

IV. MICROWAVE SPECTROSCOPY*

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A. BROADBAND MASER WITH "REACTANCE COMPENSATION"

The use of the negative L and C property of induced emission in maser circuit design has been discussed in previous reports (1, 2). Experimental verification of this approach is shown here. The cavity configuration is shown in Fig. IV-1, and the assembly in Fig. IV-2. It is a conventional ruby three-level maser operating at a signal

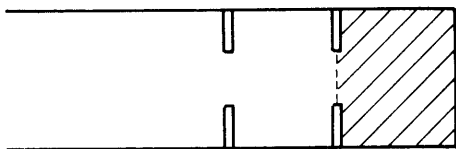


Fig. IV-1. Two-cavity broadbanding configuration.

frequency of 9 kmc and is pumped at 23 kmc.

The ruby cavity operates in the TE_{011} mode, and the dimensions are 0.373 in. \times 0.234 in. \times 0.091 in. It is completely filled with ruby to give the high effective susceptibility that is essential for this type of operation. The compensating cavity is approximately the same size, as it is filled with alumina. Both cavities are constructed by brazing copper

around the crystal and then milling out coupling holes. Tuning of the compensating cavity and waveguide coupling are adjustable during liquid-helium operation. The coupling to the waveguide must be very tight and the resulting field concentration at the coupling window lowers the Q_0 of this cavity, even at liquid-helium temperature, and degrades the performance somewhat. This would not be difficult to correct.

Pumping power is introduced into the back corner of the ruby cavity as shown in Fig. IV-2. It is necessary to resonate the cavity at the pumping frequency because approximately 20 μ w of pump power must be dissipated in the cavity to achieve full saturation of the rather concentrated rubies that are used. This is contrary to our experience with simpler masers that we have used before. In the present experiments there is no pump frequency cavity-tuning control, but there are enough cavity resonances so that the ruby can be operated near the push-pull pumping angle and still achieve simultaneous resonance. Results are shown for a "pink" ruby with a natural linewidth of 67 mc. A more concentrated ruby with a linewidth of 85 mc gave much poorer results,

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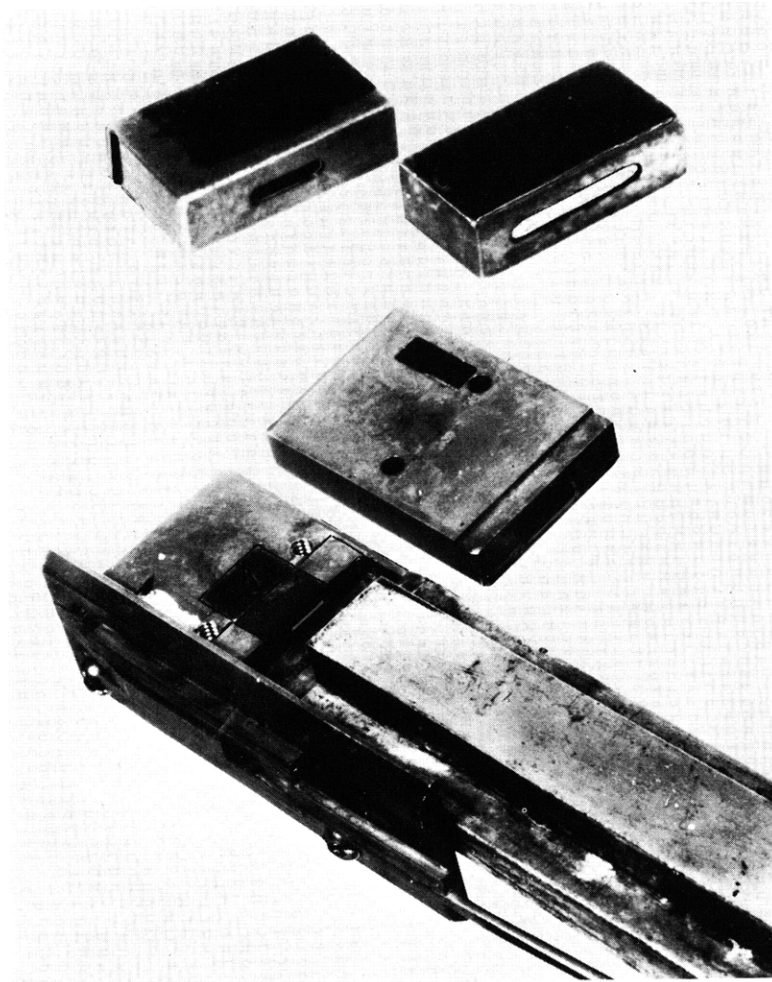


Fig. IV-2. Two-cavity maser assembly.

presumably because of a decrease in cross-relaxation time, T_{12} .

