Partial feedback unstable resonator on small scale supersonic large aperture chemical laser

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ABSTRACT

There is always a challenge on large aperture medium power laser’s resonator design, stable resonator would support significant higher order transverse modes, folded and telescope stable resonator are too complex and not preferred by engineers, unstable resonator need rather large round trip gain to compensate its high geometric out-coupling, which is difficult for this kind of laser since its gain length is limited due to the power level and large aperture. Partial feedback unstable resonator had been proposed to tackle this difficulty since the early days of laser development, however, the debates of its effect never stopped even with those distinguished optical resonator scientists such as Siegman, Anan’ev, and Weber. Recently integrated partial feedback unstable resonator design had been successfully demonstrated on a medium size chemical oxygen iodine laser. In this paper, we carry this resonator configuration on a small scale discharge driven supersonic nozzle array Hydrogen Fluoride chemical laser, a typical large aperture short gain length device. With magnification equals 4/3, we successfully get ten Watts level ring beam output.

Keywords: chemical laser, unstable resonator, partial feedback, beam quality

1. INTRODUCTION

As one of most important high power lasers, chemical laser’s average power record has never been broken, even with fast growing of all solid state lasers (SSLs) and hybrid diode pumped gas lasers[1][2][3][4][5]. Most importantly, vibrotational chemical laser, such as hydrogen fluoride (HF) and deuterium fluoride (DF) laser’s wavelength falls in 2.5-4 micrometer range, this band marks its importance in infrared spectroscopy, laser chemistry, and other novel applications, although mid-infrared SSLs proceed fast in the past decade, such as quantum cascade laser[6], transition metal laser[8], mid infrared fiber laser[7], Raman laser, their average power level cannot compete with near infrared SSLs, and are significant lower than chemical lasers, small scale combustion driven HF chemical laser could easily generate kW output.

Supersonic flows are typically used to significantly enhance chemical laser’s efficiency and compactness, by specifically designed supersonic mixing nozzle, we have realized fourfold increase of laser average power and efficiency, that lies in the facts of small signal gain (SSG), saturation intensity growing and gain length extending along flow direction. However, for a small and medium power device, with chemical laser’s high specific energy and nozzle area efficiency, its gain length will be limited if the dependence of supersonic flows mass flow rates on throat size are considered. This naturally leads to large cross-section, short single trip amplifying length active volume characteristics and this will further brings challenge to resonator choice. Traditional unstable resonator (UR) need enough single trip gain to compensate large out-coupling; stable resonator will permit significantly higher order transverse modes operation; corner cube resonator suffered from ridge diffraction loss while telescope resonator stability issues should be considered.

At the early stage of UR development, it is proposed partial feedback could possibly lower its threshold. Based on experimental studies with Nd glass laser, Anan’ev points that any stochastic weak disturb of feedback wave will be strongly intensified through UR’s de-magnifying process, then affects UR’s core region, then deteriorate the beam quality[9]; Siegman also holds that opinion[10]; while Weber et al. takes positive view with experimental study carried on Nd:YAG laser[11]. Recently, German DLR scientists incorporate integrated partial feedback negative confocal UR concept to kilowatt scale chemical oxygen iodine laser (COIL)[12], a type laser just we cared in this paper, the merits of integrated manufacture lies on the fact that edge diffraction and scattering could be significantly lowered. We manufactured similar secondary mirror and successfully transplanted this concept on a small scale supersonic HF chemical laser.

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2. EXPERIMENTAL APPARATUS

The laser used in this study is as the same of our formal study\textsuperscript{[13]}, here we show it in figure 1 and present its operation principle simply: Nitrogen Tri-fluoride (NF\textsubscript{3}) carried by Nitrogen (N\textsubscript{2}) gas flows through the discharge tube, NF3 are partially dissociated into free Fluorine atoms need by initialize the chemical pump reaction, the hot Fluorine atom flow are further cooled and diluted by the secondary N\textsubscript{2} gas flow from end of discharge tube, then the it is accelerated to low temperature low pressure supersonic flow by supersonic nozzle array, supersonic fuel gas Hydrogen (H\textsubscript{2}) are also injected from this nozzle array, mixes and reacts with the Fluorine gas flow fiercely, generates rot-vibrational excited HF molecules, the deposited inner energy will be extracted by the cavity as the laser beam. Gain length along flow direction extends about 10mm with formal SSG scanning, with the nozzle array height of 10mm and length 120mm, the gain volume is a $10\text{mm} \times 10\text{mm} \times 120\text{mm}$ cube. The exhaust hot gases after lasing are further cooled by heat exchanger, then are discharged to atmosphere and scrubbed by the vacuum system. Flow rate of fuels and dilute gases are controlled by the mass flow controller (MFC), plenum pressure and cavity static pressure are monitored by piezoelectric transducers to ensure supersonic running.

