NRC Publications Archive
Archives des publications du CNRC

The observation of transients in a CO2 or N2O ir laser by modulation of an intracavity absorber

Arimondo, E.; Glorieux, P.

This publication could be one of several versions: author's original, accepted manuscript or the publisher's version. / La version de cette publication peut être l'une des suivantes : la version prépublication de l'auteur, la version acceptée du manuscrit ou la version de l'éditeur.
For the publisher's version, please access the DOI link below./ Pour consulter la version de l'éditeur, utilisez le lien DOI ci-dessous.

Publisher's version / Version de l'éditeur:
https://doi.org/10.1063/1.90162
Applied Physics Letters, 33, 1, pp. 49-51, 1978-07

NRC Publications Record / Notice d'Archives des publications de CNRC:
https://nrc-publications.canada.ca/eng/view/object/?id=e58c89c1-b424-426e-87af-8373ebe25cfc
https://publications-cnrc.canada.ca/fra/voir/objet/?id=e58c89c1-b424-426e-87af-8373ebe25cfc

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at
https://nrc-publications.canada.ca/eng/copyright
READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site
https://publications-cnrc.canada.ca/fra/droits
LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.

National Research Council Canada
Conseil national de recherches Canada

Dec 1977

1 mode locking possible?
for 1 m cavity $\frac{c}{2L} = 150$ MHz
2. How many modes lasing?
3. Explain Fig 1
4. Caption Fig 2
5. How does peak power vary with high avge laser power?

Observation of transients in CO_2 and N_2O IR lasers by modulation of an intracavity absorber

by

E. Arimondo[#] and P. Glorieux[§]
Herzberg Institute of Astrophysics,
National Research Council
Ottawa, Ontario, K1A 0R6 Canada

Tel. 2-7835
6-1621

Ennio

[#] Permanent address: Istituto di Fisica dell' Università,
Piazza Torricelli 2, 56100 Pisa, Italy

[§] Present address: Laboratoire de Spectroscopie Hertzienne,
Université des Sciences et Techniques de Lille,
BP 36, 59650, Villeneuve d'Ascq, France.

Abstract

A damped oscillation has been observed on the output power of infrared CO_2 and N_2O lasers following a stepwise modulation of intracavity saturable absorber. The frequency of the oscillation is high (~100 KHz) for high laser power and is lowered when the power is lowered towards the passive Q-switching region. ¶ The damping of oscillation also changes with the power and approaches to infinity at Q-switch. When the saturable absorber is modulated cw with frequency of 10-100 KHz, a forced modulation of the laser power is realized. Using this resonant modulation frequency in many intracavity experiments greatly increases the sensitivity of detection.

damped
power curve.

The output power of a laser is amplitude modulated when a modulation is applied to the gain of the amplifying medium or to the loss inside the cavity, as for instance a saturable absorber. If the modulation frequency is slow, the laser is able to follow adiabatically the excitation, and a large modulation of the laser output can be realized. At higher modulation frequencies the laser damping and the relaxation processes in the amplifying and absorbing media limit the modulation in the laser output power. The ac response of a laser has been firstly investigated experimentally, in absence of saturable absorber, for modulation of the cavity losses and of the excitation density in the amplifying medium(1); recently the investigation of the ac response has been applied to determine the vibrational energy transfer in a CO_2 laser(2). The ac response for modulation of the excitation density in an intracavity saturable absorber has been experimentally examined for slow modulation frequency, in the adiabatically following regime(3). When the adiabatic following is not realized, relaxation oscillations of the laser occur: for instance the well known passive Q-switching is determined by the relaxation mechanisms in the absorber(4-5).

In the infrared-radiofrequency double-resonance experiments inside the laser cavity(7) a radiofrequency field, modulated on-off, is applied to the sample, a saturable absorber. Because of the radiofrequency transitions in the sample the laser output is decreased and the ac component at the modulation frequency in the laser power gives the double-resonance signal. The signal amplitude depends on the ac response of the laser and for the 10-30 KHz modulation frequency applied in the experiment the relaxation behaviour of the laser is involved. We have experienced that a large increase in the signal is realized if a particular value, dependent on the operating point of the laser, is chosen for the modulation frequency. A damped oscillation at this "resonant" frequency is observed when the intracavity absorption is changed by a step function.(8) The laser ac response is typical of a system in forced oscillations, with a maximum in the response when the modulation frequency coincides with the resonance frequency of the system. Thus we have investigated the ac response of CO_2 and N_2O lasers. This study is of relevance not only for any intracavity absorption experiments where a modulation and phase sensitive detection are used, but also for a comparison with the results of theories of a gas laser containing an intracavity saturable absorber.(9)