Figure IV-3 shows operation at 4.2°K with 14-db gain and 50-mc bandwidth. The intercavity coupling separates the two modes of the synchronously tuned cavity system by 120 mc. Figure IV-4 shows operation at 1.5°K with 14-db gain and 95-mc bandwidth. The cavity mode separation is 155 mc. The voltage gain-bandwidth product (not too significant for this type of operation) is 475 mc. Much higher gain-bandwidth figures could have been achieved by operating at very high gain. Figure IV-5 shows extreme bandwidth operation with 9-db gain and 122-mc bandwidth, almost twice the natural linewidth of the ruby. The Gaussian ruby line shape limits the bandwidth here. The cavity mode separation is 171 mc. The triple peak is characteristic of low-gain broadest bandwidth operation. Some of the fine structure on the curves is caused by the signal generator.

Magnetic-field tolerance is very close, an error of 2 gauss causes pronounced slope on the flat portion of the gain curve.

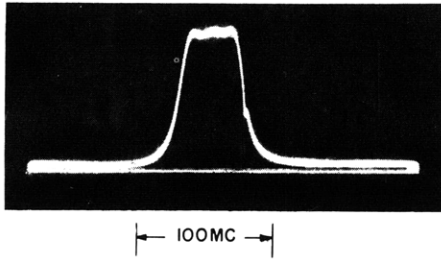


Fig. IV-3. Gain characteristic (4.2°K, 14-db gain, 50-mc bandwidth).

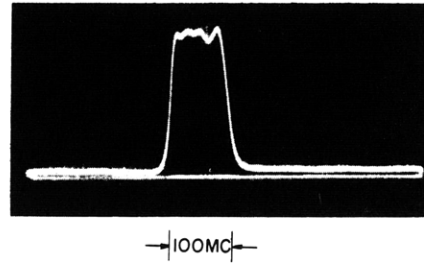


Fig. IV-4. Gain characteristic (1.5°K, 14-db gain, 95-mc bandwidth).

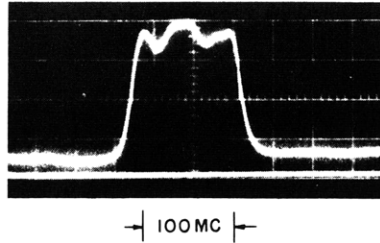


Fig. IV-5. Gain characteristic (1.5°K, 9-db gain, 122-mc bandwidth).

Since the matrix element of the ruby resonance in question is elliptically polarized, even higher effective susceptibility could be achieved in a transmission type of cavity maser by using circularly polarized cavity modes. Such a design is being developed, but thus far the microwave circuit complexity has prevented successful operation.

The large bandwidth is attractive for many radio astronomy and communication applications. To make full use of the low noise temperature, however, care must be taken in any maser system design to minimize losses in antennas, feed lines, and circulators.

There are, of course, many other approaches to broadband masers, some of which are now being developed (3). The circuit described can be used in cascade. Traveling-wave masers normally have bandwidths that are close to the natural linewidth. Tapering of the transition frequency with an inhomogeneous magnetic field, or with tapering of crystal orientation can substantially increase the bandwidth in traveling-wave or multi-cavity masers.

Calculations for the configuration of Fig. IV-1, with rubies in both cavities and both rubies at the same transition frequency, indicate poor performance. Operation in this manner has been reported by other workers; perhaps stagger tuning of the rubies was present.

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Similar negative L and C properties occur in parametric amplifiers, although for a different reason. This corrects a misstatement made in our previous discussion (1, 2).

One of the gain-bandwidth formulas stated (4) in Quarterly Progress Report No. 57 is in error. The result should be multiplied by 2 for integration over the full linewidth. The correct formula is given below. The other formulas are correct.

$$\frac{1}{\pi} \int \ln G^{1/2} d\omega = \Delta\omega_{\text{para}} \left[\left(1 + \frac{3f\chi''_{\text{max}} \omega_0}{\Delta\omega_{\text{para}}} \right)^{1/3} - 1 \right]$$

R. L. Kyhl, R. A. McFarlane

References

1. R. L. Kyhl, Maser circuits with negative L and C, Quarterly Progress Report No. 56, Research Laboratory of Electronics, M. I. T., Jan. 15, 1960, pp. 83-88.
2. R. L. Kyhl, Negative L and C in solid-state masers, Proc. IRE 48, 1157 (1960); 49, 519 (1961).
3. J. J. Cook, L. G. Cross, M. E. Bain and R. W. Terhune, A low-noise X-band radiometer using maser, Proc. IRE 49, 768-778 (1961).
4. R. L. Kyhl, Gain bandwidth in circuits with negative L and C, Quarterly Progress Report No. 57, Research Laboratory of Electronics, M. I. T., April 15, 1960, p. 54.

