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Optomechanical Design of the Grating Laser Beam Combiner (GLBC) Laser Diode Header

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ABSTRACT

A laser diode header has been fabricated for a grating laser beam combiner (GLBC). The laser diode header provides the thermal control, the drive electronics, and the optical system necessary for proper operation of the beam combiner. The diode header is required to provide diffraction limited optical performance while providing correction for worst case defocus aberration, 0.6 mrad excess divergence, and worst case decenter aberration, 1.0 mrad pointing error. The design of the header considered the mechanical design and the optical design together resulting in a small, self-contained header with 0.7 mrad range for focus correction and +/- 2.5 mrad of beam steering. The complete diode header is currently undergoing optical and mechanical performance testing.

1. INTRODUCTION

Incoherently summing the outputs of single element laser diodes is an attractive means to achieve the power level required for free space optical communications. It also provides redundancy should one or two diodes fail catastrophically.[1] A laser diode beam combiner has been fabricated which employs diffraction gratings to coalign and collimate the outputs of up to four laser diodes (FIGURE 1), with a longer term goal of summing ten laser diodes.

The design of the Grating Laser Beam Combiner (GLBC) has each laser diode mounted in individual diode headers. These headers provide the following functions, (1) temperature control/thermal interface (2) laser diode drive electronics and (3) collimation and pointing optics. This paper will concentrate on the optomechanical design of the laser diode header.

The GLBC optical system (FIGURE 2) consists of three subsystems, (1) collimation, (2) collimation adjustment, and (3) vernier pointing adjustment. All three subsystems are essential for operation the grating laser beam combiner. In this paper each subsystem is analyzed individually. Whenever possible the theoretical performance is compared to experimental results. The report concludes with a theoretical analysis of the complete diode header optical system, using a ray matrix method both to design and to analyze the optical system.[2,3,4]

The latest design effort on the GLBC was started in August of 1987. Due to loose manufacturing tolerances of the laser diodes, the optical design was performed in close conjunction with the mechanical design. The machining of the header as well as the packaging tolerances of the laser diode impose limitations on the centering and focussing accuracy of the laser. One major goal of the header design was to correct for the worst case decenter and defocus aberrations likely to occur with typical laser diodes.

The headers utilize commercially available laser diode collimating objectives to collimate the laser output. Coarse collimation adjustment is accomplished by varying the distance between laser diode and the collimating objective with shim stock spacers. This permits adjustments in increments of 25.4 µm and results in a worst case despace of 12.7 µm,(one-half the coarse adjustment). Unfortunately, short focal length lenses such as laser diode collimating objectives are extremely sensitive to despace on the optical axis and therefore require a fine focus or vernier collimation adjustment system.

Centering the laser diode's output onto the optical axis of the collimating objective can be difficult since laser diode manufacturers typically specify the centering tolerance of the laser diode in the package to only +\-0.2mm. When coupled with a high numerical aperture, short focal length lens, this decenter can result in a severe pointing error. For the GLBC, a centering adjustment of the laser diode package and a pointing adjustment lens are necessary to correct the worst case decenter aberration.

2. COLLIMATION

Several types of commercially available laser diode collimating objectives were evaluated for the coarse collimators in the diode header. Typical performance of commercially available collimating objectives from Liconix and Optics-Plus show that they are capable of >90% transmission with less than λ/30 RMS phase aberration5. Figure 3 presents data on lenses from Melles Griot, Liconix, and Optics Plus. Microscope objectives were used to focus a helium-neon laser beam so that the collimating lenses could recollimate and the WYKO Ladite could evaluate the phase front aberration. The 1.8 mm microscope objective provided rapidly divergent light (~ 30°) similar to laser diode emission in the plane perpendicular to the active region. The 8.0 mm focal length Melles-Griot collimating lens exhibited a truncation problem with divergent light greater than 25° which significantly degraded its phase front performance and rendered it unusable for the GLBC application. The Liconix and Optics-Plus lenses suffered no such beam truncation and thus were considered for the GLBC header design.

In order to minimize the header's size, the 9.0 mm diameter of the Philips laser diode package was selected as the limiting size of the collimating lens diameter. The length of the header was minimized by selecting the collimating objective with the shortest focal length. We chose the Optics-Plus LDCO-53-N as the header's collimating objective based on these size constraints and its optical performance. This lens has a numerical aperture NA = 0.5, a 4.7mm effective focal length and a 9.5 mm outer diameter. Our tests showed that this lens transmitted ~90% of incident light while introducing less than λ/30 RMS phase aberration.

