Self Pulsing Properties
of Optically Pumped FIR NH₃ Lasers

M. P. Sassi*, N. Barbeau**, and C. O. Weiss

Received 16 April 1986/Accepted 17 February 1987

Abstract. We report on measurements of periodic and chaotic self-pulsing beyond the second threshold of far-infrared NH₃ lasers. While the instabilities of the 81 μm ¹⁴NH₃ laser follow a simple pattern, for the 374 μm ¹⁵NH₃ laser different pulsing properties are found in different parameter ranges.

Pulses under conditions of high pumping power are measured in detail, in view of possible applications of these coherent, high-repetition rate far-infrared pulsed lasers.

PACS: 42.50.Tj, 42.55.-f

We have recently used NH₃ lasers in the far-infrared (FIR) to test the predictions of the laser equations (Lorenz-model) [1] about instabilities of the most basic type of lasers.

We have found the phenomena predicted as well as quantitative agreement regarding the instability thresholds [2, 3]. For more detailed comparisons with theoretical models, in particular in view of the influence of transverse spatial effects, we report in this paper quantitative measurements of pulsing frequencies, pulse widths and instability thresholds for the two systems used previously.

Since these lasers generate coherent pulses, they combine in an advantageous way the coherence of cw lasers with compression of the average power into higher peak-power pulses, very similar to mode-locked lasers in the visible. (In fact, the pulsing of these lasers may be seen as arising from the oscillation of coupled “hot-cavity” modes).

The reason for choosing optically pumped FIR lasers for the tests of the dynamics of simple lasers is the easy fulfillment of the “bad cavity” condition [4] in laser operation which, unlike for most other lasers is the typical operating condition of these systems (along with other types of laser-pumped gas lasers). The price to be paid is a relatively complex experimental system, in particular for quantitative measurements, where parameters are to be well controlled. Of particular importance is the control of the pumping frequency i.e. of the velocity group of molecules used. The pump lasers where therefore referenced to Lamb-dip stabilized auxiliary lasers. The FIR lasers were operated in a manner that only a single travelling wave was interacting with the excited group of molecules by using a ring resonator and/or pumping off the line center of the laser gas pump transition. Details of the experimental apparatus have been described in [1-3, 5].

Two regimes have to be distinguished in the operation of these lasers, i) The homogeneous broadening limit where the Rabi frequency of the pump transition (and with it the ac Stark splitting of the gain line) is smaller than the homogeneous linewidth, and ii) the “coherent” regime where the ac Stark splitting exceeds the homogeneous linewidth.

For the homogeneous regime we have, in fact, observed the predicted dynamical properties of the simplest laser model (Lorenz equations [6, 1] and the Lorenz model extended to allow for detuning [71]) including the chaos of the Lorenz equations [1].

In the “coherent” regime, a more complex behaviour may be expected, because this represents the dynamics of a coherently coupled 3-level system. Of course, a smooth transition between the two regimes is to be expected. This we found true for the 81 μm transition; however, for the ¹⁵NH₃ 374 μm transition a more complex behaviour is found. We assume that the
important difference between the two systems lies in the different relaxation rates \[2\] and possibly in different transverse effects.

In order to allow quantitative comparisons with theoretical models now being developed \[8\] or existing \[7, 1\] we report here on the results of measurements of experimentally accessible data as functions of laser parameters useful for such comparisons.

**81 \(\mu\)m \(^{14}\text{NH}_3\) Transition**

We have found that the bifurcation behaviour of this laser in the "homogeneous" regime is, indeed, the one predicted by the Lorenz equations (also extended for detuning \[7\]), i.e. at the second threshold the laser starts self-pulsing; periodic off and chaotic on line center. Notably, also in the chaotic range the pulsing frequency remains well defined \[3\]. Transitions between periodic and chaotic pulsing proceeds via period doublings on change of pump strength or resonator tuning with the exception of the resonant case where the onset of chaos is direct from the continuous emission when the pump strength is increased. The only difference we find between the "homogeneous" and the "coherent" case is that in the latter, also for the resonant case the transition to chaos occurs via periodic pulsing and period doubling. At the highest pressure (9 Pa) self pulsing can only be obtained by adding loss to the normal resonator losses which fulfill the "bad cavity" condition up to \(\approx 7\) Pa.

The important quantity for this laser is therefore the pulsing frequency which is given as a function of gas pressure in Fig. 1 for maximum available pump power.

In contrast to this clear pattern we find a much more complex behaviour for the

**374 \(\mu\)m \(^{15}\text{NH}_3\) Laser**

For this transition we find self-pulsing for two distinctively different resonator settings i) for resonant tuning and ii) for detuning the resonator by roughly \(1/2\) of the (half) gain line width.

We have investigated these two cases first at low pumping intensity where the low pump strength mostly puts one into the "homogeneous" regime. In this case we find for the line-center emission only periodic self-pulsing. The "detuned" emission shows periodic and chaotic pulsing usually with lower and upper pumping threshold.

In view of possible applications of these high repetition-rate FIR coherently pulsing lasers we have then measured pulse widths and frequencies as a function of pump power and pressure under conditions which yield a sizeable average output power, i.e. largely for higher pressures and pump power.

Figure 2 shows the self pulsing frequencies for low intensity pumping and resonant resonator setting. The pulsing threshold increases with increasing pressure mostly due to a corresponding increase in the first laser threshold \[2\]. There is always an upper limit in the pumping strength at which the laser returns to continuous emission. Under the conditions of Fig. 2 the "bad cavity condition" is fulfilled \[4\].

Figure 3 shows the "detuned" laser emission for low intensity pumping. Increasing the pump at a given pressure usually yields a sequence: continuous, periodic-subharmonic-chaotic-periodic pulsing, con-