We have observed the transient behaviour of CO_2 and N_2O lasers following a fast stepwise change in the intracavity absorber. The laser power output was monitored by a PbSnTe IR detector when a square-wave modulation was applied to the absorbing sample. To realize this modulation, a radiofrequency field, in resonance with a hyperfine transition of the sample, was switched on-off, thus changing the number of molecules affecting the laser output, or an electric field producing a Stark splitting of the absorber infrared transitions, was modulated in intensity. Figure 1 shows the behaviour observed in a CO_2 sealed-off laser, oscillating on the 9.3 μm R(16) line, when a pulsed electric field was applied to a CF_3I sample absorbing on the $^{q}R(7,2)$ $\nu_1 \leftarrow 0$ transition.(10) The low-damping modulation of the power output is typical of the laser operation near the threshold. The modulation frequency and the damping time depends on the operating point of the laser. At higher laser power, far from the threshold, the modulation period and the damping time become shorter. This behaviour is observed in Figure 2 for a CO_2 flowing laser oscillating on the 10.7 μm P(32) line, when a modulated radiofrequency field at 164.2 MHz is applied to a CH_3I sample. This radiofrequency field is in resonance with $F' = 29/2 \rightleftarrows F'' = 27/2$ hyperfine component in the excited state of $^{r}R(15,5)$ $\nu_6 \leftarrow 0$ infrared transition.(11) The recorded transient shows also the change in the steady state laser power produced by the double resonance phenomenon. The transient decay of N_2O laser has a similar behaviour but the damping time is shorter than in the CO_2 laser. In fact because of the presence of the permanent dipole moment, the relaxation time in the N_2O laser is shorter than that in CO_2.

In a theoretical model for gas lasers with or without a saturable intracavity absorber a phenomenological description is introduced for the relaxation processes in the amplifying and absorbing cells.(9) Thus the cross-relaxation mechanisms between the set of levels in resonance with the laser radiation and the other levels are neglected. In that model the time evolution of the laser intensity is governed by the equation

$$\frac{\partial I}{\partial t} = \frac{\nu}{Q} H(I)\, I \tag{1}$$

with ν and Q the frequency and the quality factor of the laser. The gain function H(I) is defined as

$$H(I) = N g^{\mathrm{amp}}(\Delta, I) - M g^{\mathrm{abs}}(\Delta', I) - 1 \tag{2}$$

where N and M are the pumping rates in the amplifying and absorbing media respectively; g^{amp} is the gain in the amplifying medium, g^{abs} is the loss in the saturable absorber and different detuning parameters Δ and Δ' have been introduced for the amplifier and absorber. The steady state is reached when the right-hand side of eq (1) vanishes and the steady state intensity I_o is determined by the equation

$$H(I_o) = 0 \tag{3}$$

At a low frequency modulation, in the adiabatic region, the laser follows the modulation frequency and the instantaneous intensity can be derived by Eq (3). The modulation in the laser intensity because of the modulation of the pump rate of the absorbing medium is given by Salomaa and Stenholm(9) as

$$\frac{\partial I}{\partial M} = g^{\mathrm{abs}}(\Delta', I)\left[N \frac{\partial g^{\mathrm{amp}}(\Delta, I)}{\partial I} - M \frac{\partial g^{\mathrm{abs}}(\Delta', I)}{\partial I}\right]^{-1} \tag{4}$$

In this expression the change in the laser frequency because of the modulation in the saturable absorber has been neglected.

By decreasing the laser pump N or increasing the sample absorption M, the threshold condition is approached. In these conditions the denominator of Eq (4) becomes small and the ac response increases. However for a laser near threshold the time response becomes slow and the adiabaticity condition is not satisfied. A small deviation from the steady state value I_0 decays with a rate $-\nu/Q\left(\frac{\partial H}{\partial I}\right)_{I=I_0} I_0$. From the analysis of ref (9) it turns out that $\left(\frac{\partial H}{\partial I}\right)_{I=I_0}$ is a finite function converging to zero for the laser approaching the threshold. Thus near threshold, at a low intensity I_0, the time constant of the approach to the steady state becomes very long. This phenomenon is typical of the critical slowing down of the relaxation constants for a second-order phase transition as the one occurring for a laser at threshold.