![Figure 1. The small-scale HF chemical laser conducts the experiment](image)

To eliminate strong water vapor absorption in HF laser band, most of our formal studies select inner cavity configuration. In this study, to align and adjust the silicon based mirror, we transferred to outer cavity by sealing active region in Brewster angle with Calcium Fluoride (CaF\textsubscript{2}) windows, however, according to our formal experience, outer cavity's efficiency will drop a lot. Based on SSG scanning results, we set optical axis 5mm down from the nozzle exit plane. The 1m radius curvature silicon primary mirror is coated with intensified gold and a 1mm diameter hole drilled in the center to help cavity alignment; the secondary mirror is featured showing with figure 2, in the center of the 1 inch polished plano silicon mirror, 7.5mm diameter and 0.75m radius curvature concave surface is manufactured and coated with intensified gold, in this way, a backward ring output negative confocal UR with magnification of 4/3 is realized if the distance between two mirror are set to 875mm. In principal, square beam rather than the ring beam is preferred if mode match with cubic gain medium is considered, however, square beam would be more easily designed with separated scraper rather than this integrated design, hence at least 22\% energy cannot be extracted due to this dis-match. Fresnel reflection of polished silicon plano surfaces of secondary mirror are used to generate natural marginal partial feedback, while the back surface is anti-reflectance coated in wide mid-infrared band. Both mirrors are fixed on the multi-dimensional freedom mirror mount.

Calorimeter power meter are used to monitor laser power output, burned pattern on thermal sensitive paper and PMMA plate are used to record mode shape, a 2.8 micrometer cut-off wavelength infrared camera are used to monitor and a 250MHz band-width Vigo infrared detector are used to monitor the ring beam intensity fluctuations.
3. EXPERIMENTAL RESULTS

It’s easy to get lasing from this kind of UR, under flow rates amount to 50 Watt with inner cavity configuration, 18Watt ring beam could be obtained. At more higher laser powers, saturated energy extraction will reduce gain length along flow direction, and leave behind absorption region in downstream, making a dis-match of gain region with cavity mode, that need further reduce the concave part diameter of the secondary mirror and move optical axis closer to the nozzle exit plane. By the indication provided with the burned ring beam pattern symmetry, we could fine adjust relative positions of the two mirrors, as shows in figure 3, the left and right are beam pattern misaligned, while the center are aligned, some of the crescent near the outer ring may came from the manufactured error of the second mirror, there are a slight step between the concave and plate region. By passing the beam through a 1m focal length CaF$_2$ plano-convex lens, we could observe the lens transformed beam pattern, which provides the information of beam quality. When se move the PMMA plate to the focal point, the center energy of the focal pattern increased gradually, and by moving of PMMA plate around focal point slightly, we could get the smallest far field transform pattern, as show in figure 4. Left of figure are the measurement of burned pattern size with a digital microscope, the scale of the large ticks amounts to 1mm, 200X magnified pattern shows in figure 4b. The ideal size of the diffraction limited beam should be around 0.35mm, that’s a rather good beam quality compared to stable resonator, the latter will support significantly higher order modes operation.

![Burned ring beam pattern under off-alignment and on-alignment of two UR mirrors](image)

Figure 3. Burned ring beam pattern under off-alignment and on-alignment of two UR mirrors

![PMMA burn pattern of focal point](image)

Figure 4. PMMA burn pattern of focal point

When monitored with infrared camera, we found there are bright spots moving fast along the ring beam, just as figure 5 shows. By adding restriction diagram on the ring beam, we could monitor the bright spots circulating characteristics by infrared detector. Strong fluctuations exists as figure 6 shows. Further Fourier time-frequency analysis and nonlinear
time series analysis both indicated no sign of order. Mechanisms of the phenomena are still unknown, correlation measurements from different detectors maybe give more information.

Figure 5. Moving of bright spots in the ring beam

Figure 6. Fluctuations of the sampled beam intensity due to bright spots moving

4. CONCLUSIONS

We manufactured an integrated marginal partial feedback secondary mirror, conducted partial feedback negative branch confocal unstable resonator on a small scale supersonic large aperture hydrogen fluoride chemical laser, under the initial un-optimized design, we obtained 18 Watt ring collimated beam output, the beam quality factor are less than 3. The experiments demonstrate the possibilities and advantages of this kind of unstable resonator on large aperture, low single-trip gain lasers.

5. ACKNOWLEDGMENT

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