both front and back surfaces polished flat to a ÷P3[4,5] finish, with the front surface having a 30' wedge. The front surface is to have a partial reflecting, dielectric coating. This surface must reflect ≥ 99% (S Pol.) and transmit ≥ 0.25% (S Pol.). This allows the coater 0.75% tolerance band to work within. The back surface of the M1 mirror is to have a dielectric anti-reflective coating applied, that will reflect < 0.25% (S Pol.).

The M2 element has the front surface polished flat to a ÷P3[4,5] finish, and the back surface ground. The front surface is to have a highly reflective dielectric coating applied, reflecting > 99.5% (S Pol.).

The mounts are specified as Newport 3" Ultima (P/N U300-AC28) kinematic type mirror mount or equivalent (to be approved by LLNL)[6]. Manufactured aluminum risers (per LLNL drawing) are to be attached to the bottoms of the mounts, as to place the centerlines of both mirrors four inches above the optical tables they will be mounted to. See Figure 1.

LLNL requires that the vendors supply two hard copies of inspection data with the tested assemblies and a brief description of testing procedures and test equipment used.

4. PACKAGING AND CLEANLINESS REQUIREMENTS

It is required that the mirror elements meet their respective specifications while in their mounts and after shipping. The other significant requirement is that the assemblies be delivered clean, to Level 100A[7] per MIL-STD-1246C.[8] Not to be confused with a Class 100 cleanroom[9], Level is a measurement of particulate and non-volatile residue that resides upon a given surface. Vendors are given copies of helpful LLNL generated "MEL" reference documents[7], as guides to help them achieve this level of cleanliness on aluminum and glass parts. LLNL will verify the cleanliness level on a statistical basis.

Completed clean assemblies must be adequately packaged including double bagging and sealed in cleanroom compatible nylon or other suitable bags to maintain Level 100A. They must be packaged in such a manor as to maintain wavefront, coating performance, cleanliness level during shipment, and for a period of twelve months after being received at LLNL. The intent is to use these assemblies as shipped, without further cleaning.

Since vendors are required to ship optics in their mounts, there is a certain risk involved. During the quotation stage, we asked that the assemblies be shipped in a reusable PETG container (polyethylene terphthalate, a readily available, low outgassing, thermoplastic used in the packaging industry), that could be vacu-formed into a clamshell style protective case. We envision something similar to the PETG cases that we ship individual optics in. The inside would be formed into a shape that supports the assembly at the mount frame (not touching the optic) and the outside would be rectangular, to fit snuggly into a cardboard box. If thin materiel is used, the side walls would have a shock absorbing effect during shipping. After several vendors made exception to this requirement, it was decided that the cost of tooling to make a few cases was not justifiable for these small quantities. We would, however, like to see this type of case used when the quantities make it more economical, and the tooling costs could be easily recovered over a larger quantity order.

5. PACKAGING RESULTS

Three of the vendors devised covers that protected the coated surfaces of the optic (while in the mount) from chafing against the packing materiel. One vendor used a clever, screw on, two-sided Delrin cover. Another vendor used anodized aluminum sheet metal covers. The third vendor designed a special, snap on, clear plastic PETG cover that really showed some ingenuity. All of the assemblies were at least double bagged, then covered in bubble wrap, and packed in a cardboard box with either contoured foam, peanuts, or more bubble wrap. One vendor took the well-packed box, glued on four soft foam corners, then packaged it inside another fitted box. In one case, the companies engineering staff was not sure the optic could survive the rigors of shipping, and were concerned the high contact stress of their kinematic mounts clamping screws would result in a chipped or broken mirror in transit. They assembled it locally, then double bagged and loosely packed it in an open box. I took delivery at the vendor's facility, then transported the assembly to LLNL on the front seat of a car. Other than the one hand delivery, no special shipping arrangements were made. Two shipped UPS, one Federal Express, and one DHL from overseas. All five arrived in good condition. In all cases, the packaging was sufficient to provide adequate protection from damage. We learned that with attention to detail, vendors can design a shippable mount and optics package, which can survive standard shipping and handling practices.