At high modulation frequency the ac response of a laser depends also on the cross-relaxations. The cross-relaxations between the rovibrational levels of the amplifying and absorbing media determine the passive Q-switching in CO_2 lasers$^{(4-6)}$. The set of equations describing the laser and the population distribution have been solved numerically by the computer. From that solution we see that in the absence of Q-switching the transient decay towards the steady state presents damped oscillations$^{(6)}$. The period and damping time of these oscillations depend on the molecular cross-relaxation rates, but the dependence on the laser operating point has not been investigated. However the slowing-down presented before should affect the laser behaviour near threshold even when the cross-relaxations are introduced.

We have measured the oscillation frequency and the damping time of the transient decay in a CO_2 laser as function of the laser output power and summarized the results in Figure 3. The transient signal has been observed by applying a Stark field square-wave modulation to a CH_3I sample irradiated by the 10.7 μm P(32) laser line. The average laser power was measured with a power meter. The data shown in the figure have been obtained by changing the gas flowing in the laser tube; a similar behaviour has been observed when the diameter of an iris inside the laser cavity was modified. Passive Q-switching action occurred when the laser power output was below 90 mWatts and the Q-switching pulse repetition period has been measured in this region. The modulation period becomes longer as the laser power is reduced and this dependence continues smoothly in the pulse period of the Q-switching region. It has been pointed out in the past(5) that the Q-switching pulse period decreases with the laser output because the recovery time needed for the laser to reach threshold condition is shorter when the laser gain is increased. The same behaviour occurs for the modulation period because at higher gain the recovery force pulling the laser towards the steady state value is larger. The square points in the figure show the behaviour of the oscillation damping time versus the laser power. As the laser power is reduced, the damping time becomes very long and approaching infinity when the Q-switching region is reached. All this behaviour is well described by the slowing down of the laser relaxation rates when the transition point is approached.

In order to see the evidence for the influence of the laser transients on the intracavity experiment signal, we have measured the modulation amplitude observed on the laser output when a modulation of constant amplitude and at different frequencies was applied to the intracavity absorber. A 30V/cm square wave Stark modulation on a CH_3I sample and the same laser line as for the results in Fig. 3 was used. The laser modulation was amplified by a broad-band amplifier and measured by an ac voltmeter. Figs. 4a and 4b present the ac response for laser operating near Q-switching region and far from it respectively. The signal output becomes larger when the modulation frequency is equal to the resonance frequency of the laser modulation, or to odd subharmonics of it.

The resonance frequency of the laser becomes lower when the laser power is lowered, as obtained in the Fig. 3. The linewidth of the resonance curves depends on the damping time of the laser and the curves are narrower and higher near threshold where the modulation of the laser power lasts for a longer time. It appears in Fig. 1 that a different modulation amplitude of the laser is obtained when the Stark field is switched on and off. This behaviour is connected to the creation of a forced modulation on the laser power when near the Q-switching region the modulation frequency is a subharmonic of the laser resonance frequency.

Because of the laser non-linearity, a large modulation of the laser power arised when the modulation frequency f of the absorber is a subharmonic of the laser resonance frequency. Thus for the conditions shown in the figure a lock-in detection at (2n+1)f is efficient for detecting an intracavity signal, while a 2f detection does not yield a large signal. Strong signals are detected at 2f when an electric field symmetrical to zero value or when the laser modulation is due to the transient nutation.(12) However these resonances are due to a property of molecules with respect to modulation rather than that of the laser.

The infrared-radiofrequency double-resonance experiments inside the laser cavity have a very high sensitivity because a non-thermal distribution over the radiofrequency levels is created by the laser pumping and because infrared radiation is detected rather than radiofrequency radiation(7,11). A large increase in the signal is provided also by the non-linearity of the laser. In operating near threshold where the right-hand side of Eq. (4) is large, the radiofrequency absorption of the sample has large influence on the laser output. When the double-resonance absorption is amplitude modulated at the frequency equal to the resonant frequency of the laser, the signal is much increased by the forced resonant modulation oscillations. From the experimental results of Figure 4, this last increase in signal is approximatively 50 times for a laser operating near threshold and 10 times at high laser power.