3. MECHANICAL DESIGN CONSIDERATIONS

The header design (FIGURE 4) holds the laser diode in the end of a barrel with a threaded retainer ring. The laser is centered in the barrel with three 0-80 adjustment screws which protrude radially outward from the header. Once the laser is centered, the retainer ring is tightened onto the diode package flange and the adjustment screws are removed. Since the adjustment screws have 80 threads per inch, one rotation yields a 317.5 µm decenter. Consistent adjustments of 1/25 of one rotation (15°) are achievable and yield a worst case decentering of 12.7 µm. Systematic adjustment of the three centering screws should yield more accurate centering of the laser to the collimating objective. The vernier pointing system is used to compensate for the residual decentering.

The collimating objective is self-centering in the barrel and held in place by a friction fit retainer ring. Shim stock spacers are used to adjust the distance from laser to collimating objective. By using multiple spacers of different thickness it is possible to achieve spacing adjustments of 25.4 µm. This results in a worst case lens defocus of 12.7 µm or one-half the spacing adjustment. The header, fabricated from aluminum and containing the laser diode and collimating objective only, was tested for thermal problems over an operating temperature range of 15°- 40°C. The far-field of the laser diode output was observed on a detector array as the temperature was varied from 15°C to 40°C and back to 15°C. The beam neither wandered nor changed diameter suggesting that if any thermal problems exist, they were negligible compared to the measurement resolution of approximately 0.6 µrad.

A 2x2 ray matrix analysis of the laser and collimating objective revealed that a despace of 12.7 µm changed the output divergence by 0.6 mRAD (FIGURE 5). To correct for this excess divergence, a collimation adjustment system with an adjustment range greater than 0.6 mrad was included in the optical system. We have achieved a laser to lens spacing which resulted in less than 0.8 mrad of divergence with little effort. Further manipulation of the spacers should yield divergences approaching the diffraction limit of the collimating lens, 0.43 mrad.

4. COLLIMATION ADJUSTMENT

A fine collimation system was designed using a two lens system consisting of a plano-concave and a plano-convex lens with equal radius of curvatures. With the two non-plano surfaces of the lenses in contact, the system has no power and hence has no effect on the collimation. As the distance between the elements is increased from zero, the system develops a positive effective power. This fine collimation adjustment system can only correct for excess divergence. Therefore, the only despace of the laser to collimating lens that can be tolerated is in the direction which increases divergence. Shim stock spacers, providing 25.4 µm increment adjustments, are used to vary the distance between the two lenses, while a threaded ring locks the fine collimating lenses in place once the desired divergence is achieved.

The GLBC header's length must be kept short while achieving the necessary correction. We considered designs of the fine collimation system with optical elements of various focal lengths to change the effective power. A 2x2 ray matrix analysis of the collimation adjustment system (FIGURE 6) revealed that using lenses with focal lengths of +/-10 cm provides 0.7 mrad correction over the usable separation distance (approximately 6.0 mm). This approach also yields less than 20 μrad of change for the smallest despace (25.4 μm) of the fine collimation elements. The 4.7 mm aperture size of the collimating lens corresponds to a diffraction limited divergence of 0.43 mrad; a 20 μrad error in the collimation correction is less than 10% of the diffraction limit and is therefore considered acceptable.

Tilt aberration may be introduced into the optical path by improperly seated fine collimation elements. The optical design specifies the shim stock spacers with a 12.7 μm tolerance which can be reduced, if necessary, to eliminate any problems due to tilt aberration. If required, the shim stock material can be etched to reduce thickness by using printed circuit board etching techniques. This has the potential for eliminating the fine focus system altogether and hence reducing the overall size and weight of the laser diode header.

5. VERNIER POINTING ADJUSTMENT

The GLBC provides pointing of the collimated beam by adding a low power positive lens at the output of the header. This lens, when translated perpendicular to the beam axis, provides precise beam steering. Translating the one meter focal length lens by 1.0 mm corresponds to a 1.0 mrad change in the pointing angle. This steering lens provides a mechanical advantage over the collimation lens equivalent to the ratio of their focal lengths. Although this mechanical advantage accounts for sensitive adjustments in the beam steering, the translation range cannot practically provide the necessary correction for a worst case pointing error.

