ELECTROFORMED SINGLE PIECE CASSEGRAIN MIRROR

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SUMMARY

Serious testing of imaging IR cooled detectors and focal plane arrays is expensive and difficult due to the lack of versatile coupling optics. Often the need is for broad band and very low level images to be coupled to an array detector which is planar. It is imperative that the signal-to-noise be optimized. The two approaches considered were modification of the dewar and fabrication of image couplers. The first approach requires suitable cooled baffles. This does not provide for control of the desired field of view other than to provide a stop or an iris. Beam diameter and focus are controlled only from outside the dewar. This approach also does not provide a versatile system which is easily modified for a number of applications.

The second approach is to design a modular image coupler and develop a low cost manufacturing process to produce a variety of similar components to simplify testing of cooled optics including focal plane arrays. In most cases the optical system must be small, light, free of stray light effects and yet cooled to liquid cryogenic fluid temperatures.

Mirrors offer nearly complete absence of chromatic aberration and attenuation with respect to broad wavelength requirements, unlike lenses. Aspheric mirrors which produce the image quality needed, have previously been notably expensive and difficult to machine and align. Manufacturing techniques for fabricating aspheric afocal and imaging systems by use of replication electroforming and single point diamond machining have demonstrated that custom designed aspherical mirror systems can be readily produced. Image couplers following principals of Cassegrain optical systems have been designed and fabricated.

A four mirror concept has been developed at UAH which enables an extremely compact folded image system to be contained within a small housing attached to a conventional low cost cryogenic dewar. The design of the system can be performed with conventional ray-tracing software and converted to actual hardware with minimal effort by single point diamond machining a standard aluminum blank into a mirror mandrel. This mandrel is then coated with appropriate layers of electroplated metal forming both mirrors and the supporting housing and ribs in one piece completing the telescope. The mandrel is removed with an alkaline etchant and the resulting single piece optical component is ready for mounting in the system without further alignment. A modular afocal beam expander was designed and built.
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INTRODUCTION:

Focal plane array research is constrained by the fact that versatile, modular test stations are not available commercially. Typical imaging detector tests mandate fabrication of expensive unique image coupling devices simulating the actual systems under consideration. Stray light and field-of-view are often not well controlled during tests, leading to lowered signal-to-noise levels and ambiguity regarding performance of an actual system. The University of Alabama in Huntsville has developed an inexpensive process for producing image coupling devices suitable for testing and developing cooled focal plane array systems. Model image couplers for cryogenically cooled focal plane array detector research have been produced by this process. Electrodeposition procedures and precision single point diamond machining, combined with optical design procedures, permits fabrication of unique optical systems.

Applications include laboratory and field studies of beam expanders, broadband and thermal image couplers suitable for non-contact measurement, IR Spectroscopy and durable lightweight compact telescopes which image on focal plane arrays. Low cost, high strength, small and lightweight deployable systems are also candidates for this technology.

This project has provided technology for producing electroformed replicate reflective optical systems which can be taken from concept through fabrication at low cost and minimal effort. Optical systems specifically designed to couple information to cooled detectors have been considered. The use of aspheric reflective optics is used to achieve broad bandpass, minimize chromatic effects and control stray light, coma and aberration. Additional control is achieved by selective non-reflective coatings applied to specific surfaces.

A four optical surface design has been employed using two small one piece interchangeable Cassegrain mirrors to achieve a wide range of optical properties. In this modular fashion, almost unlimited imaging or afocal collimating designs can be readily fabricated with excellent optical properties in very compact folded optical path configurations. Aspheric designs are used permitting excellent control of distortion.

DISCUSSION:

Testing of cooled optical systems and in particular focal plane arrays, has often not revealed the true behavior of the final system design. Overlooking problems involving field of view and stray light by using inexpensive dewars with no more than a window to allow imaging of a scene upon the detector can lead to serious design errors in the final product.
Notably an accurate model of the system using conventional practice may require an expensive mock-up approaching the value of the system under consideration. Field testing of true scenes has also been a formidable task. A low cost, modular image coupler approach was selected to provide an improvement over the present practice. Small reflective optical systems which can be used inside a commercial dewar are not available.

