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Metal mirror selection guide update

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Abstract

Two additions to the popular "Metal Mirror Selection Guide" are proposed. To aid in specifying metal mirrors, some common terms and uses must be resolved. Mirror surface finish, contour, and outline shape, as well as aspect ratio, all affect both prices and quality. Part one definitizes these issues. Proper mounts for metal optics present a seemingly impossible design problem. Common design faults and their affects on optics present severe obstacles to proper system function. A well proven approach - called dual interfacing, has proven to be unusually effective in correcting these problems. Part two of this paper discusses and illustrates the problem as well as the working solution.

Introduction

In updating our booklet, "Metal Mirror Selection Guide" (SOR Report #74-004), we plan to add at least two new sections. This useful publication is now in its' eighth printing and third revision, which means approximately 8,000 copies have been requested and distributed.

The first addition will be an attempt to definitize common HEL mirrors and basic criteria for specifications based on our most recent experience.

The second addition will address the nearly impossible task of mounting metal mirrors, affect of mounts on performance, and suggestions for specifying an ideal situation.

Metal Mirror Definitions and Criteria

Common Mirror Configurations

The most common mirror configuration is a simple flat circular disc with beveled edges, and whose thickness is typically about 1/6 of the diameter. The surface is usually flat or spherically concave or convex and the clear aperture is about 80 per cent of the diameter. This is the least expensive type of mirror.

There are several other common shapes of mirrors frequently required for specific purposes. These include square and rectangular shapes, truncated mirrors, hole-coupling mirrors and scraper mirrors.

The difficulty and cost of square and rectangular mirrors is based on the diagonal dimension of the face and the length to width aspect ratio. The thickness should be at least 1/6 of the diagonal dimension. The edges are usually beveled. This shape is preferred to elliptical mirrors.

Truncated mirrors have one or more flat sides cut from the edge of the mirror to form a "scraper" edge. The side of the truncated section is usually razor sharp and back-tapered to prevent the beam from touching the side of the mirror as it passes the sharp edge. If the area of the missing truncated section is a large portion of the original mirror it may have to be temporarily replaced during the polishing operation to prevent edge roll-off. This process, called blocking, is more expensive, but is frequently required.

(Figure 1) Mirrors with coupling holes through the face are a very common requirement. They are used as input and output couplers, beamsplitters and spatial filters. The coupling hole is either straight through, i.e. normal to the face, or at some angle to the face, typically 45°, and may be round or rectangular shaped. The hole is usually characterized as having a razor-sharp edge. It may also be back-tapered to clear the beam, similar to a truncated edge, as described above, or it may have a counterbore relief from the back side. Mirrors with coupling holes are called coupling mirrors, not scraper mirrors. Multiple coupling holes, hole grating mirrors and Hartmann plates are often specified. Coupling mirrors usually do not require blocking the hole during polishing but the figure is held to the edge of the hole.

Scraper mirrors are designed to have the beam overfill the mirror, and the surface figure is held to the very edges. All edges are razor sharp and typically back tapered similar to truncated edges. These mirrors usually require blocking material around the edges during the polishing process to prevent edge roll-off. Scrapers are used in most unstable resonator laser cavities. If the scraper mirror requires a coupling hole in it, then it is referred to as a "scraper-coupler."

Other special shapes include axicons, waxicons, polygons and composite surface components, such as corner cubes and SPAWR integrators.

The importance of proper mirror thickness cannot be overemphasized. The mirror will distort its surface figure, due to its sheer weight, unless it is thick enough to provide the stiffness and rigidity to hold the required optical tolerance. The thickness should be at least 1/6 of the diagonal or diameter, and for water-cooled mirrors it may be 1/3 of the diagonal or diameter.

Mirrors which do not meet this minimum thickness requirement can be polished by attaching them to a stiff backup structure. However, upon detaching the mirror it will assume a badly distorted shape.

Surface Contours

While most mirrors are flat or spherically concave or convex, other common contours include cylindrical, parabolic, hyperbolic, ellipsoidal, conical, and toroidal sections. The preferred shape, from a manufacturing point of view, for cylinders, toroids and off-axis parabolas may be square, rather than round or rectangular, depending on the optical geometry.

