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Simultaneous Two-Line Operation of a CW CO Laser with Arbitrary Choice of Laser Transitions*

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Abstract. An experimental scheme is discussed, by which we can operate a CO laser at two individually selectable lines from the same gain tube. There are virtually no restrictions on the wavelength separation of the two lines within the manifold of the available lasing transitions. Experimental verifications of this scheme are described and the mutual influence of the simultaneous laser operation is discussed.

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The Littrow mount of a reflection grating in the blaze-angle region is commonly used as a means for intracavity line selection of a molecular gas laser, such as the CO laser. A high-Q cavity is formed at the retrorefracted wavelength between the curved end mirror M_1 and the reflection grating M_2 (Fig. 1). The wavelength for laser oscillation can easily be changed by changing the angular position ϕ of the grating.

An interesting question arises, if we add a third mirror M_3 to the system so that a three mirror cavity can be formed under almost-Littrow-condition, as given in Fig. 2. We have followed this simple idea and have been able to verify a laser system capable to run simultaneously on various different transitions that are almost independently selectable.

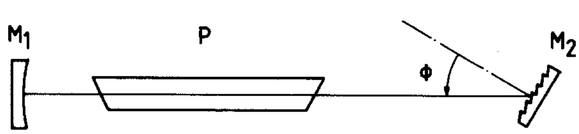

Fig. 1. Littrow configuration for lineselection [M_1: concave end mirror (gold); M_2: reflection grating as plane, wavelength selecting mirror; ϕ: angle between laser axis and normal to grating (Littrow angle) defining the laser wavelength; P: CO-laser plasma]

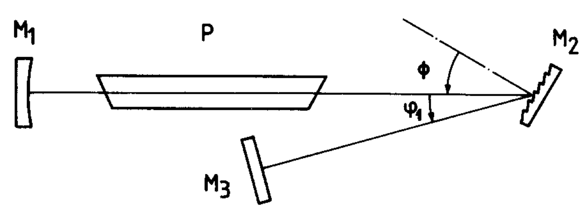

Fig. 2. Three-mirror cavity for two-wavelengths operation (M_3: auxiliary mirror defining cavity for laser wavelength λ_1 at angle $\phi+\varphi_1$)

1. Resonance Conditions for a Three- and a Four-Mirror Cavity

The resonance condition for the Littrow mount is given by

$$\lambda_0 = 2d \sin\phi\,, \tag{1}$$

where λ_0 is the retrorefracted wavelength, d is the grove distance and ϕ the position angle of grating with respect to the laser axis.

* Dedicated to Professor Siegfried Penselin on the occasion of his 60th birthday

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In a close-to-Littrow three mirror system a further wavelength can oscillate, as defined by the following condition

$$\lambda_1 = d\sin\phi + d\sin(\phi + \varphi_1). \quad (2)$$

Here the refraction angle is $(\phi + \varphi_1)$ whereas the angle of incidence is ϕ or vice versa. The small angle φ is defined by the normal to the mirror M_3 and the laser axis.

It is obvious that we can play this game with a further mirror and form two different additional cavities, if we add a mirror M_4 to the system, thus defining

$$\lambda_2 = d\sin\phi + d\sin(\phi + \varphi_2) \quad (3)$$

as can be seen in Fig. 3. Thus we have three different laser wavelengths λ_0, λ_1, and λ_2 on which laser oscillations can take place simultaneously, if the gain medium, placed in the common branch of the cavities, provides gain simultaneously for all three wavelengths.

The various wavelengths are determined in the following way

λ_0 by ϕ only,

λ_1 by ϕ and φ_1,

λ_2 by ϕ and φ_2.

Thus λ_1 and λ_2 can be changed independently from λ_0, but if λ_0 is varied, λ_1 and λ_2 vary also.

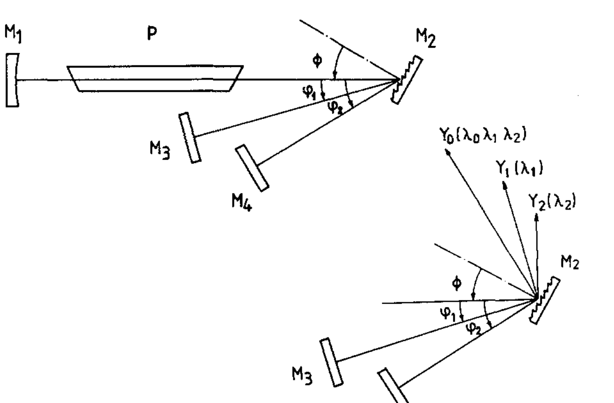

Fig. 3. Four-mirror cavity for three wavelengths operation. Between M_2 and M_3 an optical shutter (S_1, not shown in figure) can block the signal at wavelength λ_1 and between M_2 and M_4 a corresponding shutter (S_2) can block the signal at wavelength λ_2. Insert: output coupling (zeroth-order refraction) for the various beam parts.