A complete theoretical analysis of the observed behaviour for a laser near passive Q-switching region requires the solution of the coupled equations for the laser and the absorbing and amplifying media. From the point of view of application in the intracavity experiments, a large increase in the signal-to-noise ratio is realized if the modulation frequency is chosen at the laser resonance which depends on the operating point.

We are very grateful to Dr. Takeshi Oka for his encouragement during this work.

Figure Captions

Figure 1. Transient behaviour observed on a CO_2 laser oscillating near threshold, when a 20 Volt/cm Stark modulation at 0.8 KHz (lower trace) was applied to a 9 mTorr sample of CF_3I. The laser line was 9.3 μm R(16).

Figure 2. Transient decay observed in an IR-RF double resonance experiment with the 10.7 μm P(32) CO_2 laser line. The 4.5 watts RF power at 164.2 MHz was switched on-off at 5KHz and a 15 mTorr CH_3I sample was the intracavity absorber.

Figure 3. Period of the laser intensity modulation (dot points and left scale) and damping time (squares and right scale) versus laser power output, for Stark modulation of 12 mTorr CH_3I sample irradiated by the 10.7 μm P(32) CO_2 laser line. The laser power was varied by changing the laser gas pressure and passive Q-switching occurred when the average laser power output was below 90 mW.

Figure 4. Amplitude of the P(32) CO_2 laser power modulation versus the modulation frequency of a 30V/cm Stark field applied to a 22 mTorr CH_3I sample. Upper record at 120 mW output power, lower one at 165 mW; passive Q-switching occurred at 118 mW. The vertical scale was expanded 3.3 times in the lower record.

References

(1) P.T. Bolwjiin, J.Appl. Phys. 37, 4487 (1966); Th. H. Peek, P.T. Bolwjiin and C. Th. J. Alkemade, Phys. Letts. 24A 128 (1966).

(2) K. Yatsui, M. Furumi and M. Yokoyama, Opt. Comm. 22 255 (1977).

(3) J. Seligson, R. Salomaa and S. Stenholm, Opt. Comm. 19 25 (1976); 20 449 (1977).

(4) H. Statz and G. de Maars, Quantum Electronics, ed. by C.H. Townes, Columbia University Press, New York, p. 530.

(5) I. Burak, P.L. Houston, D.G. Sutton and J.I. Steinfeld IEEE J. Quantum Electr. QE7 73 (1971).

(6) F. Meyer, Bourbonneux, T. Dupré and C. Meyer Can. J. Phys. 54 205 (1976).

(7) T. Oka, "Frontiers in Laser Spectroscopy", Les Houches Summer School Proceedings, Session XXVII, edited by R. Balian, S. Haroche and S. Liberman, North-Holland Publishing Co. (1977).

(8) A damped oscillation in the laser output following a current pulse in a CO_2 laser has been observed by F. O. Shimizu, K. Nakajima, T. Komatsu and K. Ueda 32nd Annual Meeting of Japanese Physical Society Tokyo, Oct. 1977.

(9) S. Stenholm, Progr. Quantum Electronics, vol 1 part 4, ed. by J. H. Sanders and K.W.H. Stevens, Pergamon Press, Oxford 1971.

R. Salomaa and S. Stenholm, Phys. Rev. A8, 2695 (1973).

(10) H. Jones and F. Kohler, J. Mol. Spectr. 58, 125 (1975).

(11) E. Arimondo, P. Glorieux and T. Oka in "Laser Spectroscopy III" J. L. Hall and J. L. Carlsten eds., Springer-Verlag, New York and Heidelberg, 1977, p. 287.

(12) J.W.C. Johns and A.R.W. McKellar, J. Chem. Phys. 63, 1682 (1975).

