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EXPERIMENTAL STUDY OF SUPERSONIC CHEMICAL OXYGEN-IODINE LASER (COIL)

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ABSTRACT A 5kW supersonic chemical oxygen-iodine laser (COIL) was constructed. A rotating mesh-type singlet-delta oxygen generator (SOG) was used that appears to be simpler, lighter in weight, and more efficient than the rotating disk SOG. An output power of 1kW from this supersonic COIL was achieved by using the rotating mesh SOG at a Cl_2 flow rate of 150mmol/s. Theoretical modeling of supersonic COIL based on a simplified model is given.

KEY WORDS: Supersonic, chemical oxygen-iodine laser.

0. Introduction

In 1978, a continuous wave supersonic chemical oxygen-iodine laser (COIL) was successfully demonstrated for the first time by McDermott[1] and further developed in some countries in subsequent years[2-6]. Nevertheless, only a few reports were released on investigation of these COILs. It is well known that the key technique used in research on supersonic COILs is how to obtain singlet-delta oxygen $O_2(^1\Delta)$ with a higher partial pressure

and higher concentration. Two types of singlet-delta oxygen generators (SOG) were reported in the references, namely the rotating-disk-type SOG[7] and the jet-type SOG[8].

In this paper, however, a new type of SOG is presented, namely: a rotating-mesh-type SOG that incorporates the advantages of both the above-mentioned rotating disk and jet-types. Not only is it simpler in structure and lighter in weight, but it can also generate singlet-delta oxygen at higher partial pressure and higher concentration as well as lower water vapor content. In our CW supersonic COIL experiments, an electrically heated iodine water vapor generator and a simple two-dimensional nozzle bank incorporated with a stable resonant cavity were employed. An output power of over 1kW was achieved at a Cl_2 flow rate of 150mmol/s.

1. Experiment

1.1. Rotating Mesh SOG

Singlet-delta oxygen $O_2(^1\Delta)$ was generated through a reaction between Cl_2 gas and an alkaline hydrogen peroxide (BHP) solution according to the following formula:

$$Cl_2 + 2KOH + H_2O_2 \rightarrow O_2(^1\Delta) + 2KCl + 2H_2O$$

In the SOG, Cl_2 entered the liquid phase through diffusion and reacts with BHP, and the singlet-delta oxygen resulting from the reaction escaped from the gas-liquid interface again through diffusion and returned to the gas flow.

It is necessary to consider and solve the following problems in designing a high-efficiency SOG:

(1) The lifetime of singlet-delta oxygen in BHP liquid is approximately 5μs. Therefore, in designing a SOG, special attention must be paid to the rapid and sudden elimination of this oxygen in the liquid phase.

(2) A high-efficiency SOG must have a sufficiently large BHP reaction surface because the diffusion of gaseous reacting substances toward the liquid phase and the diffusion in which the reaction products escape from the gas-liquid interface are both slow processes.

(3) The sudden elimination of singlet-delta oxygen in the gas phase is also rapid, the following process serving as its major elimination pathway:

$$O_2(^1\Delta)+O_2(^1\Delta) \rightarrow O_2(^1\Sigma)+O_2(^3\Sigma)$$

where $O_2(^1\Delta)$is the higher electronically excited state; $O_2(^3\Delta)$ is the basic state of O_2. The rate constant of the above process $k=2.7\times10^{-17}(cm^3/mol\cdot s)$.

From the foregoing bimolecular process, we can solve to show the following result:

$$p^*\tau=\text{constant}$$

where $p^*\tau$ is the partial pressure of singlet-delta oxygen $O_2(^1\Delta)$; and τ is the time of $O_2(^1\Delta)$ resident in the gas phase. This means that for high partial pressure p^*, $O_2(^1\Delta)$ must reside in the gas phase for an extremely short time, i.e., the $O_2(^1\Delta)$ generated in SOG must enter jet pipes and mix with I_2 as quickly as possible.

(4) In resonant cavities, the water vapor can lead to an extremely rapid and sudden elimination of iodine atoms in the excited state.

$$I(^2p_{1/2})+H_2O \rightarrow I(^2p_{3/2})+H_2O+Q$$

Its rate constant $k=2\times10^{-12}(cm^3/mol\cdot s)$.

The severity of the foregoing process lies in that it can release such large amounts of heat that heat blockage may take place. As a result, the pressure in the cavity will greatly increase and even the excited emission will stop. In designing a SOG, therefore, it is required that BHP remain at a low temperature so that the $O_2(^1\Delta)$ gas flow contains the least water

vapor as long as BHP does not solidify.

The rotating mesh SOG that we designed and adopted incorporated the advantages of both wet-wall-type and jet-type SOGs. In this case, when the multi-layer mesh rotated through the BHP liquid pool, a wet-wall-type reaction surface was formed on the mesh. In the meantime, the circulating BHP liquid sprayed down and collided with the multi-layer mesh to generate BHP droplets, thus producing large surface area for the reaction between BHP and Cl_2. Obviously, the structure of the rotating mesh SOG allowed an enormous reaction surface and ensures a short residence of $O_2(^1\Delta)$.

