Applied Physics Letters

OUTPUT POWER OF THE 6328-Å GAS MASER

A. D. White, E. I. Gordon, and J. D. Rigden

Citation: Applied Physics Letters **2**, 91 (1963); doi: 10.1063/1.1753793
View online: http://dx.doi.org/10.1063/1.1753793
View Table of Contents: http://scitation.aip.org/content/aip/journal/apl/2/5?ver=pdfcov
Published by the AIP Publishing

OUTPUT POWER OF THE 6328-Å GAS MASER

A. D. White, E. I. Gordon, and J. D. Rigden
Bell Telephone Laboratories, Incorporated
Murray Hill, New Jersey
(Received 23 January 1963)

A gas maser with a Doppler-broadened transition will oscillate in one or more noncompeting modes, provided the mode separation is large compared with the natural line width. The term "hole burning" has been applied to the decrease in population inversion (and therefore gain) at frequencies in the vicinity of each oscillating mode due to stimulated emission.[1] The hole width and depth depend upon the power in the mode and the natural line width.

When the spacing between mirrors is made sufficiently large so that the mode spacing is smaller than the natural line width, the population inversion will be reduced over the entire range of oscillating frequencies. It can be shown that under this condition, the saturation of the maser gain can be adequately described in terms of a spectral intensity distribution $I(\nu)$ which represents the appropriately averaged two-way power flow in the maser cavity per cycle per second at the frequency ν. The averaging extends over a frequency range comparable to the natural line width and in effect replaces the line spectrum of the oscillating maser by a continuum with the same local average intensity.

In a dc excited gas maser tube with uniform bore, the gain parameter per unit length $k(\nu)$ is invariant with length; hence, the single pass power gain, G, is given by $\exp k(\nu)L$ in which L is the active discharge length. The saturation condition takes the form $G^2R_1R_2 = 1$ in which R_1 and R_2 are the effective power reflectivities at each end of the tube.[2] When the reflectivity is close to unity, the saturation condition can be written

$$k(\nu)L = a + t \ , \qquad (1)$$

INDEXING CATEGORIES

A. laser (gaseous)	spacing
A. He-Ne	T/E
B. output power	
B. Doppler broadening	
B. line width vs mode	

in which a is half the total absorption loss of the cavity including diffraction and t is half the total transmission loss. For symmetrical mirrors, a and t are the appropriate values for each mirror.

For the case where the natural line width is small compared with the Doppler line width and $I(\nu)$ varies slowly compared with the natural line width, it can be shown that

$$k(\nu) = \Big\{k_0(\nu/\nu_0)\exp - [2(\nu-\nu_0)/\Delta\nu_{\mathrm{D}}]^2 \ln 2\Big\}/1 + \eta I(\nu) \ , \qquad (2)$$

in which ν_0 is the frequency at line center, $\Delta\nu_{\mathrm{D}}$ is the full Doppler width, η is a saturation parameter depending only on the Einstein A and B coefficients and k_0 is the small signal gain parameter at line center; k_0 depends on the tube current (for a fixed tube radius) and the transition probabilities. The threshold oscillation length, L_t, is defined by

$$k_0 L_t \equiv a + t \ . \qquad (3)$$

Equation (2) can be solved for $I(\nu)$, using Eqs. (1) and (3) and the result integrated over all frequencies for which the gain exceeds threshold to obtain the total power output. The result can be written

$$P = \frac{1}{2}\pi R^2 t \eta^{-1} \Delta\nu_{\mathrm{D}} (\pi/\ln 2)^{1/2} G(L/L_t) \ , \qquad (4)$$

in which the beam radius, R, is assumed constant. The function $G(L/L_t)$ has the form

$$G(X) = X \ \mathrm{erf}\left[(\ln X)^{1/2}\right] - (2/\sqrt{\pi})(\ln X)^{1/2} \qquad (5)$$

in which erf is the error function. Note that the terms preceding the function G are all constant and the variation of power P with discharge current resides in the variation of L_t with tube current and the variation with length of discharge resides in the function $G(L/L_t)$. The optimum output power

