IV. MICROWAVE SPECTROSCOPY*

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Sections A-D of this report are abstracts of reports that are available in "Research on Paramagnetic Resonances," Final Report on Signal Corps Contract DA36-039-sc-87376, Research Laboratory of Electronics, M. I. T., September 15, 1961.

M. W. P. Strandberg

A. SPIN-LATTICE RELAXATION

A particularly simple set of solutions to the rate equations that describe the spin-lattice relaxation of a four-level system has been found. At orientations of the applied magnetic field for which the eigenstates of the system are nearly pure spin states, special relationships exist among the lattice-induced transition probabilities, so that the decay of the population differences of the levels to thermal equilibrium is described by single exponentials and the observed relaxation times can be directly related to the transition probabilities. For a particular magnetic-field orientation in dilute potassium chromicyanide, these solutions have been shown to agree with the experimentally observed relaxation.

J. R. Shane

B. A QUANTUM-MECHANICAL STUDY OF SPIN-SPIN INTERACTION

We consider the quantum-statistical mechanics of a system of spin 1/2 particles, arranged in a rigid lattice, interacting with one another and with an external magnetic field. Specifically, we are concerned with the net magnetic moment of the system and its time variation under different experimental conditions. The influence of lattice vibrations on the magnetic moment is ignored (unless otherwise stated in the report). Our considerations will therefore be generally valid for phenomena occurring in time intervals that are small in comparison with the spin-lattice relaxation time T_1. The two orientations of the spin will be regarded as the only degrees of freedom possessed by each particle, and the whole spin system will be treated as an energy-conserving system.

*This work was supported in part by U. S. Army Signal Corps Contract DA36-039-sc-87376.

Here we are not concerned with special situations such as the grouping of the spins in small clusters of two or three spins each, with strong interactions within a cluster, and negligible interactions of spins belonging to different clusters. Rather, we consider the spins to be more or less evenly distributed over the entire crystal, and thus to form a single quantum-mechanical system.

Our conclusions could probably be most simply described in terms of a spin temperature. However, we make no explicit use of this concept and restrict ourselves to purely dynamical considerations, in the hope that the effort will help clarify the application of thermodynamic methods to such problems.

It will be seen that extension of our results to particles of higher spin and to spin systems under the influence of crystalline electric fields offers no difficulties in principle.

B. V. Gokhale

C. NEGATIVE L AND C IN BROADBAND MASERS

The results of this study were given in Quarterly Progress Report No. 62, pages 99-102. A complete discussion will be found in the Final Report mentioned above.

R. L. Kyhl, R. A. McFarlane

D. A CIRCULARLY POLARIZED MASER OSCILLATOR

The frequency stability of a circularly polarized solid-state paramagnetic maser oscillator has been observed, with the objective of obtaining the information needed to construct a frequency standard with a broad microwave spectral line.

The beat frequency between two such masers with the use of ruby can be made almost free from the variation of the static magnetic field and of the angle between crystalline axes and the static magnetic field.

The stability of the 1.5-mc beat frequency is approximately 10^{-6} for short time intervals, and approximately 10^{-5} for long time intervals. The short-time stability is limited mainly by the fluctuation of the cavity resonant frequency in the liquid helium. On the other hand, the long-time stability is determined by the drift of the pump frequency, although the reason for this interrelation is not thoroughly understood.

The effect of reflections from the load on frequency is considerably reduced by the unidirectional structure used here, as compared with the effect that would be expected with a reflection type of maser.

It is also shown that the unidirectional maser amplifier can be built with reduced cross section by utilizing dielectric-loaded circular waveguide.

T. Ogawa

E. MODE CONTROL IN RUBY OPTICAL MASERS BY MEANS OF ELASTIC DEFORMATION

A new technique suggested by one of us (M. W. P. S.) has been applied in experimental work on ruby optical masers with interesting results. The technique used was that of elastic deformation of a solid-state optical maser by means of a torque perpendicular to the cavity axis. It resulted in the ability of, for the first time, exercising a large degree of control over the effective modes that give rise to the output radiation. Strikingly, it permitted optimization of the elastic deformation of any particular ruby specimen to reduce significantly its pumping energy requirements for the onset of maser oscillations. At the same time, the divergence of the emergent beam could be reduced by a sizeable fraction. In effect, this work allows one to obtain an interpretable pattern in the far field, the lack of which in an operating laser makes the correlation of theory and experiment ambiguous.

