NASA CONTRACTOR REPORT

INTERACTION OF ELECTRONIC CURRENT WITH HYPERSONIC WAVES IN SOLIDS

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ABSTRACT

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During the final quarter further noise-spectrum measurements were made of the electrical noise in CdS in the current-saturated region. However, it became apparent that more direct methods of observing or detecting phonons at microwave frequencies are required. It appears possible that circuit effects are distorting the present measurements and making their interpretation difficult. Consequently, we are now concentrating on optical methods as a means of avoiding these difficulties, and three schemes are being developed.

A new mode of low-frequency oscillations has been observed in CdS crystals which lends support to the "Monotron" model mentioned in previous reports as possible explanation of the low-frequency current oscillations.

With some reservations on the possibility of circuit effects, our measurements suggest that the low-frequency (for example, ≈ 10 Mc/sec) oscillations and noise may be more fundamental to the current saturation than has heretofore been believed.

Author

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I. CURRENT SATURATION IN CADMIUM SULPHIDE

A. INTRODUCTION

The basic problem under investigation at RCA Laboratories under this contract is the current saturation that can occur in cadmium sulphide when the electric field exceeds that corresponding to the sound velocity. No explanation of this effect yet exists which unites all the experimental data. In the following, a brief resumé is given together with an outline of our work and its relevance to the problem.

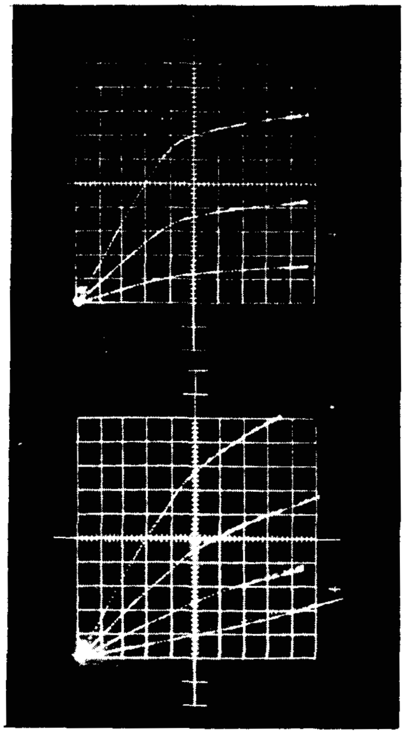
B. RESUMÉ OF EXPERIMENTAL EVIDENCE

R. W. Smith in 1962[1] observed current saturation in CdS and showed that the knee of the V-I curve increased with the conductivity of the sample (see Fig. 1). He also reported that crystal current showed low-frequency oscillations (about 2 Mc/sec) when the voltage was taken above the knee. He pointed out the possibility of a connection between this saturation and the acoustic amplification in CdS reported by White et al.[2]

Hutson, McFee, and White in 1961 observed acoustic amplification due to the interaction of sound waves with drifting electrons in CdS. The condition for greatest amplification is that the drift velocity of the electrons, v_d, should be somewhat greater than the velocity of sound, v_s. An optimum frequency ω_o is also predicted.

McFee in 1963[3] showed that current saturation in his samples was not instantaneous and that the decay of current from its Ohmic value took several microseconds. Moreover, the decay of the current was associated with the build-up of acoustic noise during the multiple-transit time of electrons in the crystal necessary to achieve overall acoustic gain. However, the spectrum of the acoustic noise was not investigated.

Quate in 1963[4] described experiments in acoustic amplification and mentioned that associated with the decay of current to its saturated value he detected a noisy signal in the crystal leads. It is not yet clear whether this noise is spurious or due to rf bunching as described by White.[2] The power was measured as a function of frequency, and Quate reported that it had a maximum near the frequency of maximum acoustic gain predicted by White.[2]



Top curves: Vert. = 5 mA/div
Hor. = 20 V/div

Bottom curves: Vert. = 0.15 mA/div
Hor. = 20 V/div

$L = 0.05$, $W = 0.03$, $T = 5 \times 10^{-3}$ cm.
Note that change in resistance is 280:1.

Fig. 1. V-I characteristics of photocurrent in a CdS crystal.

Shortly before Quate, Smith[5] looked for noise in the 600 to 800 Mc/sec range of importance according to White.[2] No noise was seen, however.

In 1963, Mayo[6] tried to observe acoustic noise in photoconducting crystals at a much lower frequency than either McFee (45 Mc/sec),[3] Quate (300 Mc/sec),[4] or Smith.[5] He discovered considerable noise at frequencies from 10 Mc/sec down to a few tens of cycles. The noise level, which increased toward lower frequencies, was too great to be attributed to any spurious effect such as contact noise of " $\frac{1}{f}$ " semiconductor noise. The frequency of this noise is too low to be accounted for by White's mechanism.[2]

In 1964, Smith[7] repeated his earlier noise experiments, but over a wider frequency range. He confirmed Mayo's result,[6] and showed that there was a broad spectrum of noise with a peak at a frequency at least smaller than a megacycle or two, and falling off at frequencies up to 1 Gc/sec which was the apparatus frequency limit in this case. No Quate-type noise peak was seen at the "optimum" frequency ($\approx$ 800 Mc/sec) predicted by White.[2]

Smith and Mayo are currently carrying out experiments on noise to cover the frequency range from 1 Mc/sec to 35 Gc/sec in an attempt to establish a general pattern of behavior from the many samples studied.

Prohofsky published a theoretical paper in 1964,[8] which proposed that the dominant mechanism in current saturation was an electron-phonon interaction involving phonons in the frequency range 10 to 100 Gc/sec. In this range, the phonon and electron masses are comparable. This theory is a linear quantum mechanical treatment of electron-phonon collisions, in contrast to White's linear classical theory.[2] Prohofsky predicts a saturated mobility which is half of the unsaturated, low-field value. This agrees very well with experiments, provided the conductivity is not too high ($\ll$ 1 mho/cm). However, no phonon activity in the 10 to 100-Gc/sec range has yet been positively detected.

C. SUMMARY OF RCA WORK UNDER CONTRACT

The effort under the Contract can be classified under four main headings: Noise Spectrum Measurements, Coherent Low-Frequency Oscillations, RF Measurements, and Optical Measurements.