Exit	Output content
Y_0	λ_0, λ_1 λ_2
Y_1	λ_1 only
Y_2	λ_2 only

2. Experimental Verification with a CO Plasma

In the wide manifold of lasing transitions of a liquid nitrogen cooled CO laser plasma, it should be easy to verify a laser that oscillates simultaneously on two and on three different lines by tuning the angles ϕ, $\phi + \varphi_1$, and $\phi + \varphi_2$ to different CO P lines within the lasing manifold, as given in a system described earlier [1].

First experiments along these ideas have been made by Urban [2] and have been taken up by Lin et al. [3]. Some interesting applications have been the motivation to look into some details of the problems that appeared in these experiments. One may distinguish two essential features, concerning the laser cavity, and the grain medium.

Similar experiments with a pulsed (TEA) CO_2 laser have been reported by Harrison and Butcher [4], whereas the observations of Wan et al. [5] have a different feature.

3. The Laser Cavity

In their experiments Lin et al. [3] have observed that not only one beam is coupled via the zeroth reflection

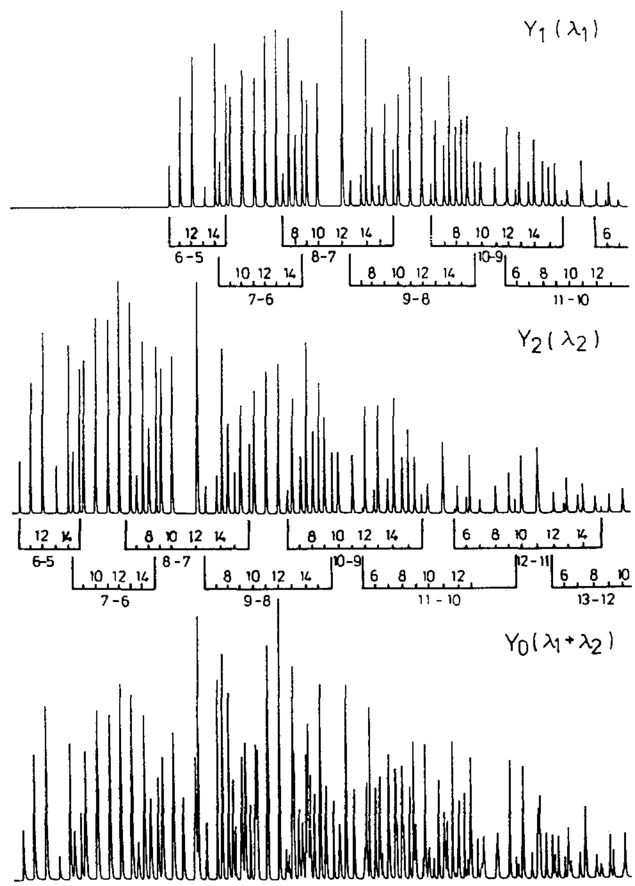

Fig. 4. (a) Output at exit Y_1, λ_1 only; (b) output at exit Y_2, λ_2 only; (c) output at exit Y_0, all lines collinearly $\lambda_1 + \lambda_2$ (plus λ_0, not verified for this angle region)

from the grating defined by the gain path, but also from the auxiliary arms of the laser cavity. In the latter, however, only the corresponding lasing wavelengths λ_1 or λ_2 are contained. Refering to the nomenclature defined above, we have outputs for λ_0, λ_1, λ_2, simultaneously at the original coupling position and for λ_1 independent of the others or for λ_2 (Fig. 3). These extra-couplings are forming extra losses for the laser cavity, but they can provide a means to stabilize the corresponding laser wavelengths.

For a given distribution of four mirrors, Fig. 4 shows a series of signals observed at the various corresponding outputs. Thus it is obvious, that simultaneous laser action for different transitions is possible in principle.

4. The Gain Medium

We also pursued the question how the various lines that could simultaneously be selected for lasing, will mutually influence each other.

If we look at the vibrational distribution within the nonlasing CO plasma, as has been carefully analyzed by Farrenq et al. [6], and Farrenq and Rossetti [7] no restrictions can be found. However, the situation will change as soon as we run a laser transition in this plasma.

We have investigated the degree of mutual influence for simultaneous operation in adjacent vibrational bands and have observed 15–30% changes in the intensity of one line when the other was switched on. The rotational relaxation is so fast, that virtually no J dependence could be observed within a vibrational band.

We have quantitatively observed the mutual influence of two particular laser transitions by switching on and off one laser path and have measured the intensity variation at the second transition. As an example the intensities of the following transitions in adjacent vibrational bands have been investigated

$$P(17)v=10\rightarrow 9 \quad \text{and} \quad P(13)v=9\rightarrow 8\,.$$

These transitions are of particular interest for a special application of our two-wavelengths laser, as will be explained later.

In a first experiment, the laser beam of $\lambda_1(P(13)_{9-8})$ was switched on and off and the intensity of $\lambda_2(P(17)_{10-9})$ was monitored. Here $I(\lambda_2)$ *decreased* as soon as λ_1 was switched on [Fig. 5, case (a)]. Then we monitored $I(\lambda_1)$ and observed an *increase* in its intensity as soon as λ_2 was switched on [Fig. 5, case (b)]. Varying the laser transitions within the J manifold of the same vibrational band did not change the effect. If the selected transitions differed by more than one vibrational band, almost no effect of the intensity of the lower vibrational transition was found, but the lower transition always decreased the intensity of a higher vibrational band.

