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ABSTRACT

Particulate contamination in disk amplifiers with high flashlamp fluxes (which can generate particles) causes three types of laser beam obscuration, which cause small-scale self-focusing. *We describe methods for obtaining* disk amplifiers that stay clean.

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Summary

The disk amplifiers that have been used in LLL's CYCLOPS and JANUS systems have generally performed well and according to the design expectations;[1-3] particulate contamination and its effects presented unexpectedly severe problems, however. While conventional cleanliness measures were taken, we find that extremely stringent measures are required.

A major system design constraint is maximization of focusable peak power per dollar. This yields disk amplifiers that have high internal radiation densities (to ∿ 20 J/cm^2) from the flashlamps. This flashlamp radiation interacts with particulates (some of which it produces) to form up to three types of opaque spot that introduce diffraction rings into the laser beam. The energy in these rings is not useable, at best, and causes extensive component damage, at worst.[4]

The particles that cause evanescent opacities can be eliminated by using appropriate clean rooms and associated techniques during assembly. Most of the particles that cause permanent opacities can be eliminated by eliminating rubbing, such as occurs during mating of threaded parts. However, metal surfaces that have not been polished or super-finished have particles more-or-less loosely attached to them, that can be detached from the parent metal and transferred to the disk surfaces as a result of firing the flashlamps, but that are very difficult to eliminate completely by conventional mechanical or chemical techniques of relatively moderate cost. We have achieved the best results with 304 stainless steel that, after part fabrication, is buffed, then electropolished, then chemically polished.

Introduction

The physics of high-brightness glass laser systems, such as are required for laser-induced fusion work, leads directly to disk amplifiers that have high internal radiative energy densities from the flashlamps. The flashlamp spectral intensity [5] peaks near 450 nm and extends from ∿ 200 nm (depending on the material used for the flashlamp envelope) to ∿ 2 μm. The flashlamp radiation interacts with particulates in the clear aperture of the amplifier to form as many as three different types of opaque spot, which introduce diffraction rings into the laser beam (Fig. 1).

The least troublesome type of opacity we have called a "plasmoid" (although we do not know that it is highly ionized). This results when a particle (presumably organic) is exploded by the flashlamp radiation. The resultant cloud is opaque to the laser beam on that shot, but succeeding shots are not obscured unless the original particle was close enough to a disk surface for the plasmoid to cause some surface damage. Even in this case, the surface pit is much smaller than the plasmoid. The second type of opacity is a metal particle surrounded by a metal halo on a disk surface (Fig. 2). The most damaging type of opacity is a fracture zone caused by a metal particle on a disk surface (Fig. 3); whereas the first two types of opacity can be easily polished off the disk surface, this third type requires grinding as well. The third type of opacity will also have a metal halo around the particle, except in the case of refractory metals like molybdenum. Plasmoids, haloes, and fractures typically have diameters of ∿ 2 mm; the metal particles and plasmoid-caused surface pits typically have diameters of ∿ 200 μm.

Figure I. Beam Downstream of Obscuration

Figure II. Haloed Aluminum Particle on ED-2 Disk

Figure III. Haloed Aluminum Particled on ED-2 Disk and Resulting Fracture

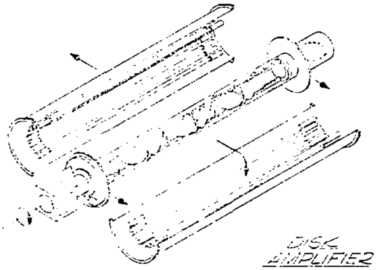

Figure IV. Design Concept for a Sealed-Optical-Assembly Amplifier

It is clear from the above that the amplifier design and materials must be such as to (1) permit proper cleaning of parts, subassemblies, and/or assemblies; (2) permit clean assembly; and (3) permit thorough postassembly inspection for cleanliness. In addition, the disks must be contained in a sealed subassembly (Fig. 4) when not in a clean environment.

Particles that cause plasmoids can be eliminated by assembling the sealed optical subassemblies in a clean room, using cleaning, clean-assembly, and inspection procedures that are well known in the aerospace, semiconductor, and precision-instrument industries. Of course, correct design can make such procedures considerably easier and better.

Correct design, correct materials selection, and correct materials processing are crucial to the elimination of metal particles. The major source of such particles in conventional designs is rubbing during assembly, especially the rubbing of mating threaded parts. By the exercise of some ingenuity, threaded parts can be designed out, and rubbing can be almost eliminated. The number and size of particles generated by unavoidable rubbing can be kept down[6] by keeping surface roughness well below 100 microinches (centerline average), by paying attention to the orientation effect, and by using materials of high shear strength, high indentation hardness, and low surface energy of adhesion.[7]

However, there is another source of metal particles that has proved very difficult to deal with. Metal surfaces that have not been polished or superfinished have small particles (typically ~ 200 μm in diameter) attached to them. These particles are bound to the surface more or less loosely: some (but not all) can be removed by buffing, ultrasonic cleaning, vapor degreasing, flushing or wiping with solvent, strippable coatings, plasma cleaning, or vacuum bakeout.

Materials Selection

Experimentally and theoretically we have found that surface asperities cause no problem as long as they are connected to the substrate metal by an effective thermal conductivity that approaches typical values for metals; the surface particles mentioned above as a problem are evidently largely thermally decoupled from the bulk metal. The heating of these particles, whether they are loosely attached to the parent metal or sitting on a vitreous surface or located away from any surface, is then controlled by the parameter $\alpha/\rho c$, where α is the (broadband) absorptivity for flashlamp radiation, ρ is the density, and c is the specific heat.