Surface Finish

The optical surface figure and smoothness which may be attained is a strong function of the proper thickness, as described above, as well as the shape. Large mirrors can become quite heavy and various techniques are used to retain the required stiffness while providing some degree of light-weighting, such as pockets in the backup structure, or the use of honeycomb material.

The porosity of the material will ultimately determine the best RMS smoothness and dig specification that may be attained. Mirror materials must therefore be specially prepared for high quality mirrors.

Mirror Material

Copper, molybdenum, tungsten, beryllium, nickel, titanium and stainless steel are the most used materials for metal mirror surfaces. Aluminum is used quite frequently for the bulk material, but it is usually plated with the plating then being polished. Copper, molybdenum and tungsten are the most frequently used for the high energy laser systems because they provide the highest damage thresholds and optical performance.

Passive, actively-cooled and light-weight honeycomb mirrors are available in all of the above materials.

Mounting Metal Mirrors

With the advent of reasonable priced interferometers those of us who design or specify optical systems finally have learned that all mounts distort. Therefore, in updating our "Metal Mirror Selection Guide" SPAWR Optical Research, Inc. will add some material based on our experience in specifying the mounts as well as the mirrors. This section will also touch on good design practice for both simple passive mirror mounts and mounts for high performance cooled optics.

Let's examine the problem: What good does it do to specify your 12" diameter copper mirror as being flat, spherical or fitting some other wierd conical section to within a 20th wave at 0.5 microns if the mounting method destroys this figure? No matter how well the mount is designed and manufactured it will degrade the performance of the optical element which it holds. This has always been true in glass. Common methods of mounting metal mirrors in High Energy Laser Systems guarantee that this fact will not only continue to be a factor - it will have disastrous results!

With ten 1/4-20 tapped holes for mounting, your copper, molybdenum, tungsten or titanium mirror can have a 3000 inch-pound mating force, insuring that it, including its optical face, will assume the same shape as the surface of the mount. If the interface has been held to a respectable 0.001" flatness, the mounted mirror is now distorted out of shape by 90 fringes. Once you, as an optical systems designer have had an opportunity to watch that high quality optical element bend and flex with the slightest mounting force, a healthy poranoia sets in. You tend to want to float everything in mercury and/or silicon rubber. Unfortunately, these schemes are rarely of much value to the high energy laser designer.

Working with the interferometer, in real time, you begin to recognize the scope of the problem and take steps to minimize the effect of the mount on the optic.

Certainly the problem has been addressed before, in glass. Glass, however, is rarely mounted by means of drilled and tapped holes in the optical material itself. Metal commonly is. Without the stiffness of glass, metal is a poor candidate for edge mounting. In addition, many laser systems make no allowance for mounts to protrude beyond the edge of the mirror.

Therefore, some new thinking has had to evolve in mounting metal mirrors. The farmer with his three-legged footstool firmly pointed the way for mount designers. Similarly, a single central point is a good scheme, relatively free from the threats of differential expansion. Still, as these interferograms will show, just a little too enthusiastic application of the wrench will tend to produce this pattern. (Figure 2) Also, the chronic case of machine screws being just a little too long, can produce permanent deformation.

As we move from 10.6 micron down to the shorter wavelengths of chemical lasers and high energy ultra violet systems these effects become intolerable.

In many of the latest systems designed and manufactured by SPAWR Optical Research, Inc. we have addressed the mounting problem by supplying optics which are, essentially, polished in the mount. By this we mean, the critical and most potentially distorting interface is made prior to finishing the polish cycle. Then, a secondary interface is designed to be as non-distorting as possible. Thus, the mount actually adds stiffness to the mirror, and allows critical and frequent alignment adjustments to be made at the secondary interface in conventional and inexpensive push-pull three-point designs.

Some typical designs are shown. (Figures 3,4,5,6,7,8,9,10) In all cases, the critical interface is in place, carefully torque controlled, during polishing. Breaking this interface would necessitate refiguring and polishing. However, the interface would not normally require breaking even during repolishing.

$\lambda/20$ (visible) mirrors of up to 30" major face dimensions have been made in this manner. These mirrors, of solid OFHC copper, uncoated, proved to be unusually insensitive to position, performing as well in the vertical as in the horizontal position.