1. Noise-Spectrum Measurements

a. Very-low-frequency (< 10 Mc/sec) acoustic noise was discovered in CdS crystals biased above the knee.

b. These results justified a renewed effort at higher frequencies which resulted in current noise being detected up to 1 Gc/sec, the noise power decreasing with increasing frequency at the rate of about 12 db per octave.

c. No increase in current noise could be detected as the frequency passed through the value which White predicts ($\omega_o = \sqrt{\omega_c \omega_d}$) as the frequency of maximum acoustic amplification. Quate, however, in similar experiments mentions preliminary evidence of a current noise peak near ω_o-value for his single sample.

d. More recent experiments at 10 Gc/sec show a rise in the noise output to a value 30 db above that extrapolated from the data described in b. above. This might be evidence of the incoherent electron-phonon collisions described by Prohofsky.

2. Low-Frequency Oscillations

a. Large-amplitude, low-frequency (typically 2 to 4 Mc/sec, depending on length of crystal) coherent oscillations have been observed in CdS crystals biased above the knee from the time current saturation was first seen.

b. The noise described under 1-b is believed to be connected to these low-frequency oscillations; first, the noise is peaked at low frequencies, and secondly, the oscillations become increasingly noise-like as the length of a given sample is increased.

c. The oscillations are sinusoidal; this suggests that they are not relaxation oscillations.

d. The oscillations are associated with hairline damage regions in the crystals at the positive terminal. This is the end at which acoustic waves are largest according to White amplification. A casual relationship remains to be established, however, since some crystals break down before oscillations are seen.

e. Oscillations do not always accompany current saturation. However, even if they have no direct bearing on the current saturation, the oscillations must still be explained. They are not simply acoustic ringing because there is no sign of decay.

f. A calculation is in progress aimed at explaining the oscillations as transit-angle oscillations (i.e., as in a "Monotron") in a collision-dominated system.

3. RF Measurements

a. The impedance was measured at low frequencies (1 to 10 Mc/sec) on a CdS crystal biased above the knee. No reactive component was observed.

b. High-frequency measurements were made by mounting a crystal in a 10-Gc/sec resonant waveguide. No changes in reflected 10-Gc/sec power were detected as the crystal was biased through the knee. This result as well as a. remains to be explained.

4. Optical Measurements

Optical methods are being currently investigated as an alternative method of detecting phonons in CdS, particularly at gigacycle frequencies. Since acoustic wavelengths at these frequencies are similar to those of visible light, then optical techniques should be particularly applicable. The reflection of light by standing acoustic waves is an established method of measuring the velocity of sound in a solid. (The theory is similar to that of the Bragg reflection of x-rays by crystal lattices.) Our problem is different in that the phonons we wish to detect are incoherent, and no standing waves are set up. Three methods are being investigated.

a. For low frequencies (< 100 Mc/sec), a method based on the Michelson interferometer will be used.

b. At frequencies above 1 Gc/sec, the scattering and diffraction of light by the crystal is more appropriate. We hope to see broadening of the optical linewidth of a laser beam as it is transmitted or scattered by the crystal.

c. The photoelastic effect is also being investigated.

The above four main topics are described in detail in the following sections.

II. NOISE SPECTRUM MEASUREMENTS

During the previous three quarters we have established that CdS crystals biased above the knee of the V-I curve produce a broad spectrum of acoustic noise with a peak at a few megacycles -- near the frequency of the low-frequency oscillations described in Section III. At higher frequencies, the noise power falls off at about 12 db per octave as the frequency increases. Noise spectra were measured for several crystals from a few megacycles to above one thousand megacycles, and consistent results were obtained. These results, when extrapolated to 10 Gc/sec and higher, predicted that at these frequencies only normal thermal ("$kT\Delta f$") noise would be seen.

A superheterodyne receiver for 11 Gc/sec was constructed and used to detect the output from a pulsed crystal mounted in a waveguide. A considerable amount of noise was found, the level being 30 db or so above thermal, and it was thought that this might be due to an electron-phonon interaction of the type described by Prohofsky. Two other crystals did not show detectable noise at this frequency, but not too much significance was attached to this since:

a. The sensitivity of the receiver was rather poor.

b. The correlation between the threshold voltage for the noise and the voltage at the knee of the V-I curve was excellent. Also, the noise increased during the applied pulse at the same rate as the current decayed.

For these reasons, it was felt that the result was not spurious, but that a better receiver should be used in later experiments. However, we already had available a receiver for 18 to 26 Gc/sec which was about a hundred times more sensitive than that used at 11 Gc/sec. Three crystals were pulsed in a waveguide mount suitable for this frequency, but no detectable signal was obtained. More crystals are being prepared and the tests will be continued.

However, the results already obtained raise a number of questions:

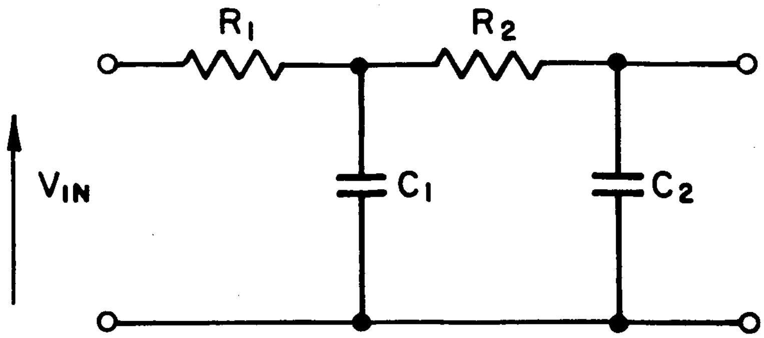
1. Is the fall-off of noise with frequency in fact as steep as that measured, or are the circuit effects misleading us?
2. Are we justified in assuming that the electrical noise measurements can be taken to indicate the general shape of the phonon spectrum as well?

Question 1 is suggested by the remarkably steady decrease of noise with frequency at the rate of 12 db/octave. This is the rate of decrease associated with an electrical circuit containing two "poles," or more simply, one containing two complex impedances in parallel. Figure 2 gives an example of such a circuit. On the other hand, it might be concluded that the shape of the noise spectrum is as measured, and should indicate that the mechanism causing the noise is essentially low-frequency, and that the rate of fall-off is not surprising. We might draw a hypothetical equivalent circuit for such a model as in Fig. 3, where we suggest lumped electrical circuit elements to take the place of mechanical or other properties of the crystal. (This is a fruitful method of approach often used in acoustical engineering, and it is known to give useful results.)