We also asked that the first bag be purged with filtered dry nitrogen, to displace any particulate-containing air, before heat sealing the bag. It has since been discussed that a dry gas may not be the best thing for coated optics, as it may dry out the coating and change its reflectivity. This requirement will be changed for future procurements.

6. CLEANLINESS TEST RESULTS

After unpacking and making notations for our file, we proceeded to evaluate the cleanliness attained on these particular parts. Of the five vendors, two cleaned the parts themselves, following guidance contained within the LLNL documentation, help from LLNL staff, and results of their own cleaning research. Two of the vendors, partnered with a well known precision cleaning company, familiar with MIL-STD-1246C and familiar with cleaning practices that will ultimately result in Level 100A clean surfaces. One vendor partnered with another optics company, that is already a supplier of cleanroom-ready sub-assemblies to the semi-conductor microlithography industry. The partner inspected, cleaned and packaged the assembly at their facility.

Few vendors can inspect for Level 100A clean surfaces themselves. LLNL has developed it's own prototype Cleanliness Verification System (CVS)[10] to help evaluate surface cleanliness on the NIF project. Not only does this system count particles gathered from the surface under test, but it sorts, bins, and counts them before calculating the MIL-STD-1246C cleanliness Level. The actual sampling of particles must be performed in a Class 100 cleanroom or under a Class 100 clean bench (using cleanroom dress protocol). The sample may, however, be taken in another facility, and the sample transported to the CVS for analysis.

During cleanliness swipe testing, a background sample was taken to increase the accuracy of the test. The area to be tested was measured and recorded, in square inches, for later input into the CVS. [10] A clean sample filter paper was installed into the special swiping tool, and a technician swiped the predetermined area of the assembly in a repeatable and controlled manner. The sample was then removed from the tool and loaded into a custom portable cassette. Once loaded into the cassette, the sample was protected from further contamination, thus preserving the integrity of the test. The sample was then transported to the inspection lab for evaluation on the CVS. The inexpensive cassettes and sample papers are treated as consumables, discarding the used papers, cleaning and recycling the cassettes.

The CVS consists of a microscope mounted CCD camera, two-axis motorized stage and driver, custom software, and a desktop computer. Our system is located within a Class 100 cleanroom, where our technicians perform the sample evaluation. To perform an evaluation, the technician first loads the cassette containing the background sample and lets the semi-automated system measure the background error. This value is checked to see that it is below the acceptable limit. Next, a part surface sample cassette is loaded onto the motorized stage, where the CCD camera views the sample through the clear cassette case. Calculations are performed automatically and a summary sheet with the derived cleanliness level and other data of interest is printed.

For production, in-process statistical sampling of both the glass and metal components should be performed. During this particular test, we were only able to sample easily accessible portions of the aluminum mount. Also, MIL-STD-1246C suggests an area of one square foot be sampled. We sampled an area much less that that, so this test did not allow as much averaging as the specifications allows.

Four out of five vendor assemblies passed with Level 100A or better, successfully demonstrating that this level of cleanliness can be achieved in a commercial environment. See figure 2. We learned that small optics vendors having good cleaning capability, or willing to partner with someone who does, can meet this challenge. Understanding cleanroom practices and MIL-STD-1246C, paying attention to detail, and following LLNL's MEL guidelines all help the vendor meet this specification.

Cleanliness Summary

	Cleanliness level achieved per MIL-STD 1246C ≥10m particle size						
Vendor							
	Level 1246C	visual inspection grade			packaging notes		
M1 assy			1= least particles				
Vendor A	99A	pass	5	dust fingerprints on optic, received hand delivered			
Vendor B	110A	fail	no data	popcorn and bubble wrap, 5 bags, protective cover			
M2 Assy							
Vendor C	92A	pass	3				
Vendor D	84A	pass	1	excellent	protective cover		
Vedor D II	100A	pass	4	excellent	protective cover		
Vendor E	92A	pass	2	packed well, but foam particles everywhere			
				protective cover			

NOTES: Total area tested was much less than 1 sq./ft.
Tested for particles only
Swiped aluminum mount only
Cleanliness level calculated per MIL-STD 1246C ≥10m particle size

Figure 2.