Table 1 lists the values for α, $\alpha/\rho c$, p (the indentation hardness), and S (the shear strength) for a number of candidate metals. The values for α were measured by us by a calorimetric method or (for copper, gold, and magnesium) estimated from published data.[5,8] The values for ρ and c are temperature-averaged from Ref. 9. The values for S are obtained from the American Institute of Physics Handbook[10] or extrapolated from materials of similar tensile strengths. The values for p are obtained from the Brinell hardness numbers tabulated in Ref. 10 or 11 (copper), or from the Brinell or Vickers hardness numbers given in Ref. 12 (silver, titanium), or from the Vickers hardness number for tantalum cited in a Fansteel data sheet. In the case of beryllium, the Rockwell B hardness number cited[12] was converted to the equivalent Brinell value.

Table 1 indicates the metals on which the experimental efforts were concentrated; however, it should be reemphasized that surface processing is critical. All of the metals listed in Table 1, except beryllium, have been tested in the "helical flasher," and at least one sample of each of the top three metals (fresh silver bright-plate, chemically polished aluminum, and electropolished stainless steel, ranked by $\alpha/\rho c$) has been free of particles. However, the silver plating separated from the substrate in "bubbles" and also presumably would not perform as well when aged, and the chemical and electrochemical polishes used for aluminum and stainless steel have not yet been capable of producing particle-free samples in trial after trial. We have chosen to use stainless steel (since it generates fewer and smaller particles when rubbed) for structural members, and to "prefire" amplifier heads before disk installation (see below). Calculations[13] indicate, and "helical flasher" experiments [14] prove, that "loose" particles of any of

Table 1. Some Relevant Material Parameter Values[a]

Metal	Broadband Absorptivity α	Heating Parameter $\alpha/\rho c$ (°K/cal-cm^3)	Indentation Hardness p (N/mm^2)	Shear Strength S (N/mm^2)
Aluminum (6061)	0.20	0.296	294	(86.2)
Beryllium	0.49	0.442	1500	~100
Chromium	0.48	0.516	8330	?
Copper	~0.5	0.559	390	150-160
Gold	(~0.6)	(0.972)	280	~90
Magnesium	~0.25	0.513	570	~120
Molybdenum	0.54	0.827	1530	~350
Nickel	0.43	0.403	980	360
Silver	0.14	0.226	(260)	~140
Stainless Steel (304)	0.39	0.379	2960	~800
Tantalum	0.54	0.898	980	~300
Titanium	0.44	0.698	640	~400

[a] Underlined values represent the best value; values in parentheses are the worst values.

these materials will create haloes and/or disk fractures; empirically, stainless steel particles generate relatively smaller obscurations.

We note, in passing, that ceramics and organics will not withstand flashlamp radiation.[14] In shadowed regions, it is permissable to use ceramics or organics that are known not to outgas either condensible materials or UV-polymerizable materials.

Design, Assembly and Test

The design concept of Fig. 4 has been expressed in two different embodiments. Note from Fig. 4 that the disks and their immediate support structure are enclosed in a sealed assembly, the transparent wall of which protects the disks from flashlamp ultraviolet radiation, from ambient particulate and vaporous contamination, and from the debris of the occasional flashlamp explosion. In one of the designs this transparent cylinder is split into semicylinders that are sealed to the support rails, while in the other, this cylindrical shield is not split and the support rails are inside it. Cerium-doped fused quartz (CeQ) is the materials of choice for the shields: Pyrex and other common glasses spall under direct flashlamp radiation, Germisil solarizes, and clear fused quartz (CFQ) exposes the disks to too much ultraviolet radiation. Stainless steel is the only metal used in the sealed assembly.

The annular volume between the shield and the outer shell of the amplifier head is occupied by the flashlamps and the flashlamp reflectors (not shown on Fig. 4.). The reflectors are silver-plated because of silver's high reflectivity (low α; c.f. Table 1). The outer shells are aluminum, and are painted on their external surfaces with epoxy-based paint.

Parts arrive from fabrication in relatively clean condition (surface processing such as electropolishing is considered part of fabrication). They are cleaned (e.g., ultrasonic cleaning, vapor degreasing) by trained clean-room technicians in a Class 10,000 clean area, then assembled and sealed in an adjacent Class 100 clean area, using clean-room garb and techniques. The latter are too extensive to recapitulate here, but we warn that particles and fluid contaminants must actively be eliminated from cleaning liquids and purge nitrogen, and antistatic measures must be used during cleaning and clean assembly. The amplifiers are initially assembled without disks (only), and the flashlamps are then fired at least ten times. After this "prefire" or "burn-in" the amplifiers are partially disassembled, the disks are installed, and assembly completed (all this occurs in the Class 100 clean area).

The split-shield design has been tested[15] for over 1000 shots (the other design will shortly be so tested). This new design provided improvement factors of about five in maximum obscuration diameter and of nearly ten in number of obscurations.

Acknowledgements

A great many people have contributed to this effort. We regret that the space alloted to this paper does not permit us to list them.

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Figure Captions

Fig. 1. Photograph of beam downstream of obscuration.

Fig. 2. Haloed aluminum particle on ED-2 disk.

Fig. 3. Haloed aluminum particled on ED-2 disk and resulting fracture.

Fig. 4. Design concept for a sealed-optical-assembly amplifier.