As previously stated, a three point laser centering adjustment is included in the design which reduces the worst case laser decentering to 12.7 μm which, in turn, yields a 2.7 mrad pointing error. The steering lens is acceptable providing it is mounted to the header in such a way that it permits +/-2.7 mm of translation. The fine focussing elements are 12.0 mm in diameter, therefore a vernier pointing lens 7.0 mm in diameter would have 5.0 mm of total travel or +/-2.5 mm of omnidirectional translation. This would correct for nearly all of the 2.7 mrad pointing error. Our mechanical design holds the vernier pointing lens in two nested eccentrics which provide very fine pointing adjustments in any direction by rotating the inner and outer elements. We have achieved decenters of less than 5.0 μm which correspond to approximately 1.0 mrad pointing error, easily corrected for with the steering lens.

6. ANALYSIS OF COMPLETE OPTICAL SYSTEM

A 2x2 ray matrix analysis was performed on the entire optical system. This resulted in a set of equations for calculating output beam radius and output beam divergence which permitted calculation of the separation distances such that the output of the optical system would be well collimated. By assuming the source size to be infinitely small (zero) these expressions simplify significantly and allow precise calculations of the diode to collimating lens distance. For a typical laser diode divergence of 25° (221 mrad) the laser diode to lens distance should be 4.677 mm. With the effective focal length of the collimating lens at 4.7 mm, decreasing the diode to lens spacing by 23 μm provides the necessary divergence for the vernier pointing lens to emit a collimated beam.

The derived expressions for beam divergence and beam radius will also permit accurate calculation of the separation distance necessary for the fine focussing elements to correct for any arbitrary defocus of the laser. Implementation of the ray matrix analysis in a computer program would permit a multivariable analysis of all separation distances.

7. CONCLUSIONS

The optomechanical design of the Grating Laser Beam Combiner laser diode header has been completed. We have corrected for the worst case laser diode defocus and decenter aberrations while maintaining margin for any unforeseen errors. The theoretical analysis of the completed diode header optical system agrees well with the theoretical analysis of each optical subsystem. Once fabrication of all the optical components is complete, test and evaluation of the complete diode header will be performed. This optical system design should provide a diffraction limited beam for each laser and pointing adjustment to permit efficient combining of the individual beams with diffraction gratings.

8. ACKNOWLEDGMENTS

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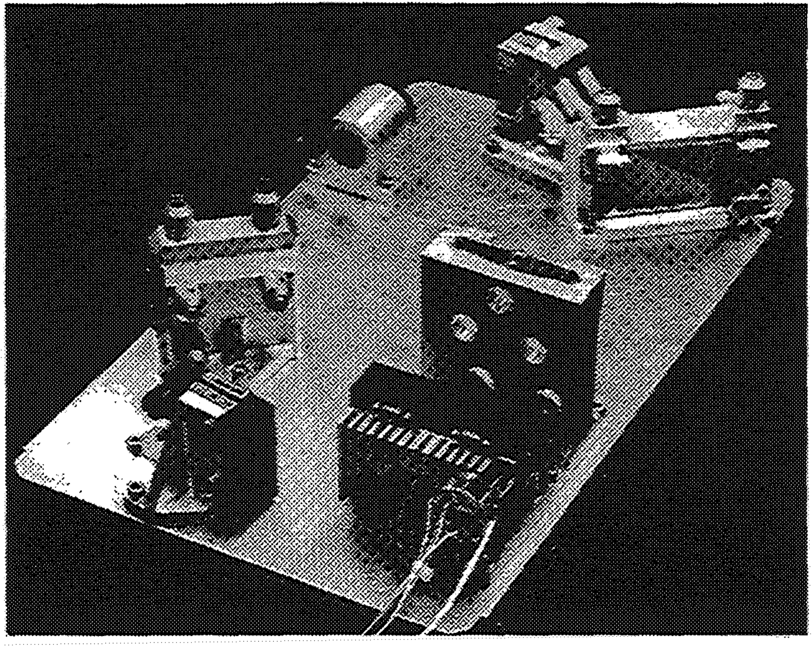

