

# Improved external cavity design for cesium D1 (894 nm) diode laser

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We have developed an external cavity diode laser for use near the cesium D1 transition at 894 nm, producing over 20 mW of single-mode power with a continuous tuning range of up to 25 GHz. Our mechanical design allows simple alignment and optimization of the cavity with very good passive stability, as temperature control of the diode is not coupled with changes in cavity length, and it could easily be used with diodes at other wavelengths. We detail the design and construction, and review the performance of the current system, which has been in operation for several years.

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## I. INTRODUCTION

We have developed an external cavity diode laser system with diffraction-grating feedback for use near the cesium D1 transition at 894 nm. Existing designs (see, e.g., Refs. 1–6) did not suit our requirements for two reasons. First, the EG&G C86136E laser diode commonly used for this wavelength region is supplied with a thin silicon oxide coating on the front facet, which makes the optical alignment for stable operation more difficult and greatly reduces the single-mode scan range due to etalon effects. Second, we required a system with high passive stability. In all cavity designs of which we were aware, temperature control of the diode is unavoidably coupled with changes in cavity length, degrading long-term stability. Our new mechanical design consists of a pair of custom-built kinematic mounts, one holding the diode and collimating lens and the other the diffraction grating in a Littrow configuration. This allows easier and more precise optimization of the laser output, and the diode temperature can be controlled with minimum effect on the cavity length, providing considerably more output power and much higher passive stability than commercially available 894 nm diode laser systems at much lower cost. Our system has been in near continuous operation for several years as the pump laser system for an optical pumping experiment on spontaneous polarization.<sup>7</sup>

## II. CONSTRUCTION

Novel aspects of the cavity design are detailed below, but elements derived from existing designs (such as the electronics or beam shaping optics) are mentioned only briefly. More detailed construction information is available from the authors on request.

The laser cavity is shown in Figs. 1 and 2. It consists of two 1/4 in. thick aluminum plates, 3.5 in. by 4.0 in., connected by four 3/8 in. diameter, 2.5 in. long stainless steel

rods, all mounted inside a rectangular aluminum tube. A 1.4 in. square hole is milled out in one plate, and a 1/4 in. thick copper block just smaller than the hole is mounted in it, using a 1/8 in. thick G10 (fiberglass) plate attached by eight screws to both aluminum plate and copper block. This ensures a mechanically rigid but thermally isolated connection. The laser diode is mounted in the center of the copper block; in our system the front window of the diode package is removed to allow a collimating lens with a short working distance. A small thermoelectric cooler (TEC) with tinned faces (Melcor CP1.4-7-10TT) is soldered to the back of the copper block using low melting-point In–Sn eutectic solder. A length of 1/2 in. wide copper ground strap is similarly soldered to the back side of the TEC, and the opposite end is clamped by a copper block to the outer can, which acts as a heatsink. This arrangement allows precise adjustment of the diode temperature without affecting the length of the laser cavity.

The aluminum plate holding the copper block is used as the fixed portion of the first kinematic mount. Another 1/4 in. thick aluminum plate is mounted to it using three ball-tipped 1/4–80 stainless steel adjustment screws (Thorlabs FAS100) and three springs, with the screw tips resting on a conical indent, groove, and flat on the moving plate to form a true kinematic mount. This plate has a hole centered in front of the diode, into which is mounted an aluminum lens holder with the collimating lens (Melles Griot 06GLC001). The lens holder is held by three screws, with enough play to allow precise alignment of the lens to the diode while tightening the screws.

The aluminum plate at the other end of the stainless rods forms the fixed portion of the second kinematic mount which holds the diffraction grating. A T-shaped 1/4 in. thick aluminum plate is mounted to it in a similar manner to the lens holder plate, but with the adjustment screw at the foot of the T replaced by a 3/16–100 actuator screw with an internal piezoelectric stack (Thorlabs PE4) to allow both coarse and fine adjustment of the grating angle. The grating itself (Edmund Scientific D43221) is cemented to a triangular block cut at the appropriate angle (54°), which is screwed to the T-shaped arm so that the grating is centered in front of the collimated laser beam. The block has a raised edge against

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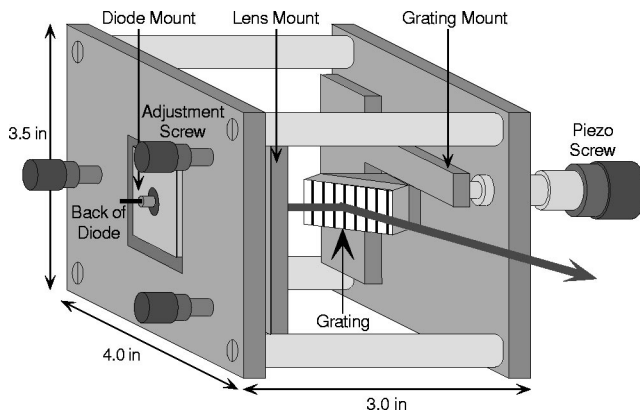


