

SINGLE MODE TUNING DIP IN THE MODULATED POWER OUTPUT OF GAS LASERS

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Received 20 October 1965

This letter describes a new method [1] for studying the saturation behaviour of gas laser transitions. In a previous paper [2] we reported that the a.c. power output of a single-mode He-Ne laser, which was obtained by modulating the discharge current [3, 4], as a function of the detuning of the interferometer shows a dip at the peak frequency of the atomic transition. This modulation dip can be understood with the theory of Lamb [5], whose notation is followed throughout this paper.

The differential equation of the amplitude of the electric field E in a laser interferometer is

$$dE/dt = \alpha E - \beta E^3, \quad (1)$$

where α is the unsaturated net gain and β is a saturation parameter, which are known functions of the inversion density N [5]. The steady state solution of eq. (1) is

$$E_0^2 = \alpha/\beta. \quad (2)$$

Consider a small deviation ΔE from the steady state. The differential equation of ΔE then is

$$d\Delta E/dt = -2\alpha \Delta E + E_0 \Delta \alpha - E_0^3 \Delta \beta. \quad (3)$$

Let ΔE be the result of a sinusoidal modulation of the inversion density, having an amplitude $(\Delta N)_0$ and circular frequency ω_m . By applying Lamb's theory it is assumed implicitly that the period of modulation is large compared with the decay times of the levels involved. The a.c. power output of a laser is proportional to $\Delta(E^2)$. Since

$$\Delta(E^2) \approx 2E_0 \Delta E, \quad (4)$$

we find, by solving eq. (3), for $t \gg \alpha^{-1}$ a sinusoidal modulation of E^2 with amplitude

$$|\Delta(E^2)| = \frac{\nu}{Q} \frac{(\Delta N)_0}{N} \frac{\alpha/\beta}{(4\alpha^2 + \omega_m^2)^{1/2}}. \quad (5)$$

If $2\alpha \gg \omega_m$ eq. (5) reduces to

$$|\Delta(E^2)| = \frac{1}{2} \frac{\nu}{Q} \frac{(\Delta N)_0}{N} \frac{1}{\beta}, \quad (6)$$

from which follows that the a.c. power output of a single-mode gas laser as a function of the detuning of the interferometer will show up as a Lorentzian "hole". This "hole" should not be confused with the population depletion holes in the velocity distribution. An interesting observation is that the gain drops out.

We have made modulation experiments on a d.c.-excited short planar He-²⁰Ne laser [6] operating in a single axial mode at 1.153 μ wavelength. The interferometer length was varied by thermal tuning.

Fig. 1 shows the d.c. and the a.c. power output as a function of the detuning of the interferometer. The curves were recorded consecutively. The modulation of the output was obtained by modulating the discharge current. The modulation frequency was 10 kc/s; the modulation depth of the current was 70%, resulting in a modulation of the power output near line center of about 10% (curves of the same appearance were found for an output modulation of only 0.1%). The total gas pressure was 1.9 mmHg, and the He-Ne ratio was 5:1.

The d.c. output as shown in fig. 1 contains the well-known Lamb dip. The a.c. output contains a dip which has to be compared with eqs. (5) or (6). Following Szöke and Javan [7] we include collision effects by modifying the Lorentzian factor in β . Then

$$\beta \propto \bar{N} \left[1 + \frac{\gamma_{ab}/\gamma'_{ab}}{1 + [(\Omega - \omega)/\gamma'_{ab}]^2} \right]. \quad (7)$$

Assuming an interferometer width of 8 Mc/s [8] eq. (6) applies, except at threshold. We have found that the modulation dip in fig. 1 is a Lorentzian function, indeed, as predicted by eqs. (6) and (7), with $\gamma_{ab}/\gamma'_{ab} = 0.3$ and $\gamma'_{ab} = 42$ Mc/s. For these values the d.c. power output was calculated from the modified eq. (96) in Lamb's paper, assuming a full Doppler width of 800 Mc/s. The results are plotted as dotted curves in fig. 1.

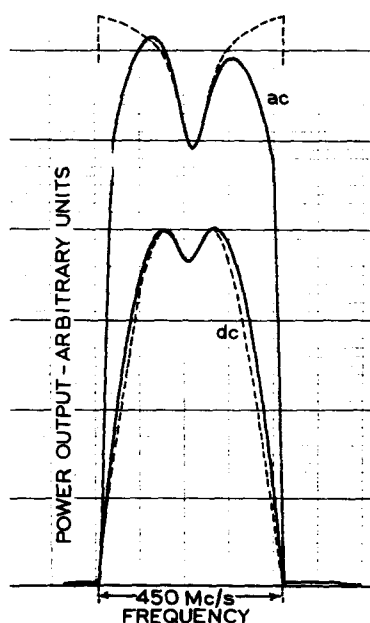


Fig. 1. The d.c. and a.c. power output of a single-mode gas laser as a function of the detuning of the interferometer. Solid lines are experimental curves and dashed lines are theoretical curves. The d.c. power output is proportional to α/β , whereas the a.c. power output is proportional to $1/\beta$ (see text).

Away from line center there is an apparent discrepancy between theory and experiment for the a.c. power output. This is not due to the assumption $2\alpha \gg \omega_m$, because the same behaviour was found at the much higher modulation frequency of 100 kc/s. A reason for the discrepancy might be the fact that Lamb's theory applies at low excitation levels only. The a.c. power output may be more sensitive to deviations from this limitation than the d.c. power output.

At higher excitation levels we found considerably higher values of the linewidths. At a relative excitation [5] of $\eta = 1.45$ we found $\gamma_{ab}/\gamma_{ab} = 0.4$ and $\gamma_{ab} = 62$ Mc/s (the relative excitation in fig. 1 is $\eta = 1.25$). An excitation-dependent linewidth has also been observed by McFarlane [9].

The a.c. power output is expected to have several interesting features which may be useful to check laser theories [5, 10, 11].

Collision effects [7, 12] can be studied by performing modulation experiments at different

pressures. Our thermally tuned laser is not suited for an accurate investigation of asymmetries and frequency shifts, since these effects are very sensitive to misalignments of the mirrors [7]. It should be noted that the inversion modulation also causes a periodic deviation of the oscillation frequency [3, 4], which may not always be neglected, as in our considerations.

The dependence of the modulation amplitude on excitation level \bar{N} can be checked only if $(\Delta N)_0$ is known. In this respect more selective and direct methods of modulation, such as optical pumping [4], are of interest.

The modulation amplitude as a function of modulation frequency may give information on the interferometer width. The frequency response of the detector and of the gas discharge [13] should be taken into account. Preliminary measurements support in our case the assumption $2\alpha \gg \omega_m$.

The author is indebted to Professor Dr. C. Th. J. Alkemade for helpful discussions. He also wishes to thank Professor Charles R. Willis as well as Dr. R. J. J. Zijlstra and Mr. A. C. E. Wessels for a valuable discussion and N. V. Philips' Gloeilampenfabrieken, Eindhoven, for supplying the laser.

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