Arguing along the latter lines leads to the conclusion that the "Monotron" model which we have proposed previously should be able to explain the effect, and we discuss this model further in Section III-C.

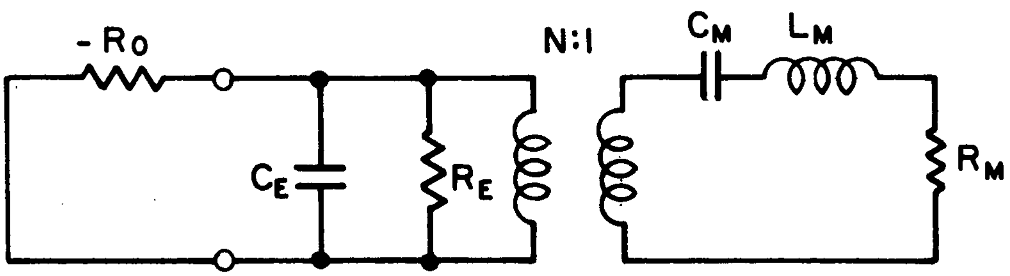
The second question noted above is clearly related to this problem. Using thermodynamic arguments it is easy to prove that two coupled systems should have the same noise spectrum. Otherwise, by connecting narrow band filters to each system and then connecting these externally by a loss-less transducer, we could make power flow in an external circuit without doing any work on the two systems which are at the same temperature. (Van der Ziel discusses this question at length in Ref. 9.) Nevertheless, it is evident that there is a need for a direct measurement of the acoustic noise spectrum by some other means.

Optical methods have already been suggested as a means of detecting the strain waves in the crystal. Ash,[10] working at University College, London, is currently constructing a detector in which acoustic waves are used to vibrate a mirror which is incorporated in a laser. The resultant modulation is easily detected and high gains are predicted. Smith, at this laboratory, expects to use the photoelastic effect as a method of observing strain waves in CdS (see last quarterly report). We are also actively engaged on the construction and evaluation of another form of detector based on the Michelson interferometer (see Fig. 4). One mirror of the interferometer will be the polished surface of a CdS crystal plated with indium. As the surface vibrates we hope to detect and amplify the resulting fringe shifts using a photodiode



$$\text{AS } \omega \rightarrow \infty, \quad \frac{|V_{OUT}|^2}{|V_{IN}|^2} \longrightarrow \frac{1}{R_1^2 R_2^2 C_1^2 C_2^2 \omega^4}$$

Fig. 2. Example of circuit with 12-db/octave fall-off at high frequencies.



C_M AND L_M CORRESPOND TO THE COMPLIANCE AND MASS OF THE CRYSTAL, AND R_M TO THE MECHANICAL LOADING. C_E AND R_E ARE THE ELECTRICAL CAPACITANCE AND RESISTANCE. N IS A MEASURE OF THE ELECTRO-MECHANICAL COUPLING. $-R_0$ IS A HYPOTHETICAL NEGATIVE RESISTANCE REPRESENTING THE EFFECT OF THE 'MONOTRON' INTERACTION DISCUSSED IN THE TEXT.

Fig. 3. Possible "lumped circuit" analogue to explain the 12-db/octave fall-off.

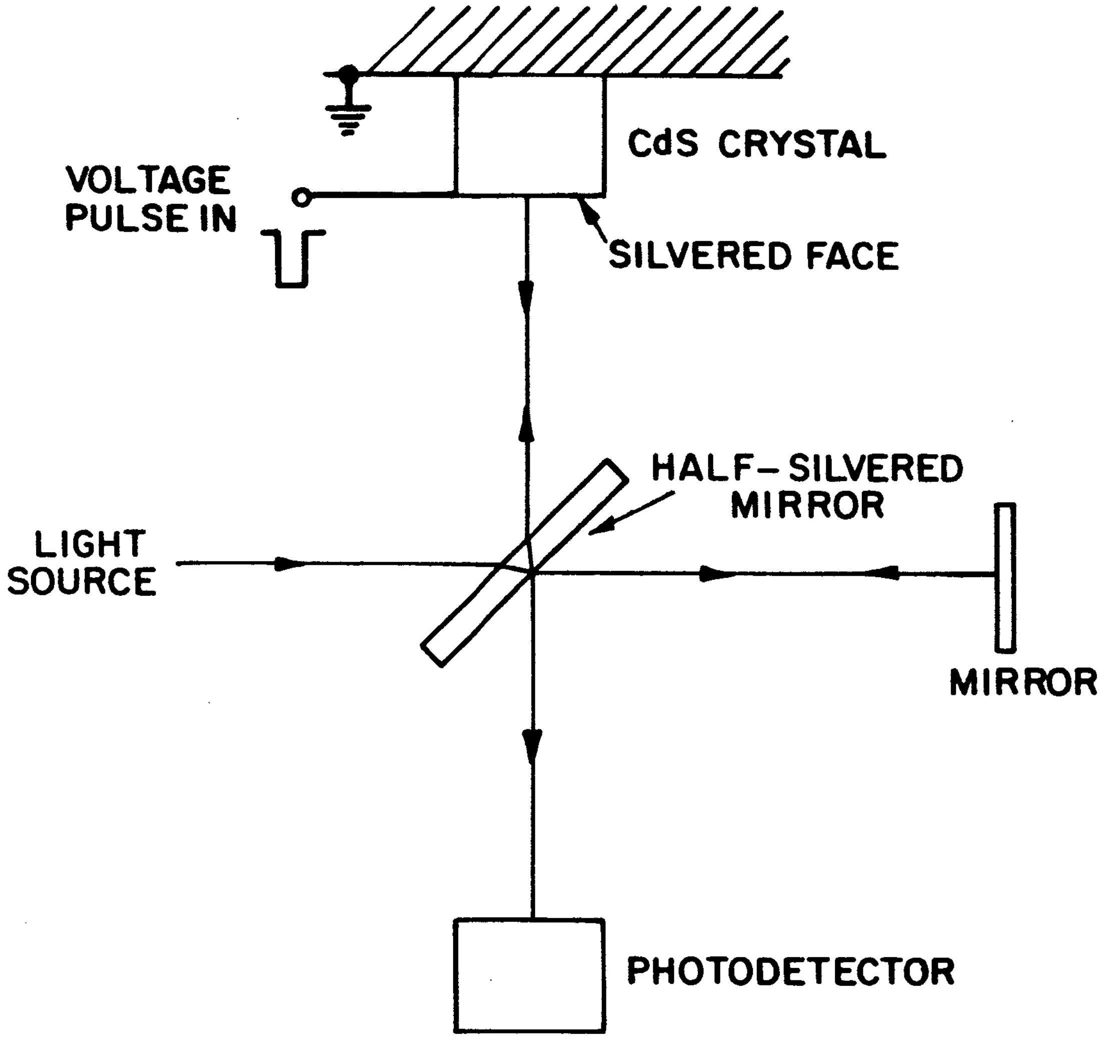


Fig. 4. Proposed acoustic detector based on the Michelson interferometer.

