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Specifications for metal optics

William J. Brady
Applied Optics Center Corporation
Burlington, Massachusetts 01803

Abstract

The designer of a reflective system must make some fundamental decisions regarding performance, environment, weight, component interfaces and cost, which ultimately affect procurement and manufacturing specifications. From the conception of system philosophy, scope and performance criteria, each component must be analyzed for function, integrity and manufacturability, and each phase of processing defined, in order to insure design requirements.

Introduction

The use of metal for optical reflectors is increasing. Unfortunately, most optical systems designers are not thoroughly conversant with metals as mirror substrates. From a material selection point of view, metal is a much more versatile material from which to make a mirror than glass. Metals can be accurately machined, drilled, tapped and bolted to other metals. The assemblies can then be used in extremely hostile environments, such as deep space or during high thermal loading. The weight constraints imposed by satellite limitations alone make beryllium, for instance, an ideal material from which to make components or even entire optical assemblies.

Material

What kind of metal? Precision optical reflectors have been made from aluminum, beryllium, copper, brass, nickel, a variety of steels and molybdenum, to name a few. From a manufacturer's point of view, the more popular materials are aluminum or beryllium, electroless nickel plated, either of which is capable of producing and maintaining diffraction limited tolerances.

The decision of which type of metal depends primarily on environment, weight and cost. Consideration must also be given to anisotropy, thermal conductivity and elastic modulus. After material selection and complete design analysis, specifications for procurement and processing can be initiated.

The question of material and process specification is directly related to component use. The finished product and it's environment dictate the procedures used to manufacture that component. The supplier will need, at a minimum, the following information:

1) Material type alloy and temper. Selection should be based on operating and non-operating temperature requirements, thermal coefficients of expansion and anisotropy.
2) Vibration, shock and inertial characteristics. Aspect ratio, mass and stiffness must be considered when selecting material.
3) Scatter requirements should be considered, as some materials will exhibit grain boundaries which will limit the micro smoothness obtainable. This particular requirement is not necessarily a problem, as nickel plating will not change the basic properties of substrate selection and 'state of the art' scatter requirements are now obtainable.

Geometry

Material specification depends, to a great extent, on a component's geometry. The shape of an optic, it's thickness, accuracy and ability to be manufactured, are items which should be discussed with the manufacturer. Integral mounting, material interfacing, system housing and configuration, all impact system specification and, thereby, the individual component specification.

Optical Requirements

Be it a flat, sphere, conic or general asphere, the optician requires a well defined specification including:

1) Figure accuracy. Wavefront deviation, image size or slope error will do. Remember, the tighter the tolerance, the more expensive the component. Also related is the ability of the substrate to retain the surface figure, so make certain the material stiffness and aspect ratio are sufficient to do the job. Here again, your supplier can help.
2) Rolloff. Optical designers, regardless of the medium used, persist in allowing virtually no edge rolloff in their specifications. Allowances of as much as 10% of

diameter for centration and loss in edging is a standard for manufacture of refractive optics, a luxury the reflector doesn't have. A minimum of .050" on a radius for a round optic and more for eccentric geometries, would not be unreasonable.

3) Scatter characteristics. Electroless nickel mirrors are being produced which exhibit 'state of the art' scatter characteristics (typically 5-10Å microstructure). It may be of interest to note that electrolytically deposited gold or rhodium, possible only on metal substrates, will not degrade scatter characteristics as vacuum deposited coatings invariably will.

4) Reflectivity. The wavelength operating range and incident angle will indicate suitable vacuum or electrolytically deposited overcoatings. For many far infrared applications in an inert atmosphere, polished bare metal substrates may have sufficient spectral response so overcoating becomes unnecessary.

Operating and Non-Operating Temperature

The anticipated thermal excursion of the system can be 'built in' to the metal optic. Machining, plating and assembly stresses can be relieved by appropriate manufacturing techniques. From raw material selection to final optical assemblies, processes can be specified which control a component's physical properties. In a cryogenic environment, for instance, components and assemblies can be processed to perform in a virtually stress free condition. The metal optic integrally mounted to a like material housing eliminates bimetallic or glass to metal stresses. These are the types of applications where metal optics shine.

At this time, I would like to briefly illustrate a metal optic specification series.