The use of replication processes to fabricate optical components has been reported. Commercial electroformed optics are available but do not include aspheric designs or compound mirror sets. The quality of these devices is usually less than required for imaging optical systems.

Two methods of improving the signal-to-noise of test systems are baffling of the optical path and closed path image coupling optics. The final device under consideration may consist of a complex optical system comprised of both.

An important aspect is the control of stray light in the form of radiant heat from the walls of a cryogenic dewar as well as the reflection of light from internal components. This is best achieved in an enclosed system with all optical paths defined, simulating the actual design under consideration. By cooling the entire enclosed image coupling assembly the apparent temperature of all other components is not radiant upon the detector.

By fabricating telescopes or other optical components using a single piece construction of only one material or materials with similar isotropic thermal expansion properties, it is in principal possible to completely eliminate the optical distortion effects of thermal contraction or expansion. The conic constants for aspheric mirrors remain constant while the physical dimensions change due to the contraction or expansion induced by thermal changes. The optical properties are essentially the same at any temperature so long as the assembly is of virtually the same thermal expansion material. The materials selected include either copper or nickel structures with or without thin gold reflecting surfaces which have closely matched thermal expansion properties. Blackened etched aluminum was selected for non-reflecting housing surfaces not attached to the mirrors. The designs may be easily repeated. The units developed can be coupled directly to the dewar cold finger for efficient cooling.

This task has defined low cost processes which expedite accurate design and fabrication of realistic broadband image coupling systems. The use of single point diamond machining and an enclosed one piece design using a soluble mandrel permit extremely rugged aspheric components to be designed and built with high accuracy. Controlled low-stress electrodeposition processes
reduce distortion. By using the UAH design, an entire four reflector cooled telescope can readily be as small as 30 mm diameter and 50 mm in length. The total weight of the optics can be 30 grams or less with an individual telescope weighing only a few grams. The design developed permits face to face pairs of Cassegrain or other two mirror systems to be developed for a wide variety of applications. Modular mounting components enable additional versatility.

Stray Light Control:

The imaged field of view for an imaging array must be controlled to avoid excessive noise levels. For the case of a single element detector such as those used for temperature measurements, spectral response and intensity sensitivity are the requirements. This type system may not require imaging if the spectral response can be demonstrated to be adequate. However it is still requisite that the signal observed at the detector is an accurate view of the scene of interest for accurate measurements, particularly when low temperature measurements are of concern. Most test setups have only a small window and do not account for stray light control. The field of view is often disregarded with no focusing or collimating optical components.

Signal to Noise Improvement:

1. The detector must be in direct contact with the cold finger or cooled chamber wall.

2. Only light from the selected FOV must reach the detector. Scattered and reflected light (or heat) must not subsequently be reflected back into the sensor.

3. Stray light (or heat) must not be reflected tangent to input baffles, or mounts reaching the sensor.

4. The FOV must usually be of infinite depth and rapidly convergent upon a flat detector array within the system. This in turn complicates the design of a system in terms of through focus distortion.

5. Obscuration should be less than 20% of the diameter of the imaging concentrator to avoid serious loss in signal intensity when low level signals are encountered. This is very difficult in compact two mirror Cassegrain or Ritchey-Cretien designs since the secondary mirror necessarily obscures the signal and proper coma correction is difficult without increasing the size of this mirror.

This task has identified that by using a unique four mirror system, folded ray paths can be made to rapidly converge an image accurately upon a flat sensor array element of 50X50 microns or
less over an area of 0.41 square centimeters. In the present face-to-face Cassegrain image coupler design the optical path can be corrected to minimize obscuration at the expense of imaging quality in the smaller mirror which is the primary. Subsequently the image may be re-corrected to provide good imaging in the smaller mirror of the second pair which is the secondary. This design yields a reduction in the obscuration observed.

