Master

DIRECT NARROW LINE TUNING OF A HIGH POWER CO_2 LASER

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We report the operation of a high power, narrow linewidth CO_2 laser suitable for application as a pump for pulsed submillimeter lasers. Grating tuning and single mode cw injection have been employed in an unstable ring resonator which produces 100 nsec duration, 200-400 Joule pulses on the 9R(22) line with a bandwidth of less than 20 MHz.

Introduction

The motivation for this work was the development of an optically pumped, 385 μm, D_2O laser scattering diagnostic which would be suitable for the measurement of ion temperature within the hot core of a tokamak fusion device. For this application the D_2O laser needs to produce a relatively long (~ 500 nsec), high power (≈ 2 MW), narrow line width ($\lesssim$ 30 MHz) pulse. The spectral purity and duration of the D_2O laser pulse depends in turn on the bandwidth and pulse length of the 9R(22) CO_2 pump line.(1) Also, because of the relatively poor efficiency of the pumping process (~ 0.1%) it is necessary to build a CO_2 laser pump with a pulse energy $\gtrsim$ 1 kJ.

An unstable resonator(2) can produce low divergence, high power pulses since it offers a large volume with excellent transverse mode discrimination. However, grating tuning is difficult because spherical and plane wavefronts are intermixed within resonator;(3) therefore, the application of unstable oscillators as coherent pumps for far-infrared lasers have been limited.

Where relatively strong transitions in the pump laser are involved, for example at the peaks of the gain curve for the 9 and 10 μm branches of the CO_2 laser, a grating tuned cw laser can be used to seed the desired transition. In addition, an intracavity absorption cell can be employed to suppress the unwanted, strong transitions.(4) However, where the generation of relatively weak lines is demanded, such as the 9R(22) line, a more direct tuning method is required. In the present work we report a direct tuning arrangement which is simple and effective and which is applicable to large unstable resonators.

The Laser Configuration

The cavity configuration used in the present work is shown in Fig. 1. It is similar to the ring unstable resonator used by Freiberg et al.,(5) with the addition of grating and injection tuning.

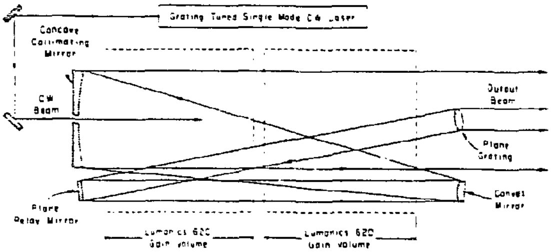

Fig. 1 Grating tuned unstable resonator.

The 5cm diameter, 135 line mm^{-1} plane grating used in first order, deflects part of the collimated laser beam via a plane relay mirror onto a 2m radius of curvature convex reflector, which is located off-axis near the grating. This convex mirror expands the beam so that it fills a 25 cm diameter, 10m radius of curvature, concave mirror. The resultant, collimated beam is directed towards the grating and thus serves as both the output beam and the feedback beam for the next pass of the cavity. This configuration effectively separates the plane and spherical wavefronts so that a relatively small, plane grating can be employed for line tuning. Furthermore, since the arrangement is an asymmetric unstable ring, it has a substantial degree of unidirectionality which avoids the extreme sensitivity of extra-cavity feedback usually associated with unstable resonators.(6)

In order to obtain single longitudinal mode operation, cw radiation from a grating tuned, single mode CO_2 laser is injected through a 1 cm centered hole in the concave resonator mirror.

The spectral resolution of the cavity shown in Fig. 1 may be obtained from a ray tracing analysis. The result is

$$\frac{\Delta\lambda}{\lambda} = \frac{(M-1)^2}{M(3M+1)}\,\frac{a}{2L}\sqrt{\left(\frac{2d}{\lambda}\right)^2 - 1} \qquad 1.$$

where λ is the central wavelength, d is the grating spacing, a is the radius of the grating, L is the cavity length, and M is the geometric magnification.

For the geometric parameters of our system, namely a = 2.5cm, $\ell/d = 135\ \mathrm{mm}^{-1}$, L = 400 cm and M = 5, equation (1) predicts a resolution of 0.0072 μm at λ = 9.26 μm. Since the line separation in the 9R branch of CO_2 is approximately 0.01 μm, this predicts that the resolution is sufficient for single line operation.

The amplifying medium within the cavity is provided by two Lumonics Model 620 modules. All four beams pass through the gain volume shown in Fig. 1. A wide variety of output pulses can be produced by firing the two modules separately, simultaneously or sequentially.(7)

System Performance

In order to demonstrate the frequency selectivity of the grating tuned unstable resonator, the system was operated on several different lines in the 9R branch, where the lines are relatively closely spaced. Reliable lasing was obtained on the selected lines with no other lines observable. In particular, the pulse energy on the 9R(22) line with both Lumonics modules in operation was 200-400 joules and appeared to be insensitive to trigger delays up to 1 μsec between the two modules. The near field beam profile was 8-9 inches in diameter with a superimposed shadow of the 2" diameter grating and its associated radial supports.

Measurements of the laser pulse shape were made with a photon drag detector, the data being acquired with a Tektronix R7912 transient digitizer having a 500 MHz bandwith. The frequency content of each laser pulse was qualitatively determined by taking the Fourier transform of the pulse shape. Fig. 2 shows the temporal behavior of a typical output pulse from the grating tuned oscillator, without cw injection. The pulse shape was somewhat asymmetric with a 60-80 nsec half-width and consisted of a series of apparently random 2-4 nsec spikes. The Fourier transform of the photon drag signal shows peaks in the spectrum which appear to be correlated with the longitudinal cavity modes.

