Short Communication

Controlled multiline CO₂ oscillator

For inertially confined laser-induced fusion experiments it is necessary to produce high power ultra-short laser pulses having a duration of one nano-second or less. One of the objectives in the case of CO₂ lasers is to extract efficiently the available energy during a controlled discharge system.

Because of the small pulse duration and the comparable collisional rotational-relaxation times, the efficiency is strongly dependent on the number of rotational lines present in the output-pulse of the master-oscillator [1].

In the case of saturation it has been found out that for a 1 ns pulse containing one rotational line only 45% of the stored energy can be extracted. By increasing the number of rotational lines in the pulse this efficiency will increase. For two lines for instance up to 65% and for three lines up to 70% [2] of the available energy can be extracted. For this reason we have tried to find a method of getting a maximum number of rotational lines with relatively comparable energy. It is well-known that the lasing rotational lines are highly competitive and in general the line with the highest gain-to-loss ratio will oscillate at the expense of the other lines. On the P-branch for instance, the gain-coefficient of the P-20 is about 10% higher than those of the nearest P-lines [3]. This means that unless some kind of loss discrimination is present, only the P-20 line will oscillate. In the present method we changed the gain-to-loss ratio over a number of rotational lines in such a way that they are equally likely to oscillate. In particular, we had to increase the loss factor of the P(20) transition.

This makes it possible for other lines (for instance the P(16), P(18), P(22) or P(24)) to compete successfully. For this purpose we used a wavelength dependent loss-element.

Previously Piltch [4] used a polished flat and a parallel sodium chloride plate as a Fabry-Perot etalon. Instead of adding such an extra optical component, which always introduces additional losses in the system, it is also possible to select with an out-coupling mirror having sufficiently high reflectivity.

We tried the multiple line selection with a flat germanium out-coupling mirror. This mirror had a thickness of 3 mm, a flatness of $\lambda/20$ and a parallelism better than 10^{-4} radians. One side was uncoated so that the reflectivity was 36%. The other side was A. R. coated with a very small reflectivity of 0.5%. For this mirror the intensity reflectivity R_{tot} can be calculated as:

$$R_{\text{tot}} = \frac{R_1 + R_2 - 2\sqrt{(R_1 R_2)} \cos \delta}{1 + R_1 R_2 - 2\sqrt{(R_1 R_2)} \cos \delta} \quad (1)$$

where R_1 and R_2 are respectively the intensity reflectivities of the first and second surface of the etalon. $\delta = 4\pi nL/\lambda_0$ is the phase change of a light ray after a round trip through the etalon.

The reflection of this mirror is given in Fig. 1.

The phase δ , being both linear with the thickness L of the mirror and the refractive index n of the used material (in our case germanium) depends on the temperature.

We can describe the variation of the phase change by the temperature as

$$\Delta\delta = \frac{4\pi}{\lambda_0} \left(n \frac{dL}{dT} + L \frac{dn}{dT} \right) \Delta T. \quad (2)$$

It turns out that in the case of germanium $\frac{1}{n} \frac{dn}{dT} \approx$

$5.2 \times 10^{-4} \text{ K}^{-1}$ is much larger than $\frac{1}{L} \frac{dL}{dT} \approx 6.1 \times 10^{-6} \text{ cm K}^{-1}$, so that we neglect the linear expansion of the etalon.

We can easily achieve an increase of phase of 2π , the difference between two maxima for the reflectivity, for an optical beam through this flat

Figure 1 The reflection R of the outcoupling mirror versus the phase-change.

Figure 2 Output intensities of the three rotational lines versus the temperature of the outcoupling-mirror.

by increasing the temperature over a few degrees.

For that case the change of n has to be:

$$\Delta n = \frac{\lambda_0}{2L} \quad (3)$$

where λ_0 is the wave length in vacuum. We calculated that a temperature difference of about 3 K lies between two maxima of the reflectivity.

By means of this technique we can choose a lower reflection for the P(20), than for the other lines, and obtain a fair competition between three or four lines. We observed that for several tempera-

tures of the mirror and for a 1 ns pulse, three or four rotational lines of equal intensity are present at the same time. The output power of each line as a function of temperature is shown in Fig. 2. It is seen that for instance at $T = 22.3, 25.3$ and 28.3 K we have equal intensities for the P(16), P(18) and P(20). In the case of a normal outcoupling mirror with one side completely A. R. coated, we always obtained one rotational line.

We also investigated several gas mixtures, but the number of lines and the relative distribution of their intensities did not change. It seems that the number of oscillating lines are only determined by the properties of the mirror and not by those of the active medium.

The laser construction on which the experiments were performed was a Lamberton-Pearson type [5] with trigger-wires and Rogowski-profiles. The electrode spacing was 17 mm. The gas mixtures were doped with a seed gas tri-*n*-propylamine [6]. The effective discharge length was 80 cm and the total length of the cavity was 187 cm. The second mirror was a 100% reflecting gold-coated mirror with a radius of curvature of 3 m. The electrical input energy was 18 or 50 J/l. The gain coefficient was about 2.0% cm.

The temperature of the mirror was stabilized by a homemade temperature control unit with an accuracy of 0.1 K or less. This unit can be made very easily as shown in Fig. 3. The mirror is mounted on a copper holder. The great advantage of this system is, that it can be easily controlled and stabilized.

Figure 3 Schematic diagram of the temperature control unit.

Further, since the temperature on which the mirror is stabilized differs by only a few degrees from the room temperature the absorption coefficient of germanium is practically unchanged.

References

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