Structurally, the rotating mesh SOG was very simple. It is composed of a stainless steel case, a spiral-like mounted stainless steel mesh and a BHP circulating pump. 450mm in diameter and 500mm in length, the case was a reclining circular cylinder, in which there was a stainless steel mesh rotating along the circumference. The mesh was rolled into several layers (generally six) in a spiral way with an interval of approximately 25mm between layers, the diameter of mesh threads being 0.5mm and the mesh size being 20.

Fig. 1 is a schematic diagram showing the rotating mesh SOG with an optimum rotating rate 40-60rpm. The BHP was composed of 35% H_2O_2 and 35% KOH solution in a 1:1 ratio with a total volume 30L. The temperature of BHP was kept below -10^0C to make the water vapor pressure at the lowest level. During the operation of the SOG, BHP circulated continuously.

At the rear of the SOG, a cold trap was mounted to reduce the water vapor content in the gas flow. The open space between the inlet of Cl_2 gas and the $O_2(^1\Delta)$ concentration test window was approximately 55L. The relative concentration of $O_2(^1\Delta)$ was

measured by recording the intensity of the 1.27μm signal with an electrically cooled germanium detector, while its absolute concentration was measured using an infrared radiation calorimetric method. Additionally, the water vapor content in the $O_2(^1\Delta)$ gas flow was measured by using the spectral method as an improvement of the method described in the references. Here are listed the results of the rotating mesh SOG experiment along with a comparison between these results and those of the rotating disk SOG.

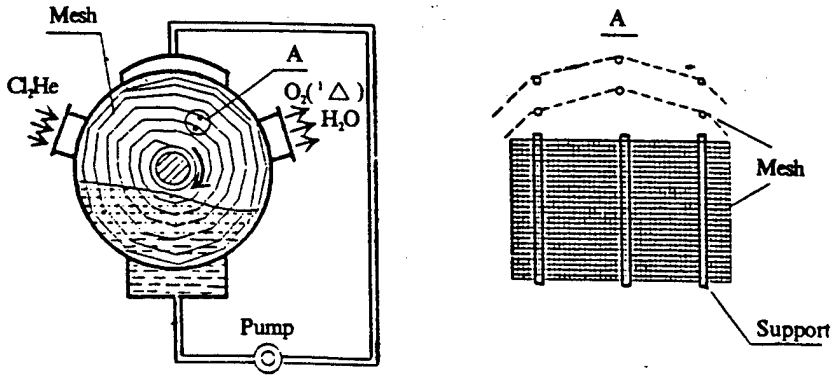

Fig. 1. Rotating mesh SOG

3	1转网式 SOG(Φ450 mm)	2 转盘式 SOG(Φ350mm)
Cl_2 流量/mmol·s^{-1}	480	600
O_2 分压/133Pa 4	10.6	8
$O_2(^1\Delta)$ 浓度/% 5	40	45
$O_2(^1\Delta)$ 分压/133Pa 6	4.2	3.6
H_2O 分压/133Pa 7	0.8	0.5
Cl_2 利用率/%8	90	96

(1) Rotating mesh SOG
(2) Rotating disk SOG
(3) Cl_2 flow rate
(4) O_2 partial pressure
(5) $O_2(^1\Delta)$ concentration
(6) $O_2(^1\Delta)$ partial pressure
(7) H_2O partial pressure
(8) Cl_2 utilization rate

1.2. Experiment on Supersonic COIL

We constructed a complete setup for a 5kW supersonic COIL as shown in Fig. 2.

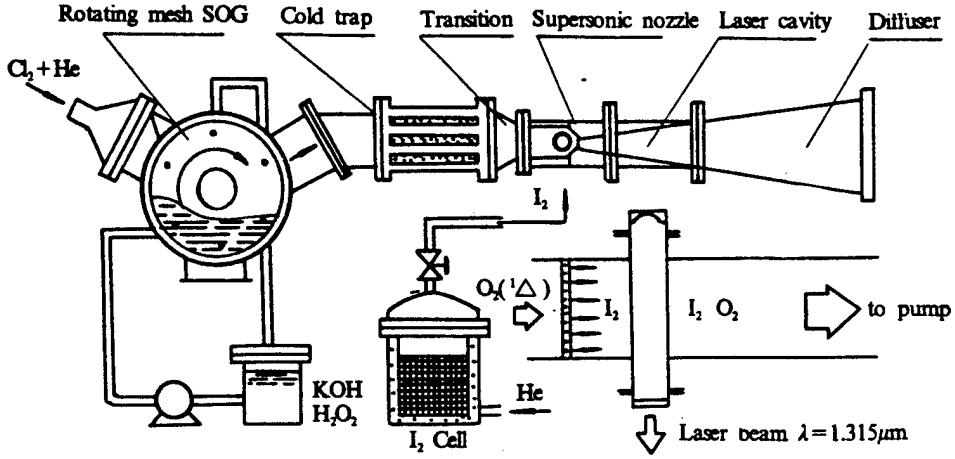

Fig. 2. A schematic diagram showing the setup of A 5kW supersonic COIL

By using the above-mentioned rotating mesh SOG, $O_2(^1\Delta)$ with a larger flow rate and a higher partial pressure was obtained, which, through a cold trap to remove the water vapor, entered a two-dimensional O_2-I_2 mixing supersonic nozzle as shown in Fig. 3. The I_2 vapor flow, produced by an electrically heated iodine evaporator, mixed with the iodine vapor sprayed from an iodine nozzle with a number of small holes in the subsonic zone of the nozzle. Then, the mixture passed through a throat passage with a cross section 1cmx50cm to form a supersonic $O_2(^1\Delta)$-I_2 mixing gas flow and enter a resonant cavity. The resonant cavity used at present was a stable resonant cavity, which consisted of two quartz mirrors with a diameter 70mm. One mirror was a plane output mirror with a penetrating rate around 5%, while the other