FIGURE 1 : GRATING LASER BEAM COMBINER

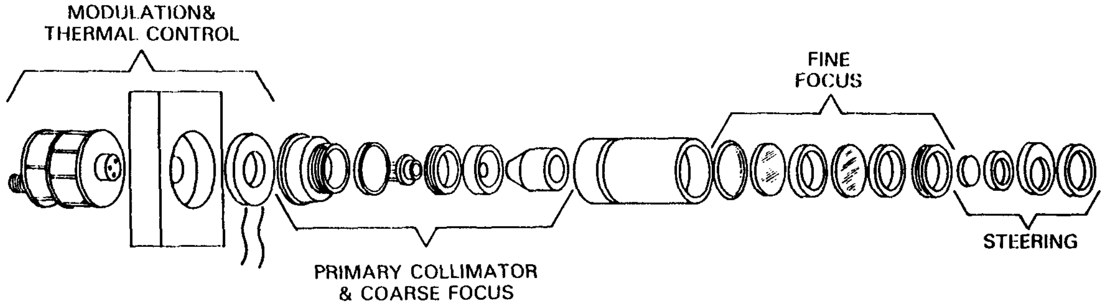

FIGURE 2 : GLBC LASER DIODE HEADER OPTICAL SUBSYSTEMS

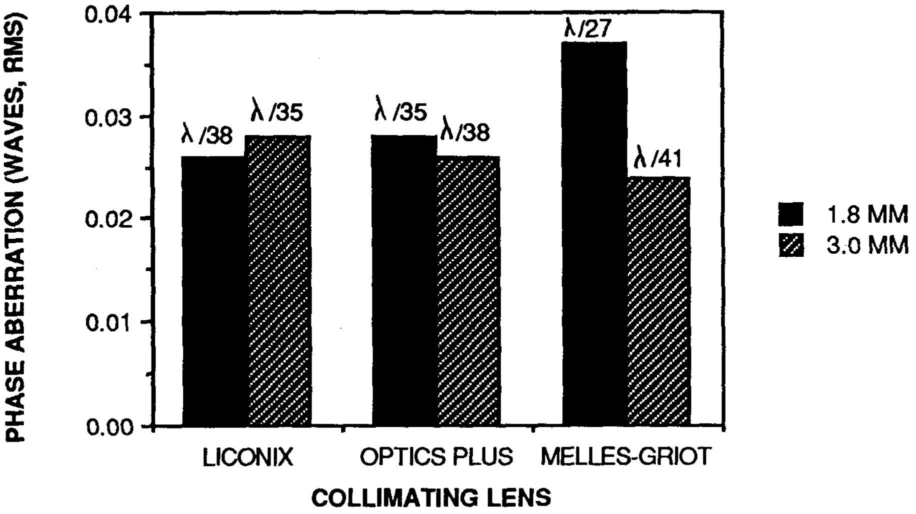

FIGURE 3 : PHASE ABERRATION DATA OF COLLIMATING LENSES

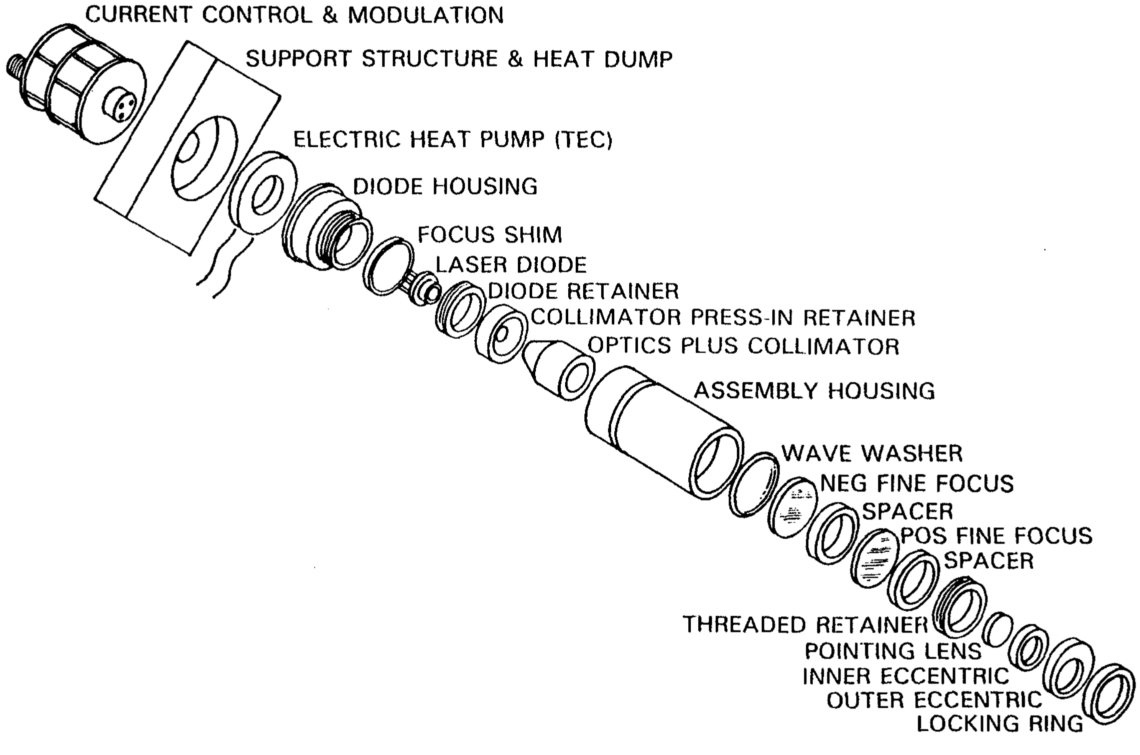