B. STIMULATED OPTICAL EMISSION IN RUBY

Equipment has been built (1) to provide an intense flash of light (up to 3200 joules in 1 msec). A ruby crystal (Al_2O_3 , with 0.05 per cent Cr_2O_3), with two parallel and optically flat sides, was irradiated, and the fluorescent radiation was studied with a mirror grating spectograph converted to hold a photomultiplier tube. The two flat ends of the crystal were coated with silver by evaporation. One end was made opaque; and the other, 0.3 per cent transparent. When the ruby crystal was irradiated with a high-intensity pulse (3000 joules) a sudden increase in intensity and shortening of the time constant were observed in the fluorescent R_1 line. This indicates that population inversion occurred between the ground level of the Cr ion and the $\bar{E}(^2E)$ fluorescent level. The output observed, then, is due to stimulated emission. The polarization of the fluorescence was also observed at high intensity.

M. J. Keck

References

1. This equipment is described in the author's Bachelor of Science thesis, submitted to the Department of Physics, M. I. T., May 20, 1961.

C. ELECTRON PARAMAGNETIC-RESONANCE STUDIES OF NEUTRON-IRRADIATED LiF

This report summarizes the author's Bachelor of Science thesis, submitted to the Department of Physics, M. I. T., May 20, 1961.

A brief outline of the theory of electron paramagnetic resonance as it applies to the resonant center in irradiated LiF is presented in this thesis. Some types of defects that may be produced by irradiation of LiF are enumerated and briefly discussed. A derivation of the static susceptibility of both F-centers and conduction electrons is given and its relation to the power absorbed is discussed. A treatment of the general theory governing linewidths is given and the effect of increased density on the resonant frequency is shown to be negligible.

The experimental results of this study show that there appear to be two different types of centers present in the irradiated crystals. Those crystals that received between 10^{17} and 10^{18} nvt showed absorptions with a linewidth of approximately 60 gauss, while those that received less than 10^{17} nvt showed the normal 110-gauss F-center absorptions. The F-centers showed a marked increase in ΔH , and a positive shift in the g -value after annealing; the other absorption was essentially unaffected by annealing, except for the expected loss of intensity. A discussion of these results is included; however, data are still insufficient to make any definite statements about the cause of this behavior. No trace of the narrow line that is thought to be due to metallic lithium was found because of insufficient irradiation.

J. J. O'Gallagher

D. ELECTRON-PHONON INTERACTIONS IN SEMICONDUCTORS

Electrons in a solid can gain or lose energy through interactions with the vibrational modes of the solid. The energy of these vibrational modes is quantized, and a quantum of such energy is called a phonon. The author's thesis (1) reviews the theory of the behavior of electrons and phonons in crystals and the nature of their interactions. Also discussed in this thesis is an experiment in which tunnel diodes were used to detect these interactions and measure the energy exchange involved. This is accomplished by plotting the slope of the I-V (current-voltage) curve of the tunnel diode against the voltage and measuring the voltages at which minima occur. A special circuit was designed to measure the slope of the I-V curve. The circuit performed well, and the results obtained were good, agreeing with data previously obtained by a different method.

H. C. Bowers

References

1. This report is a summary of the author's Bachelor of Science thesis, submitted to the Department of Physics, M. I. T., May 20, 1961. Further details will be found there.

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E. EFFECT OF A MAGNETIC FIELD ON AN INTRINSIC PHOTOSIGNAL IN GERMANIUM

Behavior noted during experimentation at Westinghouse Manufacturing Company has been investigated. Plots have been made of cell output photosignal as a function of magnetic field for constant bias currents of 5 μ amp and 10 μ amp, and magnetic fields up to 24 kgauss. Magnetoresistance was measured, and a phase shift detected. Nonlinearities were noted. Starting from an equation presented by Van Roosbroeck, analytic expressions were derived for the photocurrent under conditions of transverse magnetic field. Surface effects have been accounted for; Dember voltage in the bulk is shown to be negligible. A rapidly varying absorption coefficient presents difficulties for an exact numerical application to our problem. Consequently, special cases of high and low constant absorption coefficient were treated, and their predicted results plotted. A method has been outlined by means of which numerical predictions can be obtained when the spectral distribution of incident radiation and the spectral response of the crystal are known.

Suggestions for future experimentation are given in the author's thesis which was submitted to the Department of Physics, M. I. T., May 20, 1961, in partial fulfillment of the requirements of the Degree of Bachelor of Science.

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