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Experimental and theoretical study of a high-power c.w. chemical oxygen iodine laser(COIL)

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Abstract

A theoretical analysis of a kilowatt class COIL system has been performed in order to explain its output power limitation in the range of 600 watts. The influence of the excessive water vapour content on laser output power was studied using two theoretical models. The theoretical and experimental results confirm that decreasing the water vapour concentration by a factor of 2, allows to reach the kilowatt power levels.

Introduction

A high power kilowatt class COIL has been developed at ONERA /1/. During laser tests, the laser output has always been limited to 600 watts due to excessive water vapour concentration that has been measured. In order to optimize this device, a theoretical analysis has been conducted using two different models. The ONERA model is called model "A" /2/. The "Laboratoire de Spectrométrie Ionique et Moléculaire" at VILLEURBANNE has developed a laser delivering typically 35 watts and elaborated a complete theoretical model, called model "B" /3,4/. In this work, a theoretical study of the kilowatt laser is presented and compared with experimental results.

Experimental

The kilowatt laser experimental set-up has been previously described /5/. Typical results from 600 watts testing, expressed as a function of time, are represented in figure 1. The experimental conditions chosen for simulation, (point N), correspond to an oxygen flow rate of 0.08 mole/s with 60% concentration of singlet delta oxygen ($O_2^*/(O_2+O_2^*)$). The iodine concentration injected is 1.4%. The gain length is 150cm and the optical cavity consists of two $7 \times 7 \text{ cm}^2$ mirrors with the output mirror transmission $T=1\%$ and a maximum reflection for the other. The optical axis is placed at 14cm from the iodine injectors. The total cavity pressure of 1 Torr is obtained by adding a nitrogen buffer gas. The flow speed is about 43 m/s. The high water vapour content and its increase during the test, are clearly shown in figure 1. In this particular test, we note that the laser

power increases with the nitrogen flow rate (N_2) injected with the iodine vapour.

Figure 1

Theoretical analysis

The one dimensional model A described in /2/, takes into account only the main chemical reactions which occur when molecular iodine is mixed with oxygen flow. Iodine dissociation is achieved according to the Heidner 's model /6/ and the temperature dependent reaction rates are used for the two excitation reactions of iodine atoms and molecules. The model takes into account variations in density, temperature and velocity which result from chemical reactions, heat release and convective cooling on the walls. Laser effects were simulated using Zagidullin 's model / 7,8 / including relaxation of hyperfine levels and translational rates of iodine atoms with the hypothesis of a monomode laser. Laser intensity remains constant along the optical axis but can vary along the flow direction. In the experimental conditions of the high power device, especially high water vapour content of the laser medium, it has been found that the rate constants II of Heidner /6/ are more suited for the modeling of the laser operation. This point has been checked on a small scale COIL experiment at ONERA.

With this model, a parametric analysis was performed by varying the output coupler transmission (TR) and the percentage of active species defined by the ratio of their partial pressure to the total oxygen pressure. The resulting predictions are displayed in figure 2. The node corresponds to the conditions given in figure 1.

Figure 2

The model B has common features with model A. It is a one dimensional flow which takes into account of variations in density, temperature and velocity which result from the chemical reactions. The hyperfine structure and collisional relaxation have also been introduced. The dissociation of molecular iodine is achieved according to Heidner 's model /6/ with the rate constants number II. However, the model B is quite different from model A, it attempts to be a complete one, with all known reactions and the most recent reaction rate values. It has been tested on a small scale COIL /3/ with the calculated power reported in the last column of table I. We took into account 50 chemical reactions, among them, 9 are temperature dependent. Wall deactivation has to be considered, in particular the deactivation of $O_2(^1\Sigma_g^+)$ cannot be neglected. The wall deactivation rates have been determined in the experimental conditions of the small scale COIL. However, walls being insulated, no heating exchange has to be introduced in the energy balance. Instead of nitrogen gas, SF_6 was used as buffer gas because it is an heavier gas with a better calorific capacity, than N_2 . The laser output power is computed by an iterative calculation of the stimulated emission rate considered as homogeneous in all the laser cavity. This hypothesis is fully justified in the case of a multimode laser. The table I shows that the SF_6 buffer gas plays an important role in the laser medium cooling, leading to a better efficiency.

Table I

I_2 μ mole/s	Cl_2 m mole/s	SF_6 l/mn	pressure torr	obs.power watt	cal. ΔT K	cal.power watt
6.05	2.8	none	0.76	18.0	363	17.8
		3.0	0.86	30	93	32.2
8.56	2.08	none	0.61	17	330	16.8
		2.8	0.69	25.6	76	27.7

In these experiments, the gain length was 50 cm, the diameter of the mirrors was 2.2cm.and their transmission 1%,the size of the rectangular flow channel is 50×2.5 cm², the flow speed being in the range 10-15 m/s.

This last model has been used to do a parametric study in the previous node conditions (figure 3).

Figure 3

The output power values obtained with the two models are of the same order of magnitude, the model B being less optimistic. The variations of the laser output power as functions of water vapour content and singlet

delta oxygen percentage are very similar (figures 2 and 3).

Results.

A new stainless steel tube type water vapour trap has been developed and tested. Two laser tests have been performed using this new trap and water vapour has been reduced from the range 100-200 mTorr to 25-50 mTorr. During the first laser test, the laser output mirror with 1% transmission was burnt. The second laser test was conducted using output mirror with the transmission 2% and a laser power of 600 watts was obtained. These results are in good agreement with theoretical models and demonstrate that a significant power increase inside cavity can result from a decrease in water vapour content.

Conclusion

The two models predict successfully the experimental behaviour of the laser as a function of water vapour content. High intra-cavity laser power was obtained. Now, high power extraction will require optimization of the laser operating parameters.

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