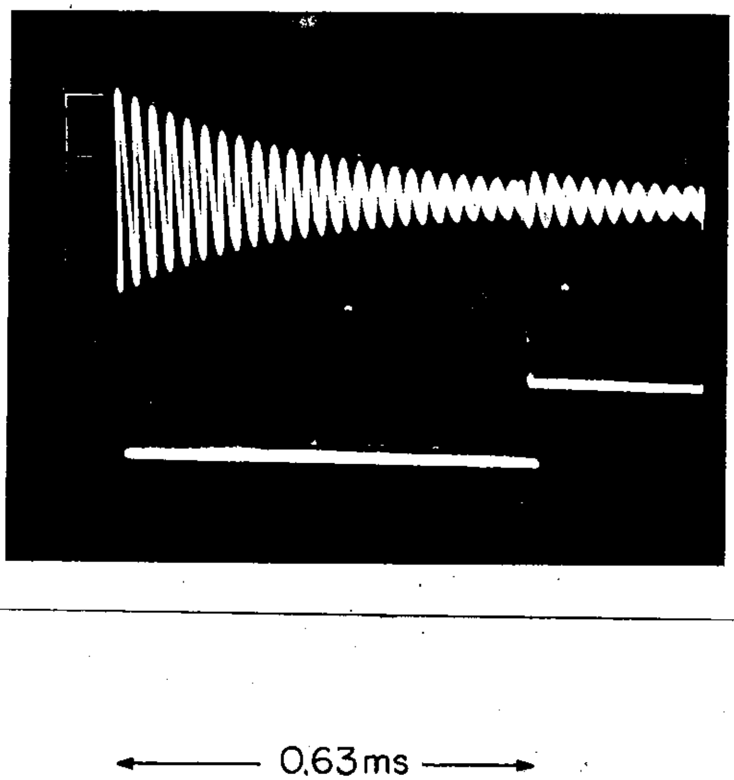

Fig 2

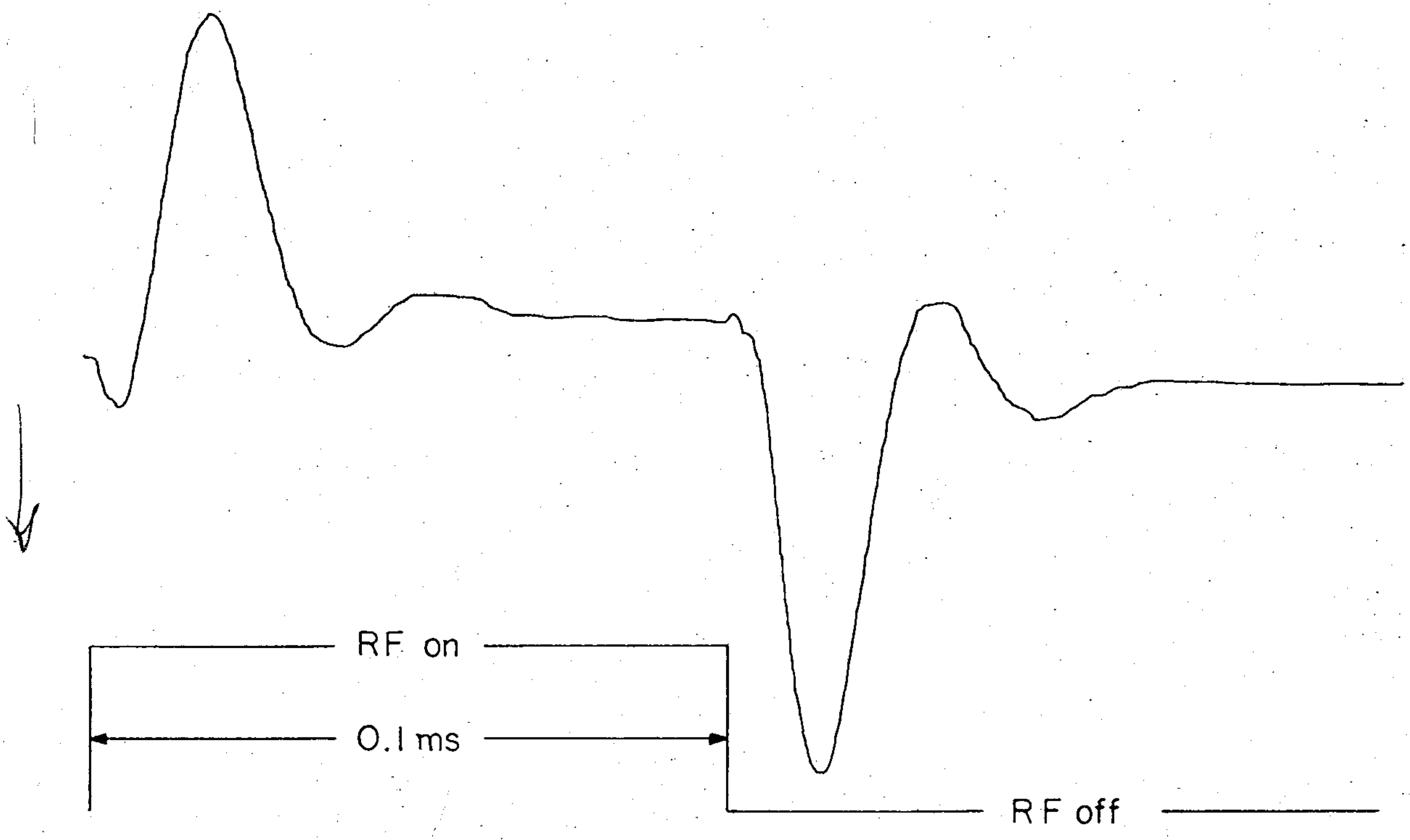

Fig 2

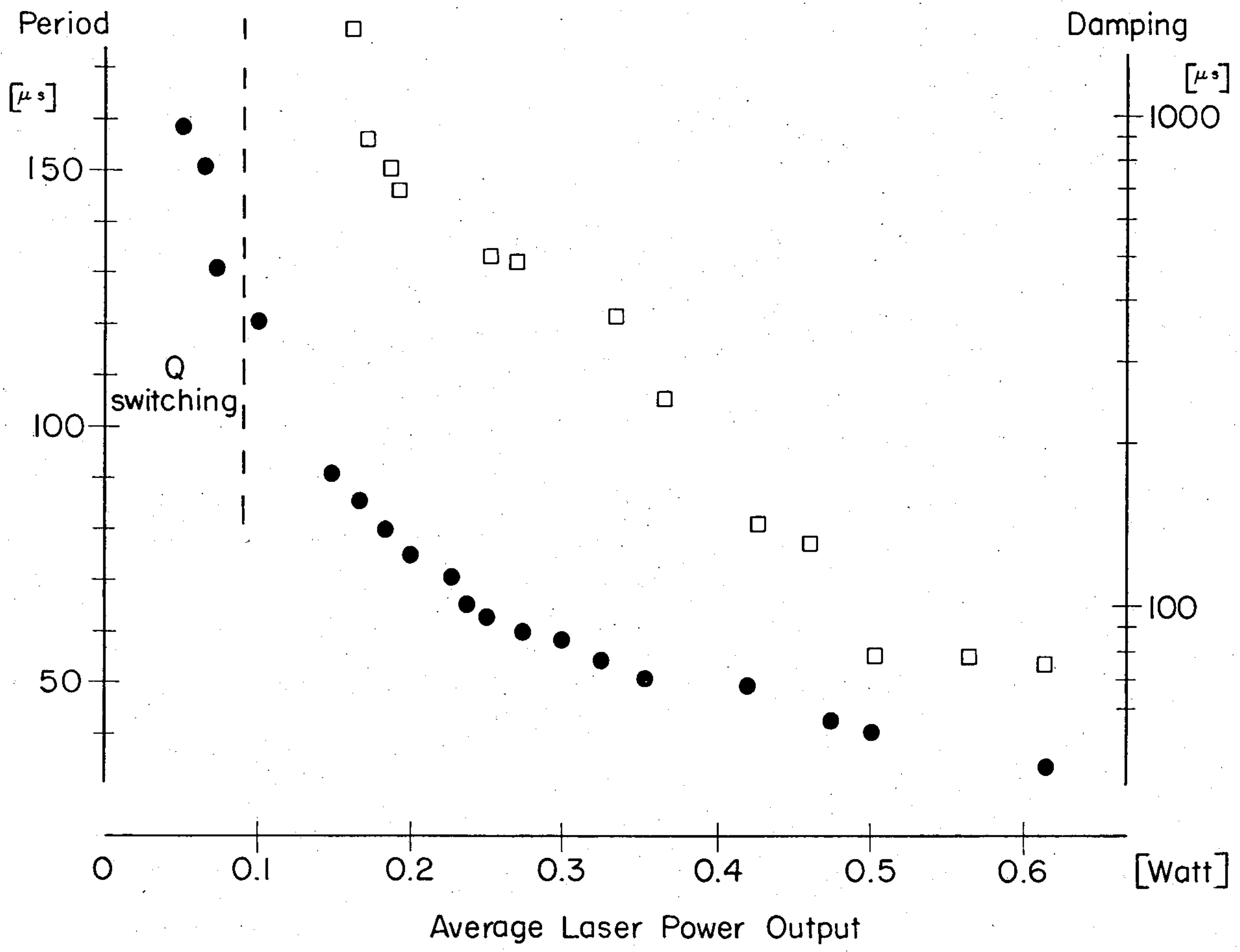
Period
[µs]
150
100
50
Damping
[µs]
1000
100
Q
switching
0
0.1
0.2
0.3
0.4
0.5
0.6
[Watt]
Average Laser Power Output

