Theoretical Model of a 16 µm Intracavity Raman Oscillator Pumped by TEA CO_2 Laser

A. C. Oliveira, A. Mirage*, N. A.S. Rodrigues, A. M. dos Santos
Instituto de Estudos Avançados, CTA, Rodovia dos Tamoios Km 5,5 - CEP12231-970; CP 6044, S. J. Campos ;*Instituto de Pesquisas Energéticas e Nucleares, CNEN, CP 11049,São Paulo
e-mail:acoc@ieav.cta.br

Abstract: *A theoretical model of a 16 µm Raman laser oscillator using the Stimulated Rotational Raman Scattering (SRRS) of a CO_2 laser in para-H_2 with the Raman cell situated inside the CO_2 laser cavity is presented. A set-up for the laser configuration is showed and a set of differential rate equations is described. Some theoretical simulations are displayed and commented.*

1.Introduction

Molecular laser isotope separation is a potential technique in the enrichment of uranium. This process has been demonstrated in the laboratory [1] scale and researches are presently carried out to develop a commercially attractive process.

The required characteristics of the laser system for the process are: high intensity, high efficiency, tunability in the 16 µm infrared spectral range and high repetition rate.

Stimulated rotational Raman scattering (SRRS) of the CO_2 laser radiation in para-H_2 has been used to achieve this purpose [2]. Since the SRRS gain in infrared is low, a multipass cell (MPC), with repeated focusing, is used to increase the Raman interaction length.

To establish the conversion threshold condition a chain of oscillator-amplifier CO_2 lasers must be used. The reduction of laser requirements seems to be an important point to enable an economically acceptable process. A Raman oscillator inside the cavity of the CO_2 laser is a possible candidate to this reduction.

2.Raman Oscillator Set-Up

The set-up used in the theoretical model is presented in fig. 1. The Raman laser cavity is composed by two branches, coupled by one dicroic mirror DM. The DM will transmit the CO_2 laser radiation (10 µm) and will reflect the 16 µm radiation. The CO_2 laser will oscillate in the branch between the mirrors TR and CM. One injected seed with circular polarization can be used to maximize the laser Raman gain and avoid parametric process.

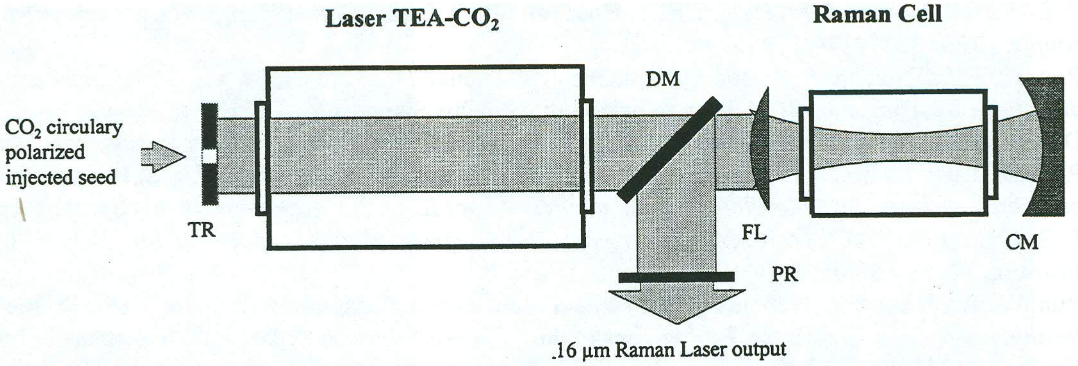

figure 1-Laser Raman set-up. TR-total reflector, DM- dicroic mirror, FL- focusing lens, CM-concave mirror , PR-coupling mirror.

The Raman cell is intracavity to the CO_2 laser. To increase the SRRS gain two focusing optical components (FL , CM) are used to focuse the pump radiation inside the cell. The 16µm oscillation (Stokes radiation) occurs in the cavity branch between the coupling mirror PR and CM.

3.The Effective Raman Power Gain

The Raman power gain coefficient for a focused TEM_{00} Gaussian beam in steady state conditions is related to a cavity configuration as [3]

$$g_1 = \frac{4P_P G_S}{\lambda_P + \lambda_S}\tan^{-1}(\frac{L}{b}) \tag{1}$$

where P_P is the pump power, G_S is the plane wave Raman gain coefficient, L is the optical focusing separation, b is the confocal parameter ($b=2\pi\omega_{0P}^2/\lambda_P$, with ω_0 the beam waist of the pump) and λ_P , λ_S are the wavelengths of the pump and Stokes waves respectively.

In the oscillator cavity set-up, the beam will travel twice per cavity round trip and the gain will be enhanced:

$$g = T(1+R)g_1 + 2\ln RT \tag{2}$$

where R and T are the reflection and transmission coefficient of the CM mirror and FL lens.

The Raman plane wave gain will determine the dependence with Raman medium properties. For a pure rotational Raman scattering in a diatomic gas this gain is [4]:

$$G_S = \frac{4\lambda_S{}^2\Delta N_{0-2}}{n_S{}^2\hbar\omega_S\Delta\nu_R}(\frac{d\sigma}{d\omega}) \tag{3}$$

where $\Delta N_{0\text{-}2}$ is the rotational inversion density of the Stokes transition, $\Delta\nu_R$ is the Raman linewidth (FWHM), n_S is the refractive index at Stokes frequency, ω_S is the Stokes frequency and $d\sigma/d\omega$ is the differential cross section.

The Raman gain depends on polarization state of the pump and Stokes radiation, with maximum obtained for circularly polarized beam. For this polarization we have [5]:

$$\frac{d\sigma}{d\omega} = \frac{\omega_S^4(J+1)(J+2)}{5c^4(2J+1)(2J+3)}\gamma_{00}^2 \tag{4}$$

where χ_{00} is the molecular anisotropic polarizability and J is the rotational state.

