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Photoconductivity in Gold-Germanium Alloys

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Photoconductivity has been observed at 77°K and 22°K in *n*- and *p*-type gold-doped germanium. The low-energy thresholds for impurity photoconduction are compatible with the activation energies found by conventional electrical measurements. Quenching effects were found in some *n*-type samples. Prominent quench bands were found at 0.8 and 0.66 ev. The characteristics of the quenching were observed as a function of light intensity, applied voltage and temperature. An interpretation of the quenching data in terms of a hole trap model is suggested.

INTRODUCTION

THE investigations of Dunlap[1] have shown that gold acts as an electron acceptor in germanium. On the basis of his resistivity and Hall data, he suggests a model in which each gold atom is capable of accepting one or two electrons. The first excess electron is bound in a state which is 0.15 ev above the valence band, while the second electron is bound with an energy which is 0.2 ev below the conduction band. These energies are such that if the number of gold atoms is greater than half the excess of normal donors over normal acceptors, so that all the normal donor levels are emptied, then the samples will be heavily deionized even at liquid N_2 temperature. Dunlap's model suggested that a study of the infrared photoconductive response of gold-doped germanium might be of interest in that confirmatory evidence for the proposed energy level scheme might be forthcoming. This proved to be the case.[2] In addition, a "quenching" of the photoconductivity was observed. The latter was of interest in that it offered an opportunity for greater insight into quenching phenomena in general in a material for which the energy level scheme and impurity content is under much better control than for conventional photoconductive materials such as CdS.[3]

EXPERIMENTAL

Samples of gold-doped germanium were obtained from W. C. Dunlap, Jr., in the form of small bars averaging about 3×3×10 mm. These were cut from the original ingots in such a way as to attempt to maximize sample homogeneity. In some cases, the samples were those used for Hall and resistivity measurements. In most cases, the sample resistance exceeded 10 megohms at 77°K, although some measurements were made with low resistance samples as well. For *n*-type samples contacts were soldered variously of tin, or alloys of either gold-antimony or indium-arsenic. Tin or indium were used for *p*-type samples. Samples were glued to a special copper block with a calorimeter adhesive. Electrical insulation between the block and the sample was assured by a layer of "Formex" enamel baked on to the block. The assembly was inserted into a cavity of a cryostat fitted with NaCl windows.

Illumination from the exit port of the spectrometer was substantially uniform over the length of the samples. The contact regions were shielded from direct radiation in some runs and not in others. No important differences were found. Temperatures were measured by a Au, Co-Ag, Au thermocouple soldered to one contact point of the sample. The measured temperatures probably represent the highest temperatures of the sample.

The photoconductive measurements were made in the usual way with a series circuit consisting of the sample, a load resistor, and a battery. The photocurrent was detected as a change of voltage across the load. Measurements were made as follows: (a) In dc light, an Applied Physics Corporation, "Vibrating Reed Electrometer" was used as a detecting voltmeter. (b) In chopped light (13 cycles), a Perkin-Elmer thermocouple amplifier with a high input impedance preamplifier was used in conjunction with a chart recorder. (c) For studies of transient effects, an oscilloscope with a direct coupled input was used.

A Perkin-Elmer monochromator was used with NaCl and CaF_2 prisms. The energy distribution of the globar radiation source was checked against a Perkin-Elmer thermocouple. Conventional methods were used to monitor the stray light response of the samples at longer wavelengths.

RESULTS

Normal Photoconduction

The normal photocurrents are linear in applied voltage and incident intensity at least over the range studied. Figures 1 and 2 show the photoconductive response of *n*- and *p*-type gold-doped germanium samples. The curves shown are typical of those found for four samples of each type derived from different ingots. The curves were obtained from chopped light

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[1] W. C. Dunlap, Jr., Phys. Rev. **91**, 1282 (1953).

[2] Results agreeing in part with those obtained here have been described by W. Kaiser and H. Y. Fan, Phys. Rev. **93**, 911(A) (1954).

[3] E. A. Taft and M. H. Hebb, J. Opt. Soc. Am. **42**, 249 (1952). This paper gives a detailed bibliography on quenching.

data. Curves obtained by dc techniques were essentially identical with those shown.

The structure in the vicinity of 0.35 to 0.4 ev is spurious and represents the combined effect of the absorption of the adhesive material on the back of the sample and to a lesser extent condensed contaminants (e.g., water vapor) on its front. The solid curves represent what is felt the true response should be.

The different curves shown in the figures were normalized by direct measurement of the dc photocurrents and the incident radiation power from the source at a photon energy of 0.5 ev. The run-to-run reproducibility of the reference value for a given sample was of order ±20 percent. Differences for a given sample presumably resulted from irreproducible geometry.

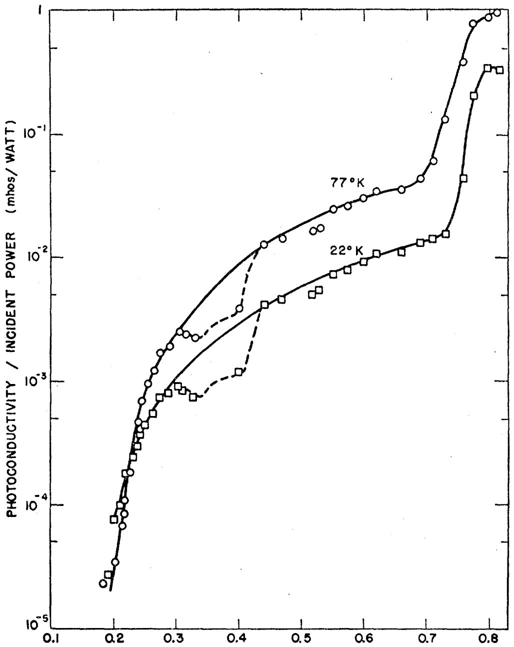

FIG. 1. Spectral response of the photoconductivity of n-type gold-doped germanium at 77°K and 22°K. Sample thickness 3 mm. Estimated $n_{\mathrm{Au}}=4\times10^{14}$/cc.

Evidence for a complexity in the photoconduction is found from a study of time constants. Figure 3a shows the pattern of photoconductive response for an n-type sample at ~22°K to a light on–light off cycle. Radiation well in the impurity range (0.35 ev) was used. Clearly two processes with widely differing time constants are involved here. The rapid response is best described by a constant of order 10^{-3} sec, the slow response by a constant of about 0.5 sec. At 77°K the same time constants are found for this sample, but at this temperature the major part (~90 percent) of the photoresponse is described by the rapid response. When quenching effects are also present, the response pattern gets very complex. Figure 3b shows such a pattern for the same sample when illuminated with 0.8-ev radiation. The quenching effects will be discussed at greater length below.

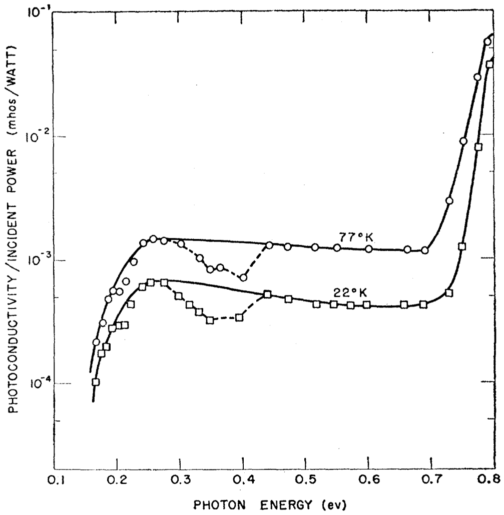

FIG. 2. Spectral response of the photoconductivity of p-type gold-doped germanium at 77°K and 22°K. Sample thickness 2.5 mm. Estimated $n_{\mathrm{Au}}=8\times10^{14}$/cc.

The complex response patterns were not found in all n-type samples. In some, no evidence was found for long response times except for quenching effects when these were present. Similarly, no long response times were found in any of the p-type samples studied. For the latter, decay times for the response to a pulse of light were of order 10^{-4} sec or less at 77°K, and about 10^{-3} sec at 22°K.

Quenching Effects

Early in the investigation it was found that quenching effects were present in the gold-doped samples. In

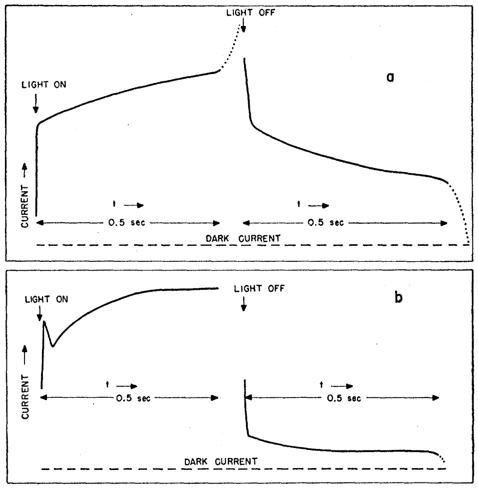

FIG. 3. A time-response pattern of an n-type sample at 22°K: (a) to 0.35-ev radiation; (b) to 0.80-ev radiation (from an oscillogram). The dotted sections result from nonlinearity in the sweep.