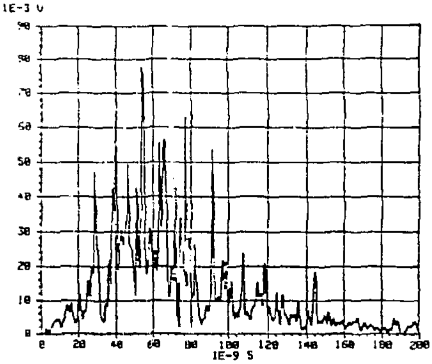

Fig. 2 Temporal behavior of laser pulse without injection tuning.

A simulation involving randomly phased modes with a spacing corresponding to the axial modes of the unstable cavity (≈ 19 MHz) and a parabolic amplitude vs. frequency distribution was used. In order to simulate the significant features of the desired pulse shape and its Fourier transform, it was necessary to include approximately 100 modes and to make corrections for the finite beam width of the digitizer scan converter tube and the bandwidth of the transient digitizer. It can be seen from comparison of Fig. 2 and 3 that the simulation closely approximates the measured laser pulse shape.

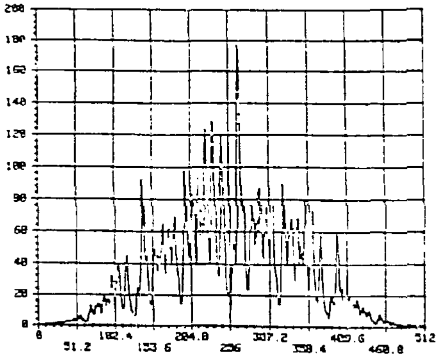

Fig. 3 Simulation of temporal behavior of laser pulse with injection tuning using ~ 100 axial cavity modes with random phase.

In order to generate a narrow linewidth, we injected 15 watts of CO_2 laser radiation from a grating tuned single mode cw laser as shown in Fig. 1. A typical pulse from the unstable ring resonator, with cw injection, is shown in Fig. 4. The pulses had a half width of 60-100 nsec with a smooth time behavior characteristic of a bandwidth of $\leq$ 20 MHz. The pulse shape was symmetric with a long, low, irregular tail. Hutchinson and Vander Sluis (4) observed the elimination of the gain switched spike in their injection laser; however, our injected power was probably insufficient for this to occur.

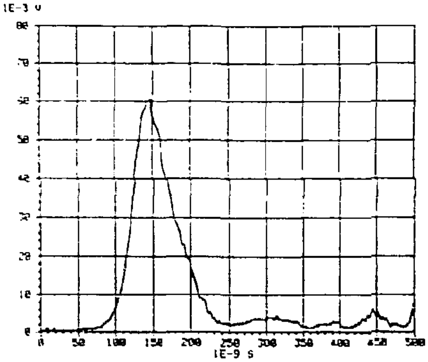

Fig. 4 Temporal behavior of laser pulse with injection tuning.

Injection tuning of this laser system was only observed to occur when both lasers were tuned to the same line, which further attests to the excellent wavelength discrimination of the grating tuned unstable resonator. On several occasions with injection tuning, we observed what appeared to be axial mode beating. An example of this is shown in Fig. 5. In order to investigate this further we looked at the output of the cw laser used for the injection experiments with a fast Ge:Cu detector. By slightly adjusting the laser cavity length with a piezoelectric translator, it was possible to obtain 0, 16 and 36 MHz beating, depending on the cavity length. Such an injected beam could be expected to excite two or more longitudinal modes in the unstable resonator, with its 19 MHz axial mode spacing.

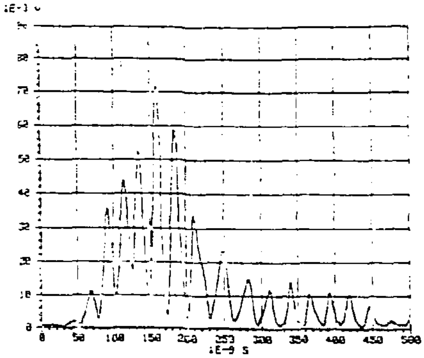

Fig. 5 Temporal behavior of laser pulse with injection tuning showing mode beating.

Conclusions and Future Work

In conclusion, we have demonstrated the operation of a relatively simple, unstable ring resonator which produces several hundred joules of laser energy in a 100 nsec pulse on a single CO_2 laser line. In addition, injection tuning with just 15 watts of cw laser radiation gives rise to laser pulses with ≤ 20 MHz bandwidth, the pulse energy and duration being similar to the non-injected configuration.

In order to increase the duration and energy of the laser pulse to meet the requirements for pumping a D_2O laser suitable for far-infrared laser scattering, we are in the process of using a second pair of Lumonics 620 modules as an amplifier for the hybrid oscillator pulse. By delaying the amplifier with respect to the oscillator modules, it should be possible to produce the required 500 nsec, 1 kJ pump pulse, while retaining the frequency purity needed for D_2O laser excitation. The immunity of the unstable ring resonator to feedback effects should be a considerable advantage in this oscillator-amplifier configuration.

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Acknowledgment

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