The above relations permit us calculate the Raman gain dependence on para-H_2 temperature and pressure, Raman linewidht, pump and Raman wavelength and focusing cavity components.

4. Rate Equations for Raman Oscillator

To obtain the Raman oscillator model a set of differential rate equations is established. The CO_2 laser is described as a four-level system, like reference [6], and the different populations densities (molecules/cm^3) are governed by the equations:

$$\frac{\partial n_1}{\partial t} = \alpha(n_0 - fn_1) + k(Nn_0 - n_1N_0) - k_{13}n_1 - SI_P(n_1 - n_2)/(ch\nu) \tag{5.1}$$

$$\frac{\partial N}{\partial t} = \beta\,(N_0 - fN) - k(Nn_0 - n_1 N_0) \tag{5.2}$$

$$\frac{\partial n_2}{\partial t} = SI_P(n_1 - n_2)/(ch\nu) - k_2 n_2 \tag{5.3}$$

$$\frac{\partial n_3}{\partial t} = k_2 n_2 - k_3 n_3 + k_{13} n_1 \tag{5.4}$$

where n_i and N_i are related to CO_2 and N_2, respectively, k_i is the collisional rate , SI_P is the stimulated emission rate, I_P is the CO_2 laser intensity, α and β are electron pump rates and f relates the excitation and de-excitation rate in electric discharge.

Two equations are used to describe the optical radiation in the Raman laser, one for the CO_2 pump intensity and other to the Stokes intensity:

$$\frac{\partial I_P}{\partial t} = SI_P(n_1 - n_2) - w_c I_P + Dn_1 - g_{eff} I_P I_S (c/L_S)(h\nu_P/h\nu_S) \tag{5.5}$$

$$\frac{\partial I_S}{\partial t} = g_{eff} I_P I_S c/L_S - w_{c,S} I_S + d_S I_P \tag{5.6}$$

where w_c and $w_{c,S}$ are the decay rates of the pump and Stokes cavity, D and d_S are spontaneous emission rate for CO_2 and Stokes, respectively, L_S is the length of the Stokes cavity. The parameter g_{eff} was introduced to present these equations in terms of intensity and is related to the Raman power gain by : $g_{eff} = g\,\pi\, w_{0P}{}^2/P_P$.

5. Results

The calculated pulses are presented in the figure 2 and 3, where the depletion of the pump beam (dashed line) and the growing of the Stokes radiation (solid line) are showed. The Stokes intensity showed in this figure is the output of the Raman laser.In the figure 3 the confocal parameter was reduced.

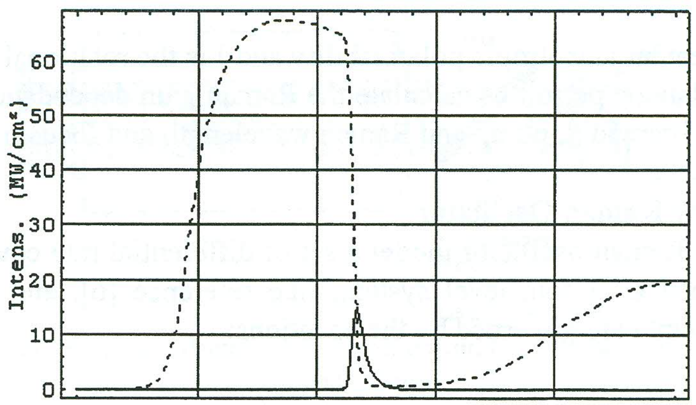

figure 2 calculated pulses- CO_2 (dashed line) and Stokes output Solid line

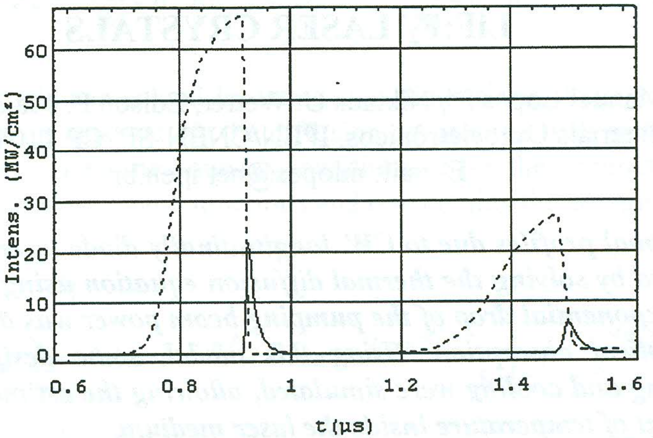

figure 3 calculated pulses- CO_2 (dashed line) and Stokes output Solid line

6. Conclusions

The theoretical model of Raman oscillator indicate that this system can be used as a source of tunable radiation in the 16 µm spectral range and model can be applied to optimize the parameters of the Raman laser.

REFERENCES

[1] H. Tashiro and K. Takeuchi , Separation Phenomena in Liquids and Gases, Fourth Workshop Proceedings, 1994.
[2] Robert L. Byer, IEEE J. Quant.Eletron., November 1976
[3] P. Rabinowitz. A. Stein, R. Brickmanand A.Kaldor, Opp Lett., vol3, pp.147-148, Oct. 1978
[4] N. R. Trutna and R. L. Byer, Appl. Opt., Vol 19, No 2, Jan. 1980
[5] J. L. Carlsten and R. G. Wenzel, IEEE J. Quant.Eletron., Vol. QE-19, No 9,Sept. 1983
[6] K. J. Andrews, P. E. Dyer and D. J. James, J. Phys Sci. Instr., Vol 8 ,pp. 493-4981975