7. METROLOGY TEST RESULTS

Reflected wavefront measurements were made on all of the vendor supplied M1 and M2 mirrors for surface verification. The purpose of these tests is to verify performance of the optical wavefront of the ISP mounted mirrors in their respective mirror mounts to meet as mounted, post shipping, requirements. The current reflected wavefront specifications for both the M1 and M2 mirrors for the ISP, after coating, are a P-V of < 1 /12and a RMS of < 1 /50 .The called out test aperture per the drawings for both optics, after coating, is 60 mm centered on the part. The instrument used for these tests was a Zygo GPI XP/HR 4-inch aperture phase measuring interferometer. The test wavelength of this interferometer is 632.8nm. All of the mirrors were set on the interferometer air ride table, inside of the interferometer enclosure and were allowed to equilibrate in excess of 24 hours before testing began. The MetroPro® software parameters were set as follows for our tests:

Scale factor: 0.5	Phase averages : 4	Intensity averages: 1	Phase resolution: High
Min Mod %: 7	Min Mod Points: 50	Terms removed: Piston and tilt, No spatial filtering	

The mirrors were set up at a distance of approximately 30 mm from the transmission flat whenever possible. M1 mirrors require measurements of both surfaces. The M1 mounts were turned around to measure the second surface, increasing the distance of the second surface to the transmission flat to approximately 100 mm. Poster board was used as an additional enclosure around the test optics to reduce the thermal effects of our test environment.

The "process stats" option of MetroPro® software was activated during the measurements to check for repeatability between acquired data sets. Each mirror was measured ten consecutive times with one minute intervals between measurements. The P-V was monitored during this process to ensure that there was no more that a .002 wave standard deviation between each measurement. Once this was confirmed the last of the ten data sets was saved as a representation of that optics measurement.

All five mirrors were tested as received from the supplying vendors. See figures 3 and 4. They were removed from their packaging, allowed to equilibrate on the interferometer for at least 24 hours and tested for surface figure compliance of P-V and RMS specifications. Every one of the mirrors tested, passed the P-V and RMS wavefront requirements. Our reflected wavefront measurements have shown that packaging and shipping had minimal, if any, effects on wavefront performance. Further, the differences between vendor test data and test data taken at LLNL are so small that they could be attributed to differences in test equipment and test set-up. All but one, met our wavefront requirements. The non-conforming surface was no surprise, as LLNL was notified in advance of shipment. After a Materiel Review Board ruled the part usable for this test, the vendor was given approval to ship.

M1 Mirror Data

OPTIC MANUF. Type & P/N	Vendor PV mounted coated	Vendor Rms mounted coated	Vendor terms removed	LLNL PV mounted coated	LLNL Rms mounted coated	LLNL terms removed	Pass/Fail
Vendor A	.061 wv	.012 wv	Tilt	.051 wv	.009 wv	Piston/Tilt	Pass
M1 Mirror							
Left Surface/Partial Reflector							
Vendor A	.073 wv	.018 wv	Tilt	.038 wv	.006 wv	Piston/Tilt	Pass
M1 Mirror							
Right Surface/AR							
Vendor B	.078 wv	.018 wv	Piston/Tilt	.049 wv	.009 wv	Piston/Tilt	Pass
M1 Mirror							
Right Surface/AR							
Vendor B	.103 wv	.023 wv	Piston/Tilt	.064 wv	.012 wv	Piston/Tilt	Pass
M1 Mirror	.037 wv	.005 wv	Pst /Tlt /Pwr				
Left Surface/Partial Reflector							

Specifications: P-V < l/ 12 (.080) RMS < l/ 50 (.020 wave)

Figure 3.