The explanation of this observation seems rather straightforward. The corresponding transitions are indicated in Fig. 6. The partial inversion is established via VV pumping and it will be disturbed by the lasing process. Thus in case (a) of Fig. 5 the lasing intensity at the higher vibrational band is reduced by the effective shortcircuiting of the VV-pumping flux by the lasing process at the lower vibrational band.

Case (b) of Fig. 5 is dominated by a different effect, the cascading of population via the lasing process into the upper lasing level of the lower vibrational band.

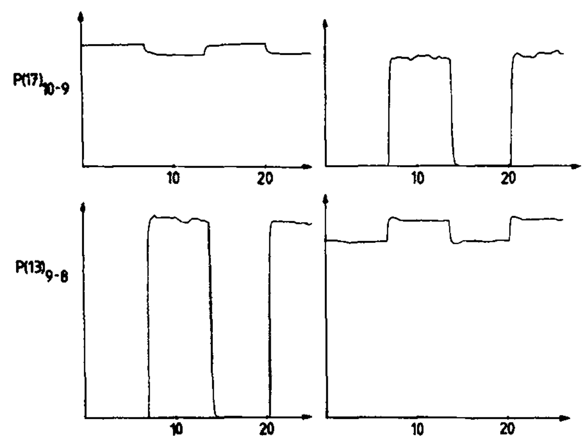

Fig. 5a, b. Intensity variation of laser output at exit, Y_1 and Y_2, respectively, for a given pair of lines from adjacent vibrational bands. (a) $I(\lambda_1)$ (lower vib. transition) switched on and off; $I(\lambda_2)$ (upper vib. transition) decreases when λ_1 is switched on. (b) $I(\lambda_2)$ switched on and off; $I(\lambda_1)$ increases when λ_2 is switched on (timescale in seconds)

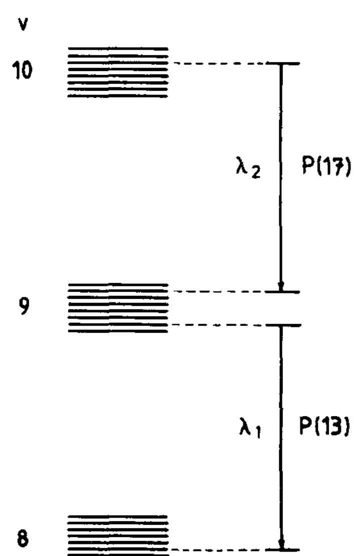

Fig. 6. Level and transition scheme for simultaneous laser operation

This cascading helps to increase the gain and it can be made available to strengthen exoticly low or very high rotational transitions, otherwise below threshold.

We can summarize our observations in the following way:

Running a CO laser simultaneously on lines from adjacent vibrational bands, such as $v+1 \rightarrow v$ and $v \rightarrow v-1$, a) the lower vibrational band will increase both in intensity and J manifold due to cascading effects, and b) the higher vibrational band will decrease both in intensity and J manifold with respect to a corresponding single line operation due to short circuiting of the VV-pumping flux.

Case (a) only holds for transitions with a common vibrational band, such as $v+1$, v, $v-1$. Case (b) occurs also for nonadjacent vibrational bands.

In all cases we have found, that for cw operations the rotational redistribution is fast enough not to prefer the one rotational level that is involved in the auxiliary transition. In Q-switch operation this will certainly be different.

5. Special 2-Wavelength Operation

For a particular spectroscopic application, the monitoring of two isotopic species of nitric oxide, we need the option to switch alternatively between the two laser lines already mentioned. There is a close coincidence between the CO laser line $P(17)_{10-9}$ at 1842.816 cm^{-1} with the $Q(1.5)$ of $^{15}N^{16}O$ and between the CO laser line $P(13)_{9-8}$ at 1884.349 cm^{-1} with the $R(1.5)$ of $^{14}N^{16}O$. These lines are suitable for low field LMR detection of these species [8].

Since only one or the other of these lines is required, we use a situation for which lasing is suppressed at λ_0, which means, that the position of ϕ is chosen to be beyond the lasing region. The two extra mirrors M_3 and M_4 are positioned at corresponding angles, as indicated in Fig. 3. For λ_1 and λ_2 there are two separate piezoelectric tuning elements enabling lock-in tracking. The modulation, however, is applied via the common mirror M_1. The laser is switched via the shutter S1/2 between the two paths. It takes only a few seconds to stabilize the resonator in each case.

Altogether we have found the system to operate reliably and with good power stability, so that it is useful for spectroscopy at two independently selectable and commutable laser lines.

Polychromatic laser operation with more than two extra mirrors may be interesting for applications in concentration monitoring with accidental coincidences, e.g. in environmental survey.

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