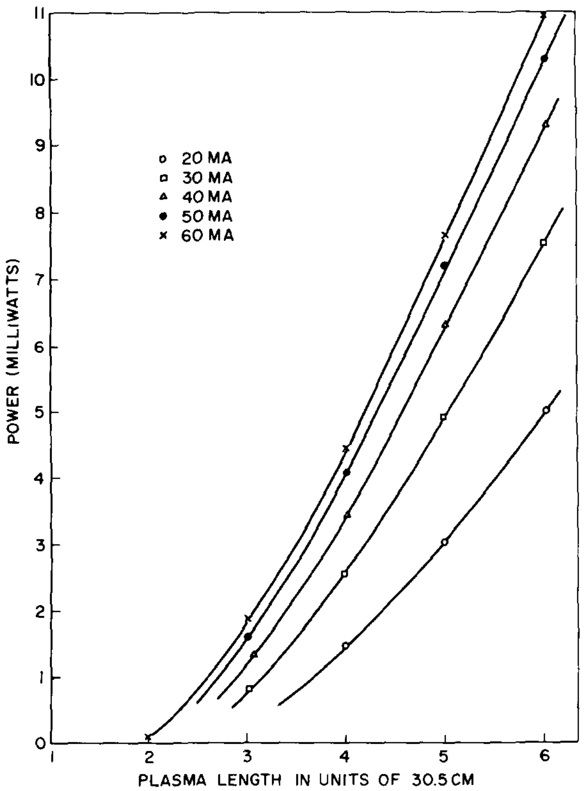

Fig. 1. Maser power output (all modes) plotted as a function of active plasma length for several discharge currents.

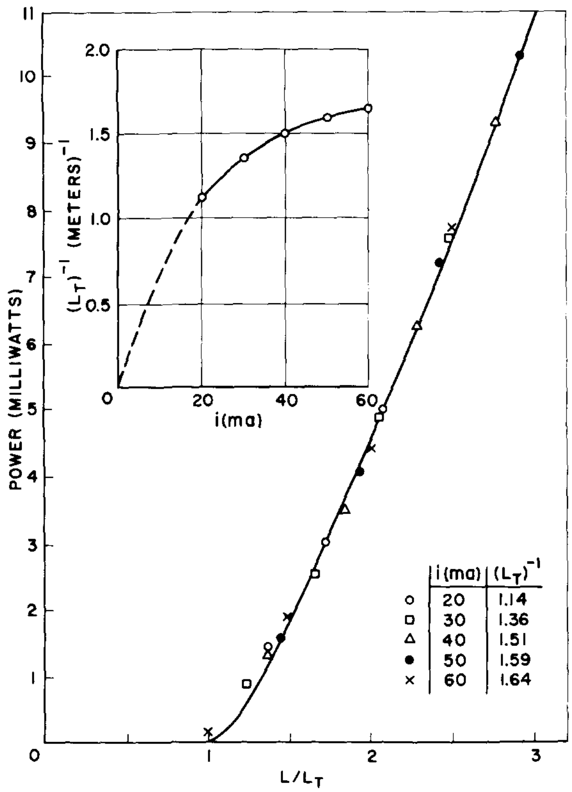

Fig. 2. The solid line is the curve $P = 7.75\ G(L/L_t)$ mW. The points result from the choice of $k_0/a + t \equiv (L_t)^{-1}$ as a function of discharge current shown plotted in the inset and in the table.

as a function of mirror transmission t for a given value of k_0 and a can be determined from Eq. (4).

Measurements of the output power of a dc excited 6328-Å 6-mm-i.d. He-Ne gas maser[3] were made as a function of active plasma length and discharge current. Plasma lengths ranging from 30.5 to 183 cm in steps of 30.5 cm could be maintained in the tube at currents up to 60 mA. Longer plasma lengths were avoided because of the high gain of the 3.39-μ transition.[4] The maser cavity consisted of a matched pair of 2-meter-radius spherical mirrors (coated to approximately 1.5% transmission) spaced various distances from 2.6 to 4 meters apart. Measurements were reproducible within a 5% range except for the lowest power measurement at 61 cm, which has a probable error of ~ 50%. Figure 1 shows the measured power (all modes) from one end of the cavity for currents from 20 to 60 mA and plasma lengths from 61 to 183 cm at a mirror spacing of 2.6 meters. Choosing the values of $(L_t)^{-1}$ shown in the table of Fig. 2 allows a universal plot of the measured power vs L/L_t.[5] The solid line is the curve, $P = 7.75\ G(L/L_t)$ mW.

Note that the fit is within experimental error for most points. It is possible that the slight discrepancies at low power arise from the neglect of two factors, that is, the small variation of beam diameter with L for a spherical mirror cavity and the variation of population inversion with distance from the tube axis. The close agreement between experiment and theory has been obtained for a number of tubes and mirror combinations.

The frequency range over which oscillation occurs is given by $\Delta\nu_D (\ln L/L_t)/\ln 2^{1/2}$. Measurements of the frequency range as a function of L should plot as a universal curve and should further confirm the validity of this approach.

[1]W. R. Bennett, Jr., *Phys. Rev.* **126**, 580 (1962). In general, each oscillating mode burns two holes in the gain frequency profile; the second is a mirror image of the first with respect to the line center.

[2]In the saturated oscillator $1 - G^2R_1R_2 < 10^{-6}$.

[3]A. D. White, J. D. Rigden, *Proc. IRE* **50**, 1697 (1962).

[4]Nerem 1962, Boston, Massachusetts; paper TPM 14-4, J. D. Rigden, A. D. White, and E. I. Gordon. Gains as high as 23 dBm in a 6-mm tube have been measured. These gains are sufficient to saturate the 6328-Å transition in long tubes.

[5]The values of $k_0/a + t = L_t^{-1}$ are consistent with measured values of k_0 (at 60 mA) $\approx$ .07, $t \approx$ .015 and $a \approx$ .025 and with measured values of L_t as a function of discharge current.

SUN PUMPED CONTINUOUS OPTICAL MASER[1]

Z. J. Kiss, H. R. Lewis and R. C. Duncan, Jr.
RCA Laboratories
Princeton, New Jersey

(Received 30 January 1963)

We have achieved optical maser action in the $CaF_2:Dy^{2+}$ system at liquid neon temperature (27°K), using the sun as the pumping source. The threshold power required to obtain maser oscillations could be supplied with a 10-in.-diam condensing mirror. Maser action at liquid nitrogen temperature is anticipated using a 20-in.-diam condensing mirror.

Maser action in the $CaF_2:Dy^{2+}$ system was reported[2] at 2.36 μ. The maser oscillation takes place in a sharp $^5I_7 \rightarrow {}^5I_8$ $4f - 4f$ transition, and it is pumped in broad $4f - 5d$ absorption bands starting at 10,000 cm^{-1} and extending throughout the visible region of the spectrum. The low pulsed maser threshold, the long lifetime (10 msec for a 0.05 molar % Dy^{2+} in CaF_2), and the convenient location of the broad pumping bands of this system make it especially suitable for sun pumped operation.

Figure 1 is a photograph of the experimental arrangement. A 1-in.-long 1/4-in. × 1/8-in. cross section CaF_2: 0.05 M % Dy^{2+} maser crystal is placed in a dewar filled with liquid neon just outside the focal point of a 14-in. aperture spherical mirror. The dewar was wrapped with aluminum foil except for the area of illumination to insure better optical coupling. The output maser beam was chopped, fed into a Perkin-Elmer monochrometer and recorded with a PbSe detector having a time-constant of 15 msec. The maser output is shown on Fig. 2. The lower trace of Fig. 2*a* is the scope trace when the monochrometer was set just off the

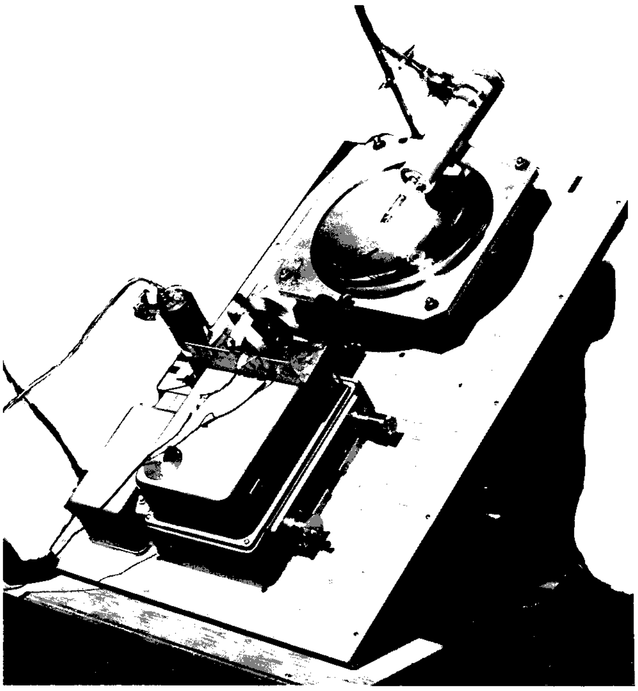

Fig. 1. Photograph of the experimental arrangement showing the liquid neon dewar, 14-in. spherical mirror, 30-cps beam chopper, monochrometer and PbSe detector.

INDEXING CATEGORIES

A. laser (continuous)	
A. CaF_2:Dy	
B. sun pumping	
D. liquid Ne(27°K)	
E	