was a spherical mirror with greater than 99.5% reflectivity. The distance between the two mirrors is 1m.

An output power of over 1kW was achieved at a Cl_2 flow rate of 150mmol/s. Fig. 4 lists typical data of the supersonic COIL experiment.

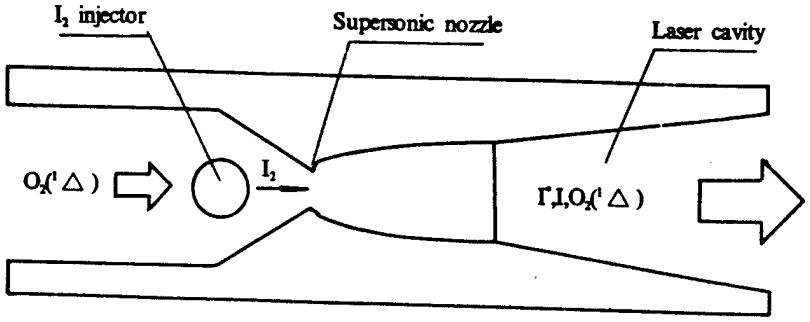

Fig. 3. Supersonic O_2-I_2 mixing nozzle

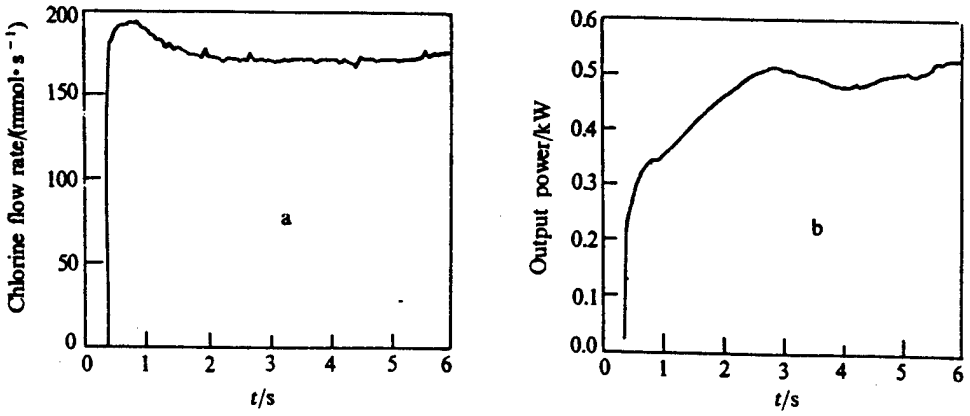

Fig. 4. (a) Chlorine flow rate and (b) output power

Calculations were also made of a premixed one-dimensional supersonic COIL model, which revealed its small-signal gain as being in the $1x10^{-2}cm^{-1}$ order of magnitude. This result was compared with the small-signal gain coefficient of the subsonic COIL as shown in Fig. 5. The numerical values of the small signal gain coefficient proved to be extremely important, because

unstable resonant laser cavities can be used only when the small signal gain coefficient reaches a certain value.

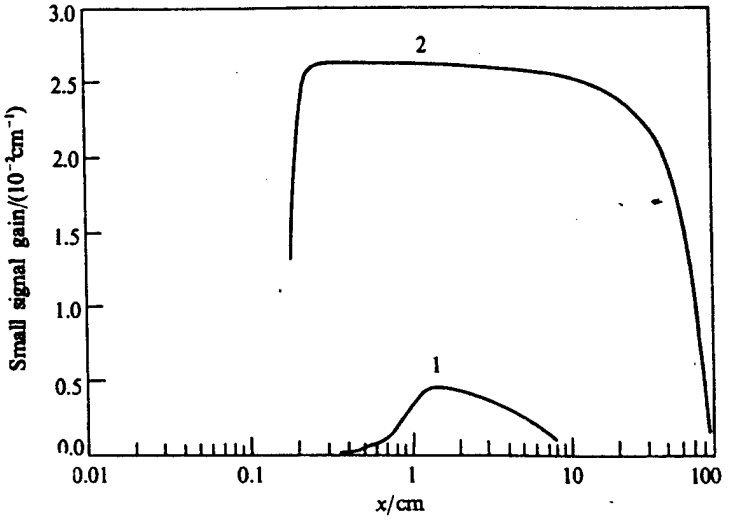

Fig. 5. Theoretical calculation values of small signal gain

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