figure 3

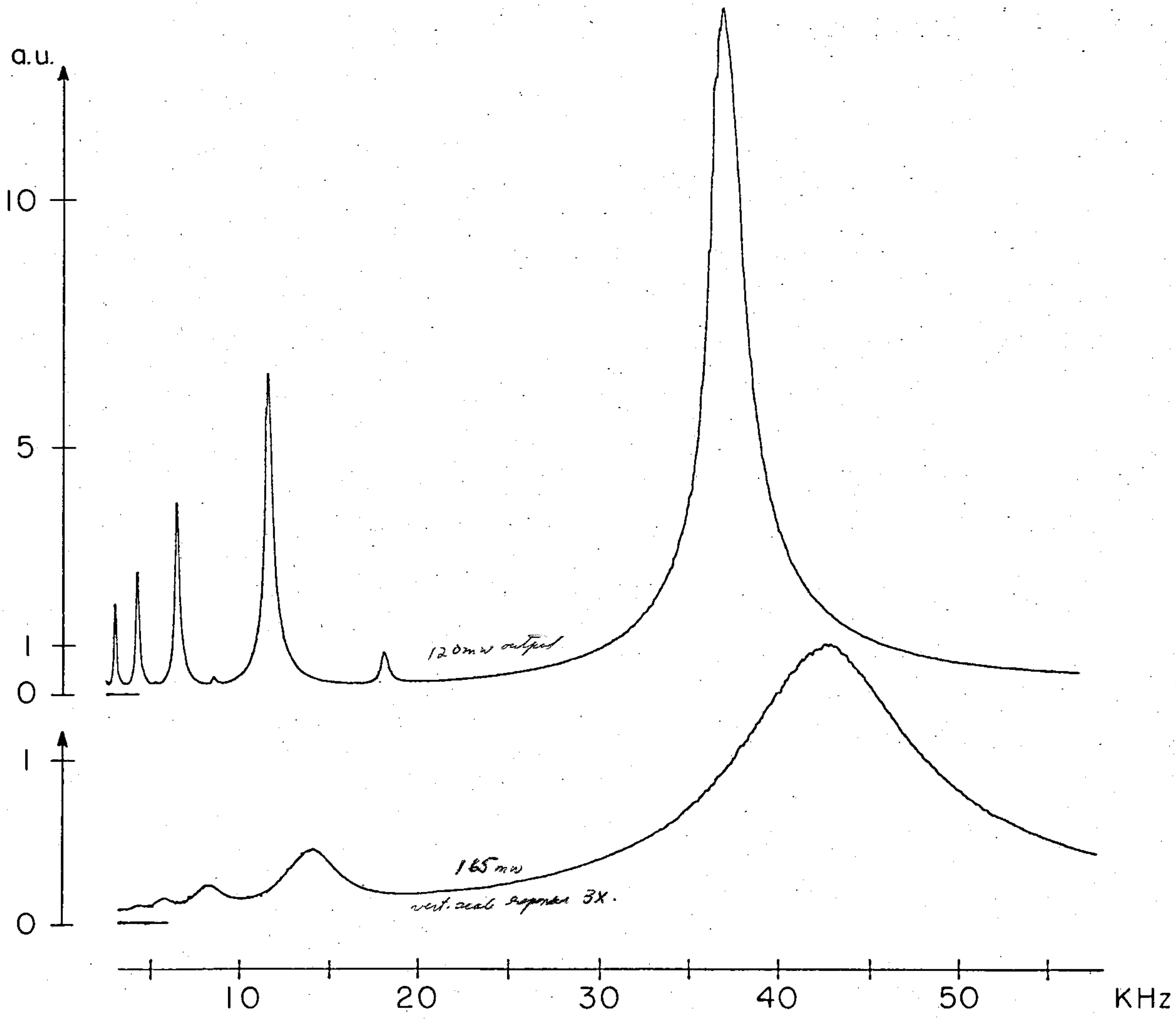
a.u.
10
5
1
0
1
0
120mw output
165mw
vert. scale expanded 3X.
10
20
30
40
50
KHz

Fig 4