A designer has a requirement for a diffraction limited parabolic reflector working at 1 micron, with the best available stray light rejection (scatter). The optic will operate in deep space and sun loading will occur. Weight limitations are stringent.

Beryllium with electroless nickel plating is chosen for it's physical characteristics and manufacturability. For heat dissipation, integral mounting to the instrument housing (also beryllium) is incorporated. A thorough design analysis is performed, parameters set and tolerances budgeted within the framework of existing manufacturing technology.

A toleranced mechanical drawing of the component is drawn up and the specifications are defined as follows:

A) Material Specification.
   1) This may be as simple as specifying a manufacturer's code, ie. HP-20, S-200, or a complete specification, including the chemical assay (% oxide, % impurities, etc...), physical properties (microyield, density, etc...). Pressing axis orientation to mirror orientation is specified. Pressing axis shall be oriented perpendicular to optical axis.

B) Machining Specification.
   1) For our example, beryllium should be progressively machined to keep residual stresses as low as possible. Several machining heat treats are performed and a dye penetrant inspection incorporated after etching to determine cracks (Mil-I-6866).

C) Plating Specification.
   1) Nickel plating: For our example, .004 to .006 inch of nickel will do nicely. The phosphorus content of the bath is altered to more closely match the bimetallic stresses of nickel to beryllium. Operating temperature will indicate to the plater how to achieve this.
   2) Artificial aging of the nickel is specified (heat treat) 350° for 4 hours, and a cyclic stabilization, alternate heating and cooling of the plated substrate.

D) Optical Specification.
   1) Surface quality, accuracy, clear aperture, focal length, etc...
   2) Our mirror is to be bolted directly to the instrument housing so pad to optical axis perpendicularity (self alignment) can be lapped in.
   3) A temperature cycle over the operating range after final polish is mandatory.
   4) Spectral response and scatter characteristics for our mirror would indicate electrolytically deposited gold and a final test of all optical functions.

Conclusion

The actual specification series for 'state of the art' metal optics depends on a number of parameters. From intended use, material selection and processing, through assembly, alignment and application, each manufacturing step requires analysis of impact on performance and cost. Each procedure must interface with subsequent procedures and be fed back into design requirements. The 'impossible' requirements of a few years ago are now being specified and manufactured. The free exchange of information embodied in symposiums like this, as well as improved communication between designer and supplier, promise to advance applicable technologies to as yet unimagined frontiers.

Questions and Answers

From Valerie Olson/Rockwell

Q: Would you always recommend heat treating after nickel plating?

A: Yes, as a quality control check of the substrate preparation. In the event of improper cleaning, the heat treating process (350°F for 4 hours) will cause blisters in the nickel plating.

From J. Appels/O.S.C.

Q: You mention Mil-O-13830 to specify metal mirrors. How do you apply this specification while we in the glass field (for which it was written) have so much trouble?

A: Without trying to take on the military specification establishment, I only meant to imply that metal mirrors can be optically specified and toleranced the same way glass mirrors are.

From Vernon L. Williams/Westinghouse Electric Corp.

Q: On a beryllium substrate with nickel plating, what is the maximum temperature for applying coatings (Ag, for example) which will not destroy the figure?

A: A.O.C. has successfully cycled beryllium mirrors from +1000°F to -411°F with no degradation of figure. Spinel overcoatings have been applied at 500°F, again with no degradation.

From (Not Identified)

Q: Is there a technique to know when you have reached a dead soft condition? Elastic methods to detect residual stress areas?

A: One method to detect residual stresses is an interferometric evaluation of the optical surface pre and post temperature cycling. If there is a change in the optical characteristics, the substrate has not been sufficiently stress relieved.

Comments

From J. Bagby/Hughes Aircraft, Culver City

I would suggest that instead of 200°F per hour cooling and heating rates, use 20°F/hour.

Author reply: We have quenched nickel plated substrates in liquid neon (-411°F) with no difficulty. I wouldn't recommend this on just any component, but, if warranted by in-use environment, this type thermal shock can be survived by metal reflectors which have been properly processed.

From J. Zimmerman/Honeywell Electro-Optics Center

Honeywell has had experience in plating of nickel on beryllium for cryogenic applications. Samples from four platers were evaluated (all supposedly to the same process specification). Two survived, two failed. On the failed units, the plating vendor indicated that they did not follow the specification exactly.

Author reply: Specifications are useless unless adhered to.