and tuned amplifier. This method is applicable, however, only for acoustic vibrations below about 100 Mc/sec since the vibration amplitude decreases with frequency for a given amount of power input. From preliminary calculations, it seems probable that such a device should permit investigations of the acoustic noise spectrum up to at least 100 Mc/sec and give a reliable check on the electrical noise spectrum measurements.

For frequencies above 1 Gc/sec, there is considerable promise in the investigation of light scattered by the crystal. If light at frequency f_0 interacts with a phonon of frequency f_1 then frequencies $f_0 \pm f_1$ will be present in the scattered light. Normally, f_1 is very much smaller than f_0 and the effect is negligible. But if $f_1 \sim 100$ Gc/sec, it may be possible to detect these frequencies. Suppose the wavelength of the light is 6000 Å (i.e., $f_0 = 5 \times 10^{14}$ cps). Then a difference in frequency of 100 Gc/sec corresponds to a difference in wavelength of about 1 Å. This can be easily detected using a Fabry-Perot interferometer to analyze the scattered light. Thus, if a continuum of phonon frequencies is present we would expect to see the effect as a broadening or division of the optical linewidth. It remains to be determined whether the amount of light scattered will be too small for exposure times to be practical, bearing in mind the low pulse-repetition frequencies and short pulse lengths which have to be used to avoid heating the crystals.

SUMMARY

So far there is no direct evidence that either the White or Prohofsky explanations of current saturation is valid. Prohofsky's theory does, however, predict the slope of the V-I characteristic above the knee with good accuracy. But in neither case is there evidence of excessive electron or phonon activity in the frequency ranges predicted. Interestingly, all our measurements consistently point to yet another range of lower frequencies as being of greatest importance.

III. LOW-FREQUENCY OSCILLATIONS

These have been described at length in previous reports under this contract. In this report, we record the observation of a new mode of oscillation in a crystal which may lead to a better qualitative understanding of the current saturation phenomenon. A mathematical model, based on the "Monotron" effect, was set up. We have also shown that thermal avalanching is not the cause of the oscillations.

A. A NEW TYPE OF LOW-FREQUENCY OSCILLATION

We report here experimental findings which indicate that the "Monotron" computations for a short crystal mentioned in Appendix A of our last report are relevant and may, when extended, be able to account for the low-frequency current oscillations.

At 44 Mc/sec, the acoustic wavelength in CdS is 0.1 mm. To investigate the behavior of a short crystal, two slices, 5 and 10 wavelengths long, were cut from a crystal of photoconducting CdS and transducers were bonded to them. Both crystals oscillated near the frequency of their lowest acoustic modes (i.e., 2.2 Mc/sec and 4.4 Mc/sec, respectively), and the transducers enabled us to investigate the acoustic waves in the crystals. (The oscillation prevented ordinary amplification.) The data for the shorter crystal are shown in Fig. 5.

This shorter crystal oscillated near its acoustic resonant frequency (4.4 Mc/sec), but the voltage applied to the crystal could change the frequency slightly. This frequency-pulling is shown in Fig. 6. Eventually, when too high a voltage was applied, the oscillations became unstable, as seen in Fig. 5b. However, at a rather higher voltage, it was seen that the oscillations went into a second stable mode, although the voltage was critical, as shown in Fig. 5c and by the isolated point in Fig. 6.

This behavior is very reminiscent of the "Monotron", where two modes of oscillations are possible at widely spaced voltages, and suggests that the computation in Appendix A (Quarterly Report No. 3) is indeed relevant, although not yet complete. In the larger 1.0-mm crystal, similar behavior occurred, except that the frequency was lower, and the high-voltage mode of oscillation could not be distinguished. However, in this case, the transducer