In specifying metal mirrors for critical high energy resonator use, we suggest that there is little value in precise tolerancing or adherence to optical figures when the mount is treated as a simple support mechanism. In truth, there is no value in an interferogram which portrays the mirror as it was, possibly even before deblocking, when it has no function until it is mounted. Simply stated, the only time we are concerned with the mirror performance is when it is in the mount. Doesn't it make sense to specify it this way? Commonly available commerical mounts are not designed for metal mirrors and almost certainly will not provide satisfactory results in critical high energy applications. Mounting at the edge, in a solid cell, gives the wielder of the wrench the maximum possible leverage. If transfer of the mount figure to the mirror is complete (and such leverage practically assures it) then a $\lambda/20$ @ 10.6μ can degrade to twice that specification even if the mounting surface could be held flat to 11 millionths of an inch. Similar specs at 1.06μ would require a flatness of one millionth. Of course, U.V. systems would require 1/4 of that tolerance in a machined, mating face. Therefore, we can eliminate any suggestion that a flat mounting area can be properly machined to provide even acceptable tolerances. Also, if this was possible then finishing the rear side of a metal mirror to such a tolerance, relative to the reflective surface would more than double the cost of the mirror.

In our experience, these simple facts leave us virtually no where to go, except for our primary-secondary interface scheme. This concept allows for the use of rugged, inexpensive mounts employing conventional push-pull adjustments and standard pointing arrangements. We can accommodate precise pointing, vibration, shock and water-hammer considerations, while maintaining reasonable optical figure tolerance.

Perhaps there are other designs which will do the job as well. Mercury tubes, air bags with gravity vector sensing regulators and active optic systems have been used in many areas of optics, with varying degrees of success. In most cases these are an expensive and elaborate means of accommodation of poor mount designs. We suggest that the dual interface approach is one which is proven, is practical and is compatible with the most demanding high energy laser application.

Through our extensive experience with Government, Military and the growing commercial HEL community, we have repeatedly used dual interfacing in our systems designs for these diverse fields. Never have we failed to meet or exceed the performance requirement.

Specifications, after all, must first be attainable and then they must truly control the performance of the components and the system.

As is always the case, more work needs to be done. However, what we are suggesting is not the result of unsupported theory, nor of a single occurence. This concept is proven, available, and presents the best answer available today, to a problem of long standing in metal mirror performance specifications.

I invite you to step up to the interferometer, and test your nerve.

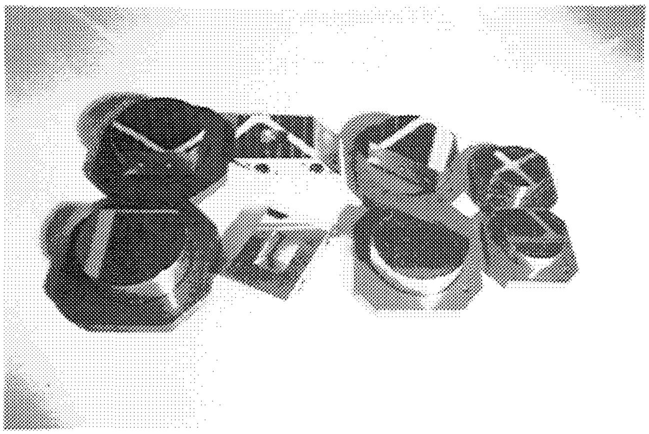

Fig. 1. Example of truncated, scraper and scraper/coupler mirrors. All examples shown are actively cooled.

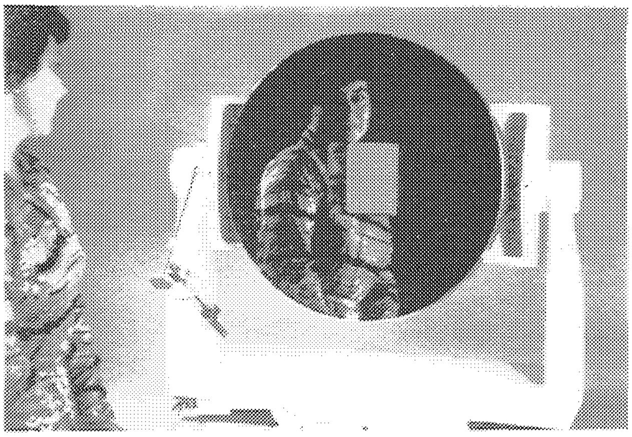

Fig. 4. Close up of 24" primary with spherical power. Dual interface.