M2 Mirror Data

OPTIC MANUF. Type & P/N	Vendor PV mounted coated	Vendor Rms mounted coated	Vendor terms removed	LLNL PV mounted coated	LLNL Rms mounted coated	LLNL terms removed	Pass/Fail
Vendor C	.038 wv	.005 wv	Tilt/Power	.077 wv	.017 wv	Piston/Tilt	
M2 Mirror				.051 wv	.007 wv	Pst/ Tlt/ Pwr	Pass
Vendor E	.066 wv	.014 wv	?	.089 wv	.018 wv	Piston/Tilt	
M2 Mirror				.074 wv	.014 wv	Pst/ Tlt/ Pwr	Pass
Vendor D	.065 wv	.012 wv	Tilt	.072 wv	.014 wv	Piston/Tilt	
M2 Mirror				.045 wv	.008 wv	Pst/ Tlt/ Pwr	Pass

Specifications: P-V < l/ 12 (.080) RMS < l/ 50 (.020 wave)

Figure 4.

8. PHOTOMETRY TEST RESULTS

Our specifications require the vendor to make photometry tests on the coating witness samples. With one exception, the vendors chosen for this procurement could only supply a transmission measurement on these coatings due to equipment limitations. Most commercial spectrophotometers are not large enough to measure a three inch mirror, and are not equipped to make sensitive reflectivity measurements at 45∞. Nor do most have the highly reflective calibration standard required to null the test equipment to perform a reflectivity measurement. When evaluating the vendor transmission data, one must assume that very low transmission percentages mean the coating is a high reflector. This also assumes a low absorbing, low scatter substrate and coating.

LLNL Photometry tests were performed on a custom built ratio reflectometer, capable of measuring transmission and reflection at one specific wavelength. Several different wavelengths are available for this machine as required. In addition, our equipment can measure coating spatial uniformity over the surface. We measured all five parts at once, to minimize any internal equipment induced inconsistency errors. All of the vendor coatings met our specifications. See figure 5.

	Vendor Data				LLNL Data		
Vendor	HR	Trans.	AR		HR	Trans.	AR
M1 Assy							
Vendor A		0.3	0.02		99.81	0.4	0.14
Vendor B		0.7	0.2		99.56	0.6	0.04
M2 Assy							
Vendor C		0.06			99.6		
Vendor D	99.8				99.55		
Vendor E		0.26			99.65		
Note: All values are in percent measured @ 45deg. AOI and 1053nm All values are in "S" polarization							

Figure 5. Photometry test results

9. SUMMARY

This procurement shows it is possible to purchase NIF-ready assemblies at this level of integration, as four out of five vendors met or exceeded all specifications. We proved that if a vendor understands the specifications, and pays close attention to detail and guidelines, most can meet this challenge. This demonstrates assemblies, such as M1 and M2, can be purchased on a cost-competitive basis.

10. ACKNOWLEDGEMENTS

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11. REFERENCES

[1] D.M. Aikens, LLNL, "National Ignition Facility small optics overview", *SPIE*, Vol. 3782, 63 (1999)
[2] R.D. Boyd, et al., LLNL "Beam Diagnostics, alignment system for the NIF" Input Sensor Package, *SPIE*, Vol. 3782, 65 (1999)
[3] American Society of Mechanical Engineers, "Dimensioning and Tolerancing, an ASME national standard for engineering drawing and related documentation practices", *ASME* , New York (1995)
[4] International Standard ISO, "ISO 10110 Optics and Optical Instruments, preparation of drawings for optical elements and systems" International Organization for Standardization, *Geneve*, Switzerland (1996)
[5] D.Y. Wang, et al., LLNL, "Surface imperfection specification, optics drawings and ISO 10110 for NIF optics", Vol. 3782, 66 (1999)
[6] T. McCarville, LLNL, "NIF small optics mirror mount specifications", Vol. 3782, 70 (1999)
[7] I.F. Stowers, LLNL, "Optical cleanliness specifications and cleanliness verification" Vol. 3782, 69 (1999)
[8] MIL-STD-1246C, "Military Standard 1246C, Product Cleanliness Levels and Contamination Control Program*" Institute of Environmental Sciences*, 940 E. Northwest Highway, Mt. Prospect, Illinois tel. 847-255-1561
[9] US Government, "Federal Standard 209E, Airborne Particulate Cleanliness Classes in Cleanrooms and Clean Zones" *Institute of Environmental Sciences*, 940 E. Northwest Highway, Mt. Prospect, Illinois tel. 847-255-1561
[10] Cleanliness Verification System, for more information see http://www.llnl.gov/IPandC/op96/08/part-clean.html