FIG. 1. Simplified three-dimensional view of the external cavity. The outer can and thermoelectric coolers are not shown.

which the grating rests, and the arm has a milled relief cut for stable mounting of the block. As originally designed, the cavity length  $L$  was chosen so that  $L$  and the grating angle  $\theta$  change together according to the continuous tuning criterion,  $\Delta\lambda/\lambda = \Delta L/L = \Delta\theta/\tan\theta$ . However, after running the laser for several weeks it was decided to shorten the cavity as much as possible, to increase the longitudinal mode spacing and reduce the tendency to mode-hop (see Sec. III).

Extensive steps are taken during construction to ensure optimal mechanical stability of the two custom kinematic mounts and the complete laser cavity. All aluminum compo-

nents are anodized prior to assembly of the laser, to prevent wear at the tips of the adjustment screws. The adjustment screws (other than the piezo screw) are mounted in tapped brass bushings instead of directly in the aluminum plates. The screws are greased lightly with fluorinated grease and threaded into the bushings, then the bushings are press-fit into undersized holes in the aluminum plates. The brass cold-flows into the threads of the screws, resulting in a tight and stable fit with minimal backlash. In addition, the springs which hold the kinematic mounts together are extremely stiff to reduce vibration of the plates. After mounting, socket heads are epoxied to the screw knobs to allow adjustment using an Allen wrench (hex key) from outside the can, thus minimizing any disturbances.

The laser cavity is housed in a well-insulated aluminum can for thermal and vibrational isolation. The can is a 6.4 in. length of 3.5 in. by 4.0 in. (interior) rectangular aluminum tube with 1/4 in. walls. The laser cavity is affixed to the can by only two screws into the bottom edge of the plate holding the laser, to prevent stress on the cavity caused by differential thermal expansion of the stainless rods and aluminum can. The ends of the rectangular tube are closed with 1/4 in. aluminum plates, with holes drilled to allow access to the adjustment screws from outside the can. Styrofoam panels 1 in. thick cover all sides of the can. On top of the can is a small uninsulated area in which two TECs (Melcor CP1.4-127-10L) are mounted above a copper spacer block, for temperature stabilization of the entire can. A large finned heat-sink screwed to the can clamps the TECs in place, with fiberglass washers for thermal isolation.

The entire can is mounted on a vibration-isolation mount consisting of alternating layers of 2 in. Styrofoam and 1 in. aluminum plates. Long hold-down screws pass through holes in alternate layers, so that there is no direct metal-to-metal contact from optical table to laser can, yet the can is fastened securely to the table. An outer slip-on cover constructed of 1 in. Styrofoam covers the entire laser when in operation, except for the heatsink on top and the laser output port, providing an additional degree of thermal and acoustical isolation.

We first assemble the laser cavity completely without the lens holder or grating block in place. The lens position is adjusted to give a collimated beam, using the mounting screws for coarse adjustments and the kinematic mount screws for fine tuning. The grating angle is adjusted in both planes while monitoring the diode lasing threshold current, until a drop in threshold indicates the onset of optical feedback. The laser cavity is then mounted inside the can and temperature stabilized as all further adjustments can be made from outside the cavity. The laser is tuned towards the desired wavelength using an iterative process of minimizing the threshold current (and thus maximizing feedback) and adjusting the diode temperature to optimize the laser output power.

External optics are needed to condition the output beam for most applications, as the output beam has an elliptical profile and residual astigmatism. Control electronics use standard circuits similar to those found elsewhere in the literature (see Ref. 1 for a list of references).