Applications:

- Thermal Imaging
- Image Couplers
- Focal Plane Arrays
- Low Resolution Detectors
- Non-Contact Temperature Measurement
- Spectroscopy
- Selective FOV
- Remote IR Detection
- Stray Light Control
- Collimated Beam Expanders
- Multiple Reflection Designs
- Chromatic Aberration Free Designs
- Broad Band Operation – IR to UV
- Minimized Coma
- Minimized Obscuration
- Mass Production
- Cooled Interchangeable Assemblies
- Collimated Designs
- Focused Designs

Deposition Processes Permit:

- Aspheric Designs
- Low Cost Accurate Optics
- Light Weight
- Elimination of Alignment
- Rapid Replication or Design Change.

ACCOMPLISHMENTS:

The fabrication of a specific dewar design would only serve to satisfy the needs of an individual requirement. Proper shielding and coating of the cryogenic dewar and associated housing components for an experimental set-up would not likely satisfy a large number of individual tests. Therefore the approach pursued was to design a modular optical image coupler which could be modified easily to accomplish the task of coupling sensor elements such as focal plane arrays to the actual scene of interest while controlling the field of view and stray light. The use of compact face-to-face Cassegrain mirror pairs eliminates extraneous light from reaching the detector array.
Fabrication processes were developed to investigate low cost reflective optics of this type to circumvent the problems of baffling and coating the dewar walls as described. By using reflective optics many types of detectors and detector systems can be isolated when an environmental test is required. The use of a reasonably long standoff reflecting objective inside a system of shielding will enable focusing or defocusing a source to match the needs of a given detector system. Reflected light from a mirror has no chromatic aberration and as such mirrors can be focused in the visible and used from UV to IR with no change in focus and no variation in chromatic aberration correction. Thus the total aberration e.g. spherical, may be about one fourth that of comparable quality lens systems. The principal disadvantage is that imaging devices incorporating additional optics are inherently dimmer, i.e. the image formed is less intense than the object by the number of reflections times the reflectivity even in an off axis system. When central obscuration is also an issue, the intensity suffers as a function of the required obscuration.

Collimating afocal and imaging optical systems have been designed. Included is a very compact four mirror high order aspheric system designed to image to a 50x50 micrometer pixel in a plane array of 128x128. Optical design computer codes were used to develop the optical designs taking advantage of the aspheric options to minimize coma and distortion due to the planar focal requirements. An additional computer simplification was performed from this data to develop a table of values including all required machining information along with the optical surface data for input to the UAH, diamond machining center to fabricate the electroforming mandrel. Cooled mirror telescope designs can be ready for input to manufacturing in one day. Diamond machining can be implemented quickly since master programs and blanks exist at this point. Diamond machining has been used to fabricate aluminum mandrels with external optical surfaces enabling inspection of the surface quality. An optional gold optical surface is formed by depositing a layer of gold prior to copper or nickel. A copper mirror with nickel reflective surfaces is likewise produced by depositing a thin layer of nickel prior to the heavy copper deposit. These mandrels were then plated with a 0.040 inch coating of either copper or nickel to form the telescope with the optical surfaces inaccessible due to the re-entry shape obtained. The aluminum was dissolved away leaving a single piece mirror telescope including the secondary mirror support ribs. The one piece structure requires no alignment. Data analysis for modular pairs of mirrors has been completed and allows selection of pairs to produce afocal beam expanders with selective gain from 0.2 to 5.0. Diffraction limited optics are entirely possible including diffraction grating coatings and AR coatings. Engineering properties of materials may be selected. Copper may be used for high thermal conductivity and nickel for strength in light weight designs. Vacuum and electrodeposition combinations are possible.