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F. E. Hanson, H. Rieger, and D. B. Cavanaugh

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Relative efficiency of $^{200}Hg\ ^{79}Br$, $Hg\ ^{79}Br$, and HgBr electric discharge lasers

F. E. Hanson, H. Rieger, and D. B. Cavanaugh
Naval Ocean Systems Center, San Diego, California 92152

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The spectra and relative efficiency of $^{200}Hg\ ^{79}Br$, $Hg\ ^{79}Br$, and HgBr in a small UV preionized electric discharge laser have been measured. There is a similar improvement in laser energy for both isotopic samples compared to the natural abundance mixture which can be attributed to a narrower gain spectrum and consequent higher peak gain. At the highest output measured, the increase in laser energy was about 25%. We estimate this is due to roughly 15% increase in small-signal gain.

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The characteristics of $HgBr_2$/HgBr dissociation lasers using natural abundance isotopic material have been extensively studied in recent years.[1–4] Because the gain spectrum of the HgBr($B \rightarrow X$) transition is smeared due to different spectral shifts for each of the 14 isotopic species, one would expect the average gain to be less than the peak gain in one particular species. In fact, Ediger *et al.*[5] did observe a 15% relative improvement in slope efficiency (dE_{laser}/dE_{pump}) of a photodissociation laser when $^{200}Hg\ ^{81}Br_2$ was substituted for $HgBr_2$. It is difficult, however, to make a quantitative interpretation of a UV pumped system such as this which shows strong absorption at 193 nm[6] because the depth profile of the pump changes with increasing pump intensity. The increase in gain that was presumably responsible for these results was not apparent from their experiments. In the case of an electric discharge laser there may be some intrinsic differences in the relative gains of different isotopes because the HgBr $B\,^2\Sigma$ vibrational manifold is significantly hotter than the gas temperature.[7]

All samples of $HgBr_2$ were prepared in a similar manner by a direct reaction of the elements in sealed, evacuated pyrex tubes. These tubes held an excess of bromine and were heated to ensure complete reaction. After removal of residual bromine, the white crystals of $HgBr_2$ were purified by sublimation and showed no trace of the UV excited pinkish-orange fluorescence indicative of Hg_2Br_2.[8] The natural abundance $HgBr_2$ that was synthesized gave similar results to commercially available material. The ^{200}Hg and $^{79}Br_2$ used in this work were isotopically enriched to 96% and 95%, respectively.[9]

The glass discharge laser tube was essentially a scaled down version of tubes we have used previously in this lab.[1,3] It was operated at 155 °C and filled with 3% nitrogen in neon at a total density of 1.23 amagat (1000 Torr @ 20 °C). Electrodes were of 1-cm-diam stainless steel tubing pinched at each end and separated by 1 cm. The discharge was driven by a standard thyratron switched LC inversion circuit using four 2.7-nF barium titanate capacitors which gave a current pulse of approximately 100 ns (width at base). Discharge voltage and current were both measured from which we obtained the energy deposited in the discharge as a function of charging voltage. The cavity consisted of a full reflector ($R > 99\%$) and a $R = 90\%$ output coupler separated by 45 cm with an active gain volume of $9 \times 1.0 \times 0.15$ cm^3. Laser intensity was measured on a calibrated ITT F4000 photodiode after suitable neutral density attenuation. Typical pulses were digitized and integrated so that a calibration of pulse energy from peak power could be made for each isotope and charging voltage. Results are shown in Fig. 1 for the two isotopic samples and the natural abundance mixture.

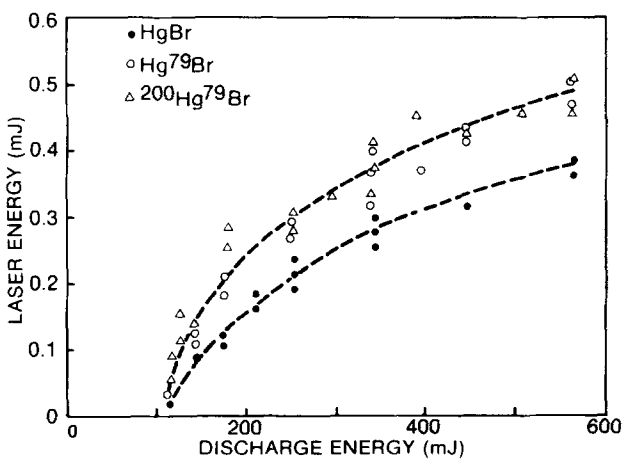

FIG. 1. Electric discharge laser performance for three isotopic compositions.