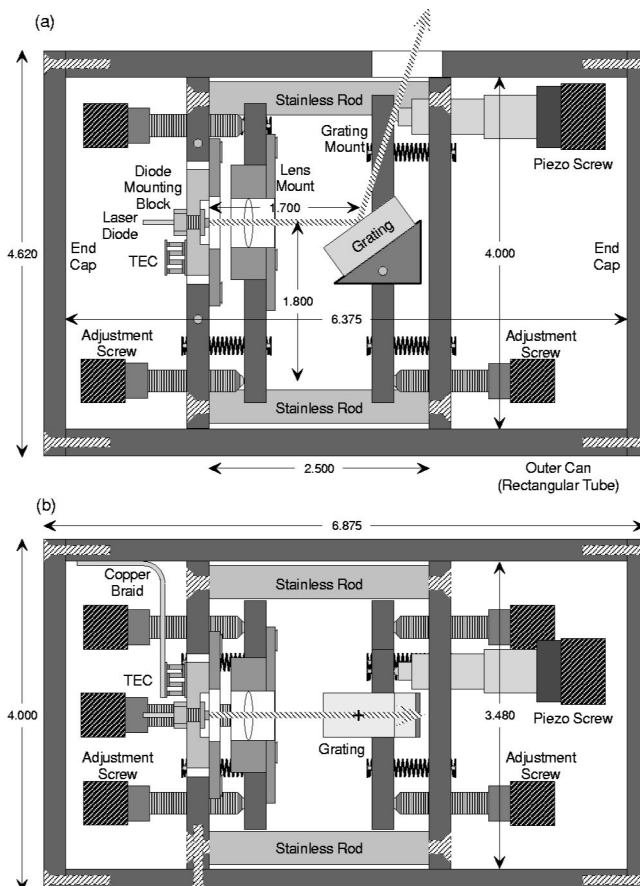


FIG. 2. Cutaway views of the external cavity and can from the bottom (a) and side (b) (dimensions in inches).

### III. PERFORMANCE

The EG&G C86136E laser diode is specified to operate with a free-running center wavelength of  $905 \pm 10$  nm at  $25^\circ\text{C}$ , shifting at a rate of about  $0.3$  nm/ $^\circ\text{C}$ . It is desirable to run the diode slightly below room temperature (since the life span of the diode decreases when heated), while avoiding condensation which severely degrades the performance and the span of the diode. Consequently, it is necessary to frequency select individual diodes before purchase to ensure that their room-temperature center wavelength is close to  $894$  nm (the manufacturer will do this upon special request). The diodes we have used were selected for center wavelengths of  $896$ – $898$  nm, and run optimally near  $894$  nm at  $17$ – $20^\circ\text{C}$ .

The continuous single-mode tuning range of the laser is limited to a few GHz if the grating angle alone is varied using the piezo. External cavity lasers using optimally anti-reflection (AR) coated EG&G diodes have achieved continuous tuning ranges of several THz. Thus, one of the limiting factors is clearly the factory AR coating (SiO) on the EG&G diode, which has a front facet reflectivity of  $5\%$ .<sup>5</sup> We attempted to reduce the reflectivity on our first diode by applying an additional layer of  $\text{Sb}_2\text{O}_3$  in a simple evaporator (using a method similar to Ref. 2), but failed to significantly improve the diode characteristics. Slight etalon effects between the two dissimilar coatings may have negated the benefits of any AR improvement. Consequently, we shortened the laser cavity as much as possible; the cavity length was reduced from  $4.2$  to  $3.0$  cm by shortening the stainless steel rods, thus increasing mode separation from  $3.5$  to  $5$  GHz, which resulted in a noticeable improvement in single-mode performance. The resulting small mismatch in the tuning criterion does not appear to be a limiting factor on the continuous tuning range of the laser. We have not AR coated two subsequent replacement diodes for the same system, but performance has remained similar to or only slightly better than the first diode. By varying the injection current in addition to the grating angle, we have achieved a single-mode scan range of up to  $25$  GHz after careful optimization. The intensity variation which results is not critical for our current experiment. As expected, mechanical lag in the piezo affects the linearity of the frequency scan, and mechanical hysteresis means that the widest tuning ranges are usually only achieved for frequency scans in one direction.

We obtain an upper limit of  $3$  MHz for the instantaneous laser line width, using a scanning confocal Fabry–Perot etalon. By monitoring the transmission fluctuations through a Cs vapor cell near an absorption peak, we have measured a laser line width of about  $4$  MHz for a  $500$  ms averaging time. A Fourier transform of the transmission data shows that

much of this width is due to residual line noise on the diode current supply, along with residual mechanical vibrations. It could consequently be easily reduced for more demanding applications.

For our application, the  $894$  nm laser needs to be tunable across a several GHz range of the D1 spectrum in day-to-day operation. It is therefore impractical to lock the laser to an atomic transition, and the passive stability of the laser becomes important. In general, the laser drifts a few tens of MHz overnight and remains single mode; over several weeks, the drift is typically a few hundred MHz. It is difficult to track the true long-term stability of the laser, since in the course of normal operation we adjust and optimize the laser on a daily basis. However, it is noticeable that the stability of the laser improves greatly during the first few weeks after assembly. We attribute this to metal creep following the tightening of bolts, as the cavity slowly achieves a long-term equilibrium position.

The present diode in our system has been in nearly continuous operation for more than two years. Despite well over  $10\,000$  h of operation, the spectral qualities of this diode have not degraded noticeably. We have generally run the laser at a current of  $100$ – $110$  mA, somewhat less than the manufacturer's rated maximum of  $125$  mA. The threshold current has crept up slowly by several mA, but not enough to significantly reduce power output. We expect similar long lifetimes to be typical for diodes of this type if catastrophic failures are avoided.

### ACKNOWLEDGMENTS

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