The results of a typical experiment are shown in Figs. IV-1, IV-2, and IV-3. The ruby rod was 1.5 inches in length, and 0.1 inch in diameter. The latter dimension had been chosen for reasons of pumping efficiency and ease of stressing. The rod was chucked 1/16 inch into an indexed collet from one end, and was surrounded by four FX-100 xenon flash lamps in the fashion described by P. Miles.[1] Its other end was fitted with a stirrup that permitted weights to be hung from it. By varying the weights and the orientation of the rod, a unique set of conditions was established for optimum maser properties. The near- and far-field patterns were studied photographically with simultaneous monitoring of the time development of the emergent radiation. Monitoring was facilitated by a beam splitter in the optical system, and served as a check on the conditions of excitation, since we were particularly interested here in the near-threshold properties of ruby optical masers. Figure IV-1 is the far-field pattern of the unstressed rod at threshold. Figure IV-2 is the far-field pattern of the same cantilevered rod with a weight of 91 grams suspended from its free end.

In Fig. IV-2 the threshold has been reduced from 271 joules to 194 joules. Figure IV-3 is the far-field pattern for the same conditions as in Fig. IV-2, except for the input energy which is the same as that for Fig. IV-1. These patterns were photographed through a 650-mm focal length lens, and the beam divergences are ~40 minutes and ~8 minutes for Figs. IV-1 and IV-2, respectively. The near-field patterns for the same set of conditions show equivalent reduction in complexity as the rod undergoes stressing to an optimum point. It is important to note that photographs similar to Figs. IV-1 and IV-2 were obtained when the time development consisted of a single microsecond pulse, or a short sequence of pulses.

Several obvious conclusions can be drawn from these results. Stressing can evidently be used to bring the reflecting faces of solid-state optical masers into the best internal

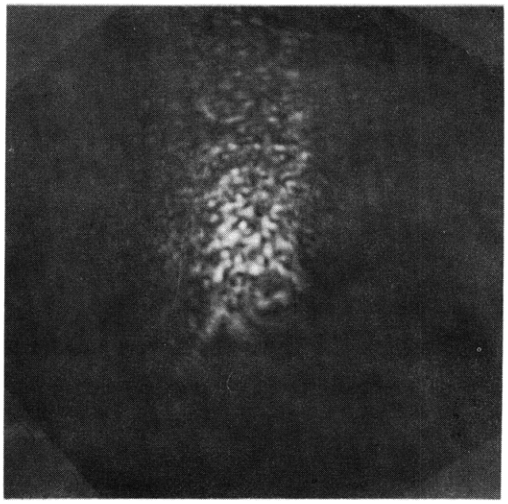

Fig. IV-1. Far-field pattern for unstressed rod at threshold (271 joules).

Fig. IV-2. Far-field pattern for stressed rod at threshold (194 joules).

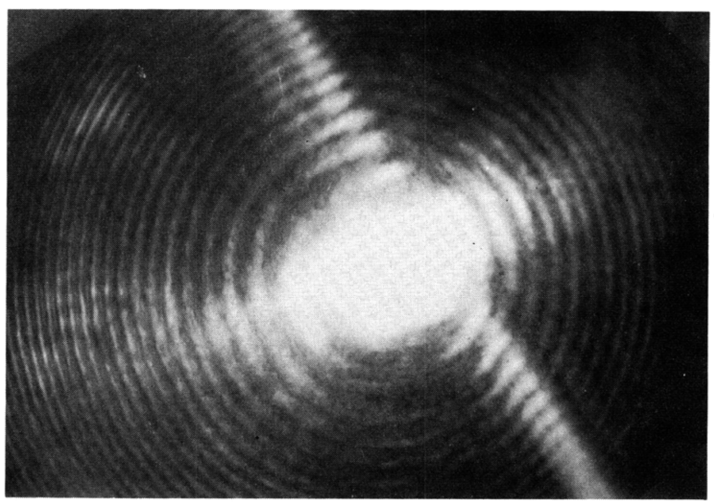

Fig. IV-3. Far-field pattern for stressed rod above threshold (271 joules as in Fig. IV-1).

alignment, as far as local inhomogeneities of such far from optically perfect media permit. It can raise the Q of selected modes at the expense of less desired and more complex ones.

Similar results can be used to extract information about the largest diameter over which an imperfect medium can sustain coherent oscillations in a lower-order mode. For ruby that is available at present this would seem to be 0.015-0.050 inch. For this reason, there seems to be little point in using rubies that are in excess of these diameters. On the contrary, larger rods require more pumping energy and are bound to have more complicated properties in proportion to their volume.

The work on which this note is based will be the subject of a later paper.

M. S. Lipsett, M. W. P. Strandberg

References

1. P. A. Miles, First Joint Progress Report of the Laboratories for Molecular Science and Molecular Engineering, M. I. T., 29 January 1961, p. 29.