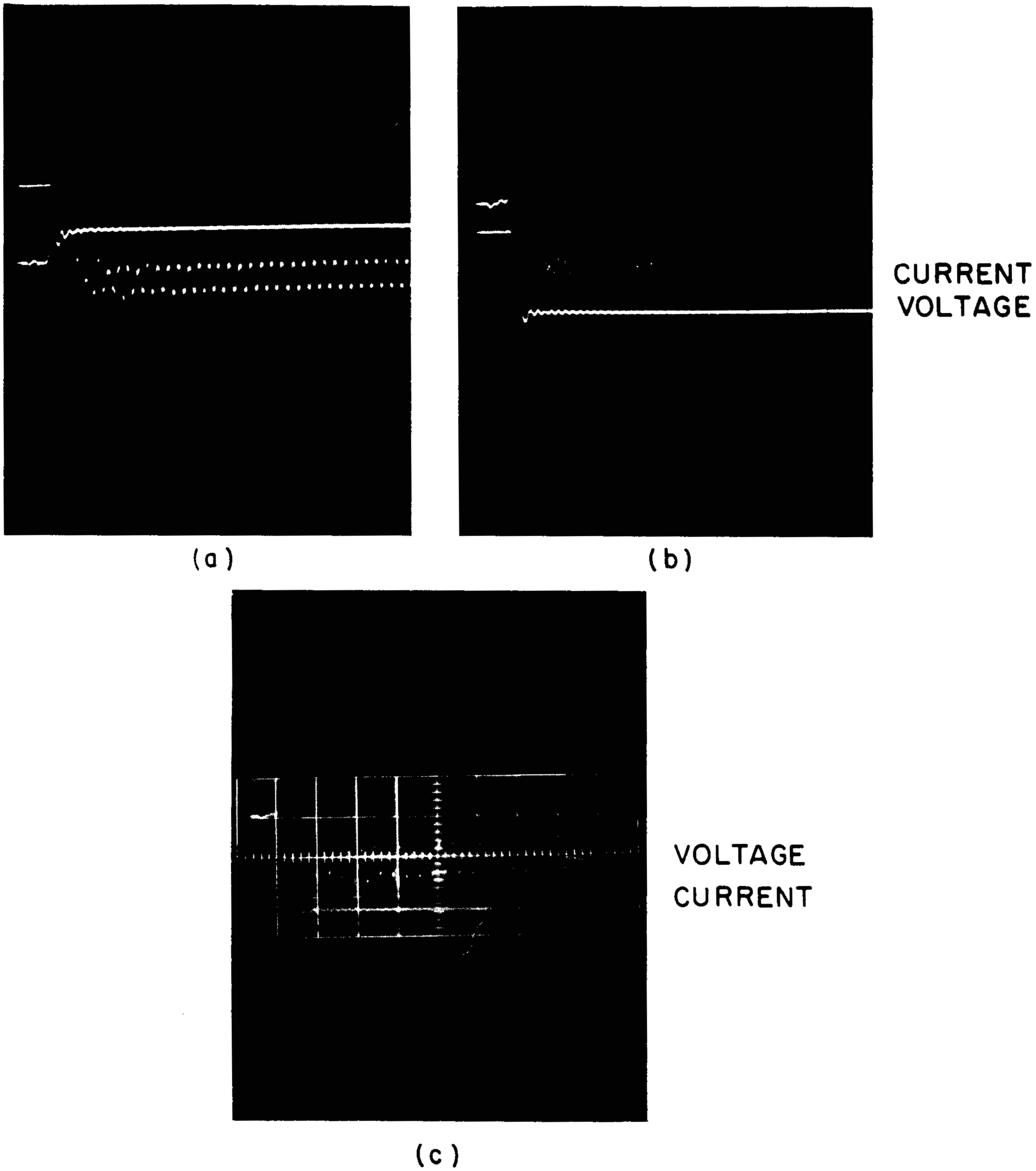


Fig. 5. Current oscillations in 0.5-mm-thick photoconductive crystal.

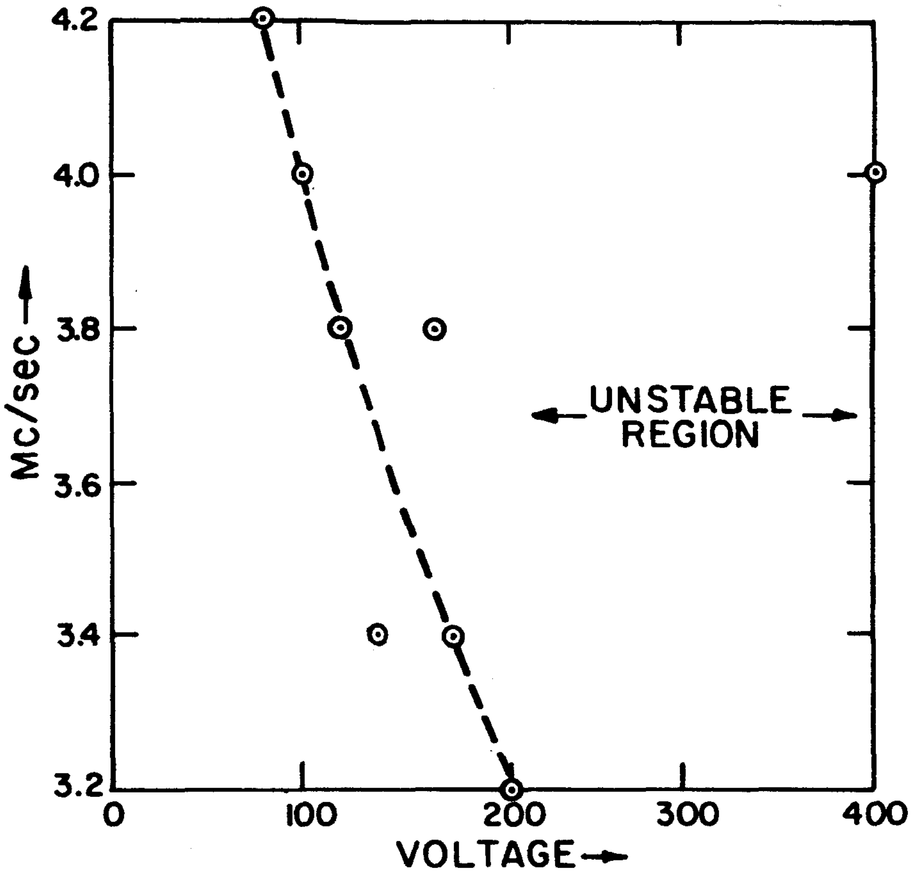


Fig. 6. Dependence of voltage and frequency for oscillations in the 0.5-mm crystal.

output was very different from the current output (see Fig. 7). It appears that the current oscillations are related to the higher-frequency acoustic oscillation; i.e., the envelope frequency in the acoustic oscillation (upper trace) is the same as the base frequency of the current oscillation.

These results may help us to understand the transition from stable oscillation in a short crystal, to incoherent, unstable oscillations in longer crystals. However, a linear theory is unlikely to do more than explain the oscillations in a short crystal. A nonlinear theory would be needed to explain the "squegging"* in the 1-mm-thick crystal (Fig. 7).

* "Squegging" is a phenomenon which occurs in a tube oscillator when too much feedback is used. It can cause the generation of several frequencies simultaneously, or, as the feedback is increased further, cause the oscillator to stop after only one or two cycles. (This latter case is also known as "blocking".) The transducer waveform in Fig. 7 is very like that produced by a squegging oscillator, and we use the term descriptively without assuming anything about the cause of the oscillation in Fig. 7.