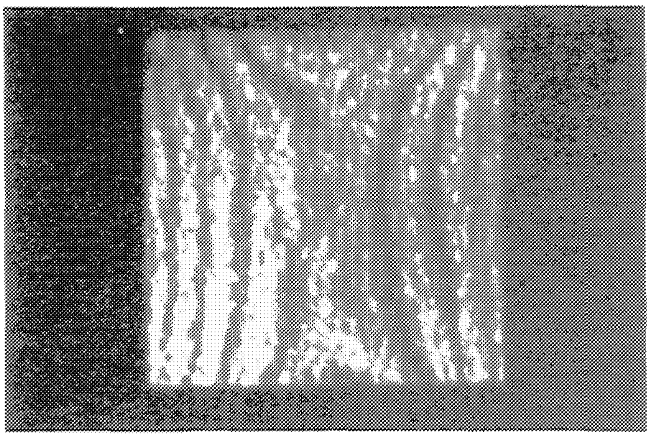

Fig. 2. Example of distortion caused by stressing to an uneven mount. Hole pattern is two tapped holes, center, vertical.

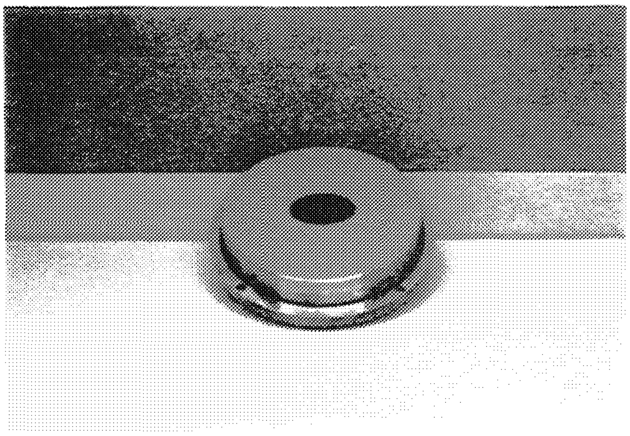

Fig. 5. View of dual coupling mirror in primary mount showing non-distorting secondary interface.

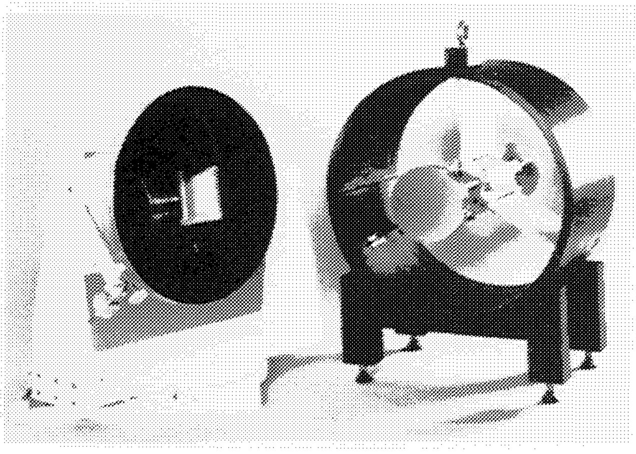

Fig. 3. 24" aperture focusing set for HE laser with square annulus. Secondary is also focus mount.

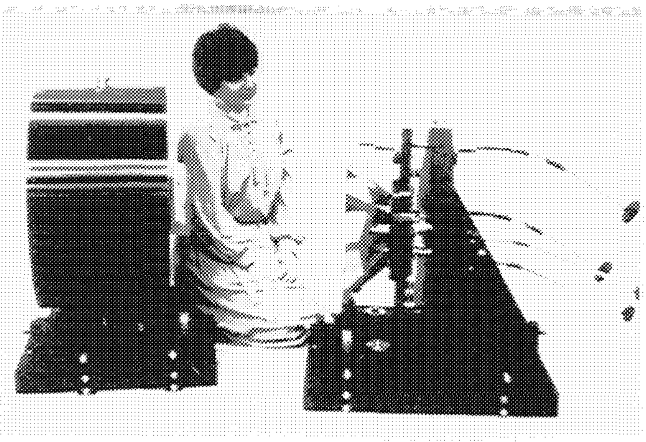

Fig. 6. HEL set of approximately 30" diagonal primary and feedback mirrors. Both mirrors use dual interfacing.