FIGURE 4 : GLBC LASER DIODE HEADER OPTOMECHANICAL DESIGN

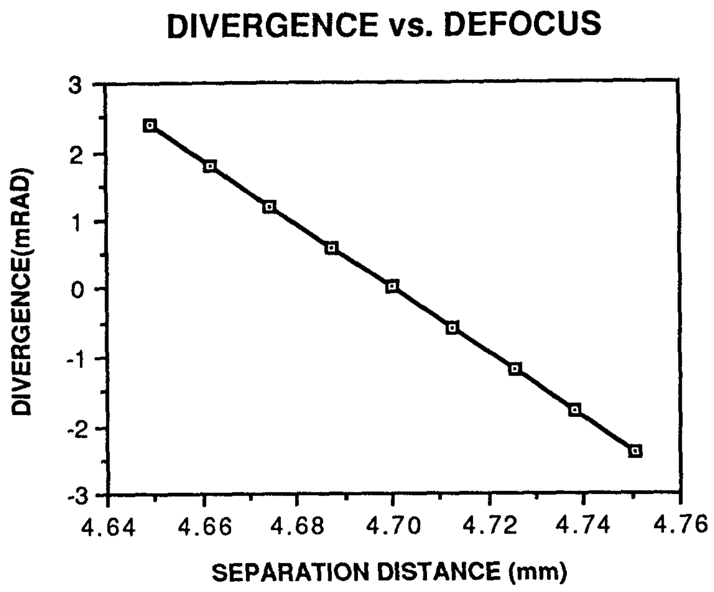

FIGURE 5 : 2X2 RAY MATRIX, COARSE COLLIMATION ADJUSTMENT

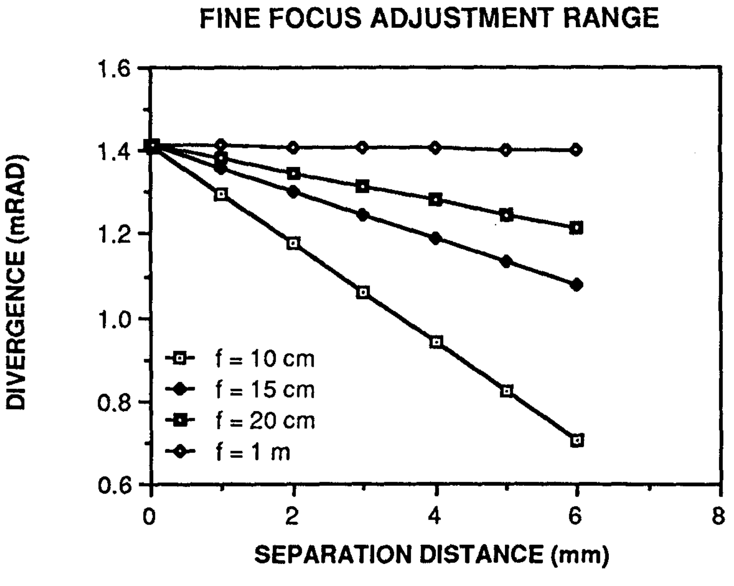

FIGURE 6 : 2X2 RAY MATRIX, FINE COLLIMATION ADJUSTMENT