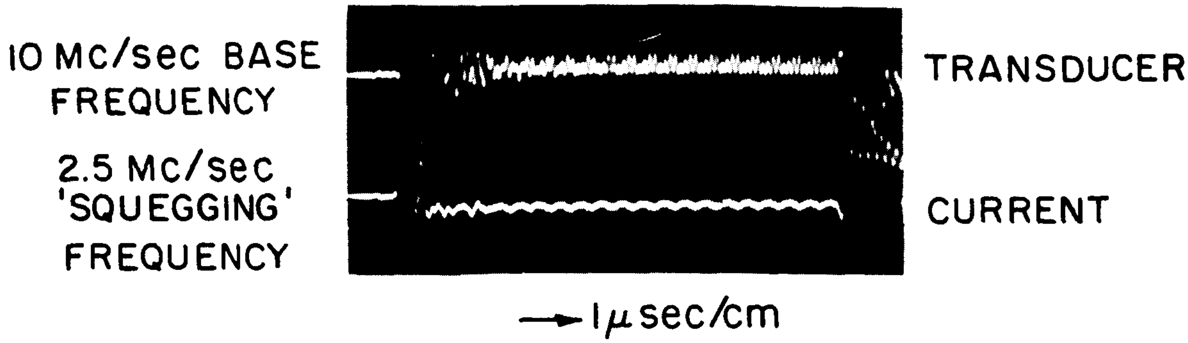


Fig. 7. Transducer output during current oscillations in 1.0-mm-thick crystal.

With these results, and those already established, a pattern is appearing. Coherent oscillations can only be obtained when the crystal is less than a millimeter or so long. If the crystal is, say, 4 mm long, only noise is produced, and the noise level appears to increase with the length of the crystal. Our observations in Fig. 7 fill in the gap between the coherent short-crystal oscillations of Fig. 5 and the noisy oscillations of long crystals,[12] and give us some idea of the physical process involved. These may be a mixture of "White" amplification plus a limiting or blocking process which causes "squegging" and prevents cw oscillations. The resistivity of the crystals was about 10,000 Ω-cm and this gives an $\omega_o = \left(\frac{\sigma}{\epsilon} \cdot \frac{v_D^2}{D_n}\right)^{1/2}$ of about 100 Mc/sec, for the frequency of maximum acoustic gain. Thus, conditions are not inappropriate for "White" amplification at 10 Mc/sec (as shown in Fig. 7), although a lower conductivity might have been better. Other samples have not yet shown the same behavior.

The most important result of these observations is that they seem to be the first example of a crystal trying to oscillate in a mode relying on "White" amplification. We have previously mentioned our concern that such oscillations have not been reported by other workers.

The coherence of Gunn oscillations in GaAs is also known to depend upon the length of the crystal. Gunn[13] notes that crystals longer than 0.2 mm produce only broadband noise over a band from a few megacycles to about 1 Gc/sec.

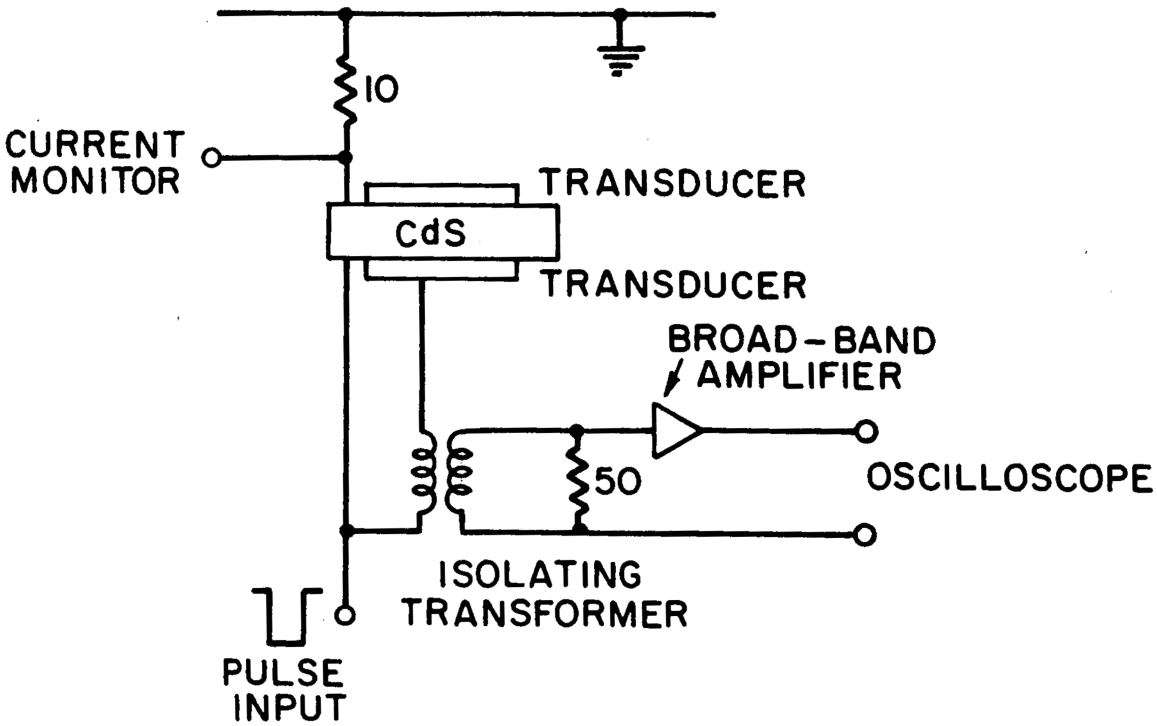
The experimental layout for the experiment described in this Section is shown in Fig. 8. (The crystals used were deliberately made as large as possible transversely in order that the one-dimensional theory should be a good approximation.)

B. ON THE POSSIBILITY OF A THERMAL INSTABILITY BEING THE CAUSE OF THE OSCILLATIONS

In general, crystals that oscillate show signs of damage near the positive electrode, where the electrons leave. Typical damage patterns are shown in Fig. 9. The cause of this is undetermined, but an attempt was made to develop a theory which would explain it in terms of thermal avalanching (i.e., local heating causing thermal excitation of electrons into the conduction band, leading to further heating, and so on). The specific heat of CdS is about 0.1 cal/gm°K, and with the type of heat dissipation that occurs in semiconducting crystals with 1-Ω-cm resistivity, temperature rises of the order of 1°K/μsec can be expected. If this heating can be localized by acoustic activity in the crystal, then possibly, higher rises would be expected, and in general the conductivity of semiconductors is temperature-sensitive. However, the high-purity crystals being used are found to be relatively unaffected by slight changes of temperature about 300°K. Most of the carriers are already in the conduction band, and no sharp changes of conductivity occur.