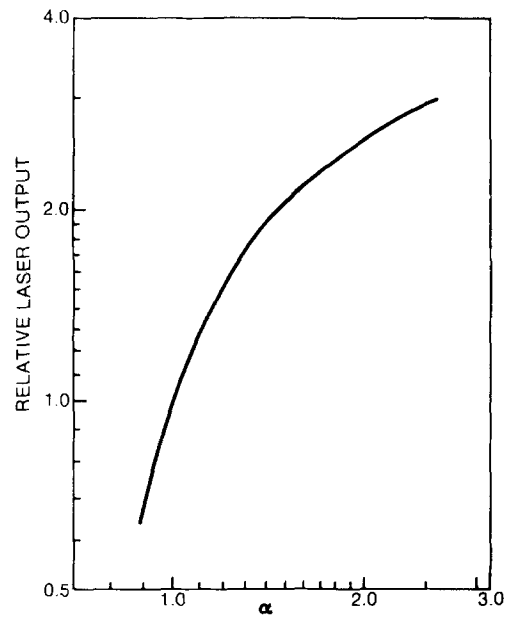

FIG. 2. Normalized output vs gain for cavity flux model.

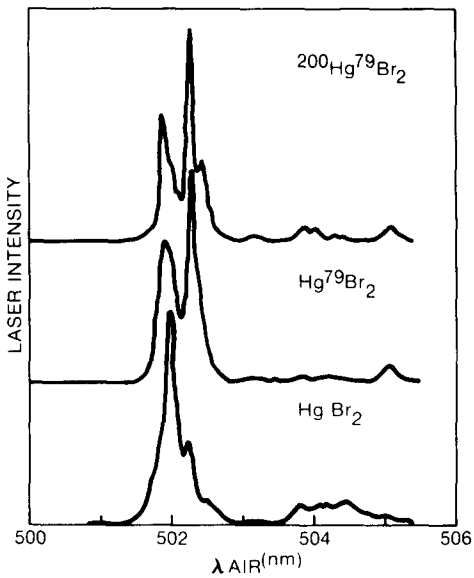

FIG. 3. Laser spectra of the three samples of Fig. 1.

There was no measurable difference in lasing threshold for any of the samples. Both $^{200}Hg\ ^{79}Br_2$ and $Hg\ ^{79}Br_2$ show essentially the same improvement in laser energy relative to $HgBr_2$ over the complete range of discharge energy. At the highest charging voltage the increase was about 25%. We attribute this improvement to a small change in the intrinsic small-signal gain g_0. The relative effect one would observe then depends on the specific parameters of the laser device, in particular the extraction efficiency. We estimated the sensitivity of laser output with the scaling in gain for this device from a simple time-dependent model of cavity flux using a steady state expression for the saturated gain

$$\frac{dI}{dt} = I\left(\frac{c\alpha g_0(t)L_{\text{gain}}/L_{\text{cav}}}{1+I/I_{\text{sat}}} - \frac{1}{\tau}\right) + \beta g_0(t).$$

Here the time dependence of $g_0(t)$ was taken from the measured sidelight fluorescence (mirrors blocked), α is the isotope-dependent gain factor, τ is the cavity decay time due to mirror transmission plus 4% loss per round trip, and the last term represents the contribution of spontaneous emission to the buildup of cavity flux. I_{sat} was taken to be 200 kW/cm^2 for the natural abundance mixture.[1] In this simple model I_{sat} is inversely proportional to the cross section for stimulated emission and therefore scales as α^{-1}. Using these parameters and a peak value for $g_0(t)$ of 6.6%/cm the model gives the same laser output as was measured at 250-mJ discharge energy for $HgBr_2$ (0.2 mJ). This gain then corresponds to $\alpha = 1$. In the limit of large α the output increases by a factor of 4.2. For comparison, we measured a lower limit for the peak gain of 6%/cm at 502 nm ($\Delta\lambda$ 1 Å) and an extraction efficiency of 15%–20% from the sidelight depression when lasing. The normalized output from this model is shown in Fig. 2 as a function of α. At 250-mJ discharge energy the isotopic samples give a 40% increase in laser output which implies a 15% change in gain.

Figure 3 shows the discharge laser spectra for all three samples obtained from a PAR OMA-2 system with a 1-m Jarrel–Ash monochrometer (1180 g/mm). Using the spectral constants Tellinghuisen and Ashmore[10] have recently measured for the B and X state of $^{200}Hg\ ^{79}Br$, the isotopic shift in this region of the spectrum is only about 0.5 Å for adjacent Hg isotopes compared with 6–7 Å for the two bromine isotopes. The expected similarity between the two isotopic samples containing ^{79}Br is evident. For all three the most intense emission is in the vicinity of the (0–22) vibrational bandhead in contrast with $^{200}Hg\ ^{81}Br$ which lases most strongly on the (0–23) bandhead.[5] There is a fairly unambiguous correlation between the wavelengths of calculated bandheads ($J' = J'' = 0$) and the three sharp peaks near 502 nm observed for $^{200}Hg\ ^{79}Br$. These are at 5018.4 Å (0–22), 5022.4 Å (5–28), and 5024 Å (9–34, 10–36). Of course the bandheads from the highly excited vibrational levels may only contribute a small amount to the total transition strength at these particular wavelengths.

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