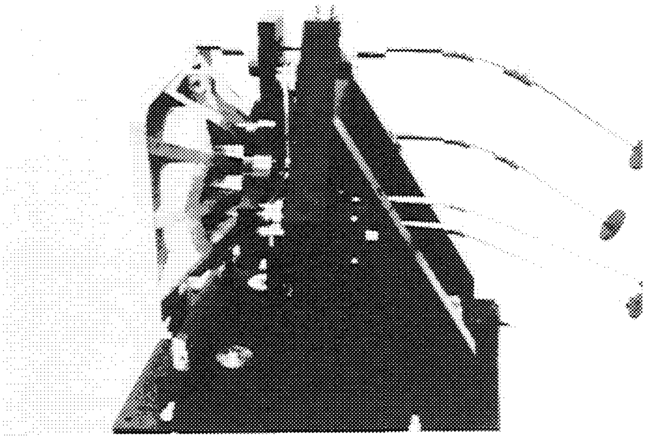

Fig. 7. Close up of rectangular primary mirror and mount. Critical interface is inside of the copper casting.

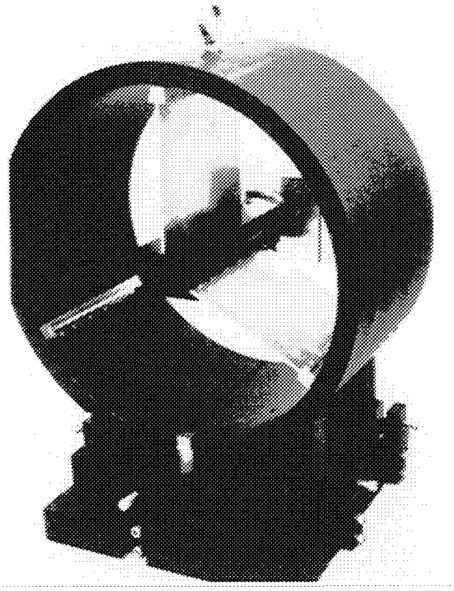

Fig. 9. One of three feedback convex passive copper mirrors in dual interface rugged mount.

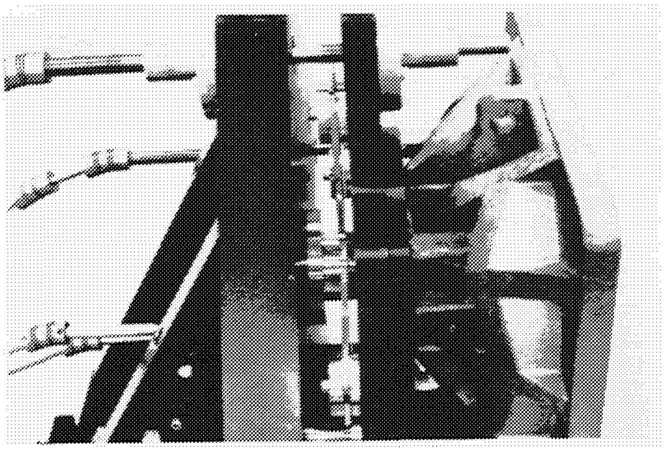

Fig. 8. Secondary interface uses custom flexures. High shock design.

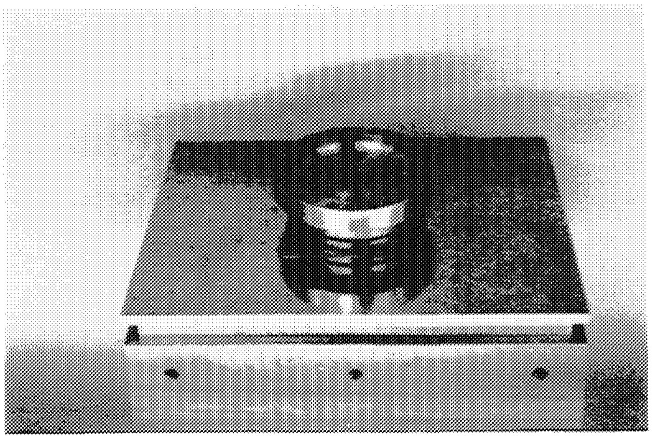

Fig. 10. One of the feedback mirrors with primary interface installed, prior to final polish cycle.