The localization of the heating by the acoustic activity was suggested by an effect from gas plasma physics. It is found that electrons tend to drift from regions of high rf electric field into weaker regions, (details are given in Appendix A of Quarterly Report No. 3, where the mathematics for a gas plasma is compared with that for a semiconductor). It was thought that such an effect in a semiconductor would tend to confine the electrons near the Ohmic contacts, where the rf fields are weakest, but where damage to the crystals is observed after they have been made to oscillate.

No confinement effect could be discovered in the mathematical analysis, however. This is a result which might be predicted from the collision domination of a semiconductor "plasma". The effect seen in a gaseous plasma is due to electron inertia in a collisionless system -- in a collision-dominated plasma such phenomena would not be expected. Nevertheless, at



(WITHOUT THE TRANSFORMER IT IS DIFFICULT TO OBSERVE BOTH THE CURRENT PULSE AND THE TRANSDUCER OUTPUT SIMULTANEOUSLY)

Fig. 8. Experimental layout.

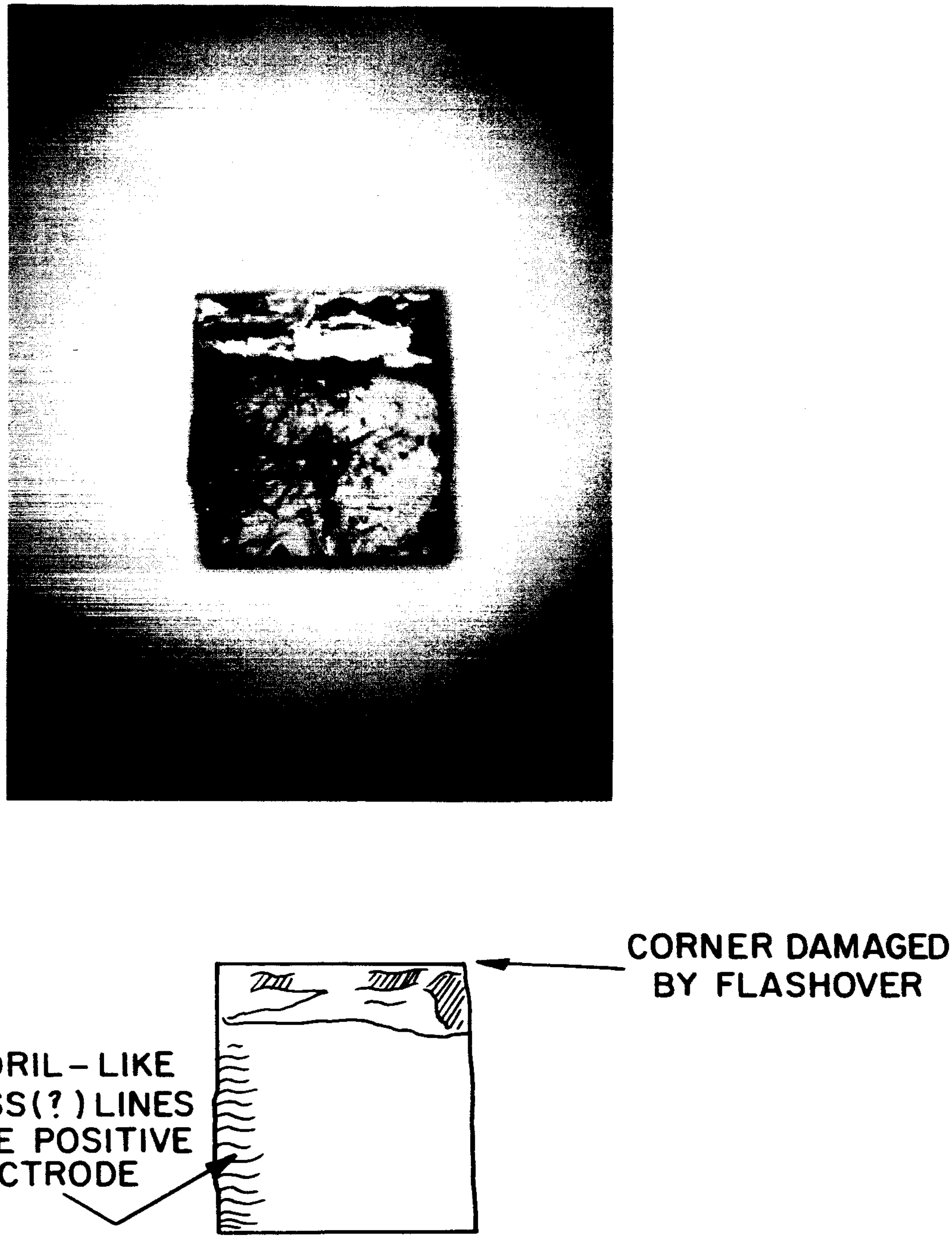


Fig. 9. Typical crystal damage.

high frequencies and low temperatures, some semiconductors begin to approach the properties of a dense gas plasma, e.g., InSb, and in this case an effect might be seen, but for the present work it can be disregarded. As far as InSb is concerned, it is becoming less certain that the oscillations seen (e.g., by R. Larrabee; see our previous Report) are related to these in CdS or GaAs. This is suggested by the greater ease with which rf power can be coupled out of InSb, implying that the oscillations have a longer wavelength in the InSb than an acoustic wavelength.

C. ON THE "MONOTRON" MODEL

In Appendix A of the third quarterly report we gave a formal solution of the problem of the rf impedance of a piezoelectric crystal with bias applied to it. It was clear that an analytical solution was difficult, but we have since persisted in trying to obtain such a solution since computer results are hard to interpret with so many independent parameters.

Qualitatively, we felt that the low-frequency oscillations could be considered as being similar in nature to those of the "Monotron," and the two modes of oscillation which we have reported above in a CdS crystal have added to this conviction. Since this work was done, Kikuchi[14] has reported two modes of oscillation in a crystal of cadmium selenide, although under conditions of nonuniform illumination. Kikuchi's paper does not attempt an explanation and is not too detailed on some of the experiments. Nevertheless, it seems likely that the basic mechanism is the same in both cases. The physical constants of CdSe are very similar to those of CdS.

At the moment, the correct combination of crystal parameters necessary to produce oscillations is not fully known, and so we were probably fortunate in having been able to observe the second mode. But this sort of observation, together with the noise spectra measurements, suggests that the low-frequency oscillations may be more fundamental to the current-saturation effect than had previously been believed.

IV. RF MEASUREMENTS

Measurements of the rf spectrum of CdS in a coaxial cable have been continued. Several additional crystals have been examined. As reported in the Quarterly Report No. 3, the signal from ~ 30 Mc/sec to ~ 1.2 Gc/sec falls off with increasing frequency. Measurement below 30 Mc/sec is more difficult and the uncertainties are greater. However, there is strong evidence that the signal from ~ 30 Mc/sec down to ~ 5 Mc/sec either levels or falls. Figure 10 shows some of the data.

This rf spectrum is not what would be expected from linear (Hutson-White[2]) amplifier theory. But there is some evidence from other work that the above results are not unexpected when a different point of view is taken. If this is confirmed, the rf spectrum analysis may prove to be a useful adjunct to other physical measurements.

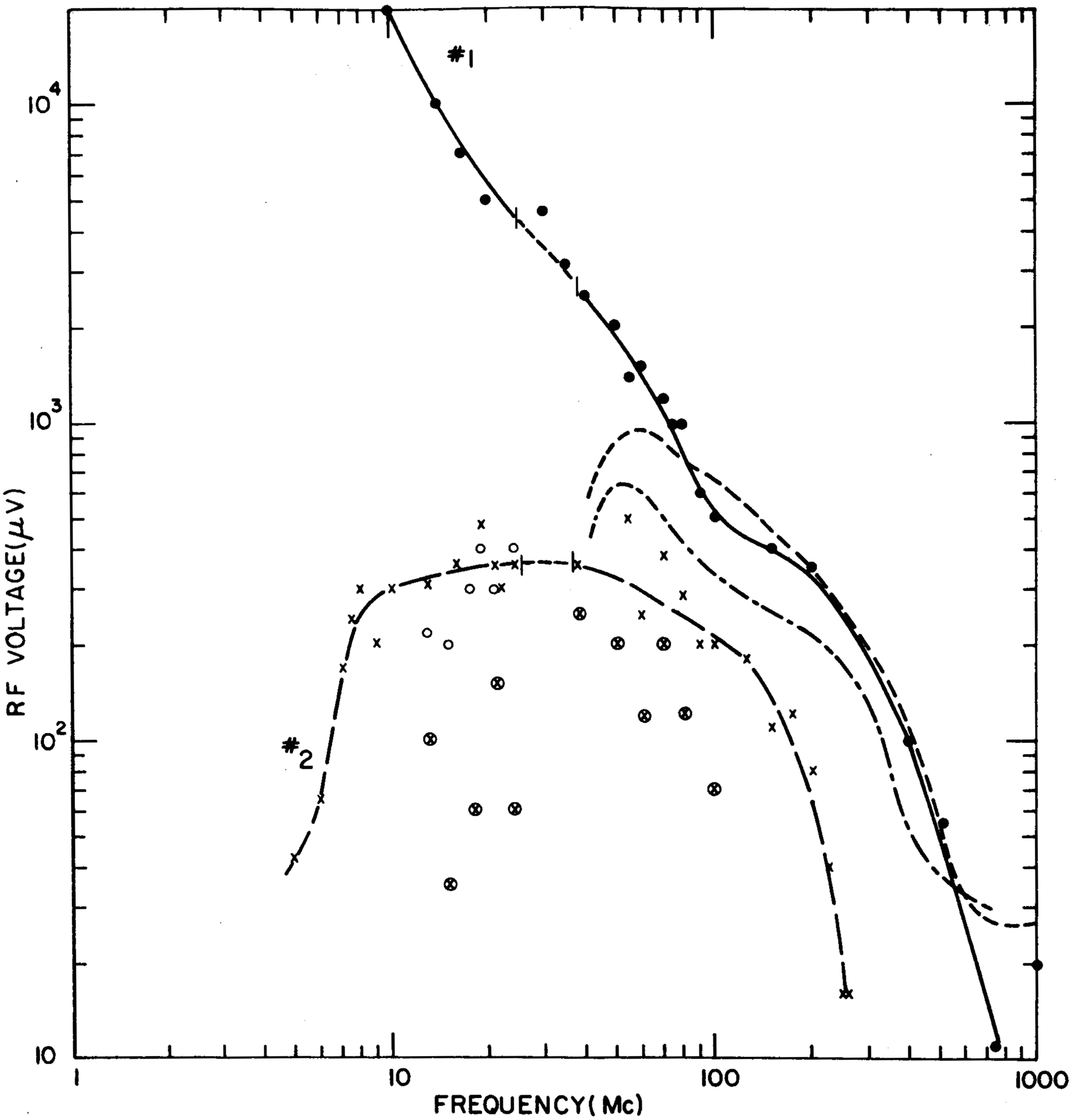


Fig. 10. RF spectrum of acousto-electrically active CdS.

V. OPTICAL MEASUREMENTS

In Quarterly Report No. 3 we briefly discussed the use of optical techniques as an alternate approach to the study of the strain induced in an acousto-electrically active CdS crystal. We pointed out then that negative results have been obtained in the experiments performed so far. Since the optical approach is attractive and potentially powerful, we have looked a little deeper into the physical bases of the various methods that could be used.

The experimental and analytical background goes back to the elegant work of Pockels et al. years ago.[15] Pockels showed the electro- and piezo-optical effects in crystals could be simply expressed by a system of equations, which essentially describe how the index ellipsoid of the solid responds to electric fields and stress tensors. The distortion of the ellipsoid is given by a number of coefficients whose value depends on the symmetry of the crystal among other things.

Although the theory does not predict the magnitude of the coefficients, it does make general statements which can be most useful in thinking about the best crystallographic direction to look and also the best experimental technique to use. For example, suppose polarized light is to be used. Then the two parameters describing the change in state of polarization resulting from an electric field or a mechanical stress are the ellipticity and the azimuth of the polarized light. A simple crossed polarizer-analyzer system alone cannot detect a change in ellipticity. Hence, this simple scheme should not be used where only a change in ellipticity is predicted.

By going through the system of Pockels' equations, a table can be drawn up, indicating the best direction along the crystal to look and can give a good lead to the best experimental technique to use.

We have gone through some of this and now have a better feeling why our previous experiments did not work, and, furthermore, we have some new ideas for experiments that appear to have a very good chance of showing visually what is going on in the crystal and even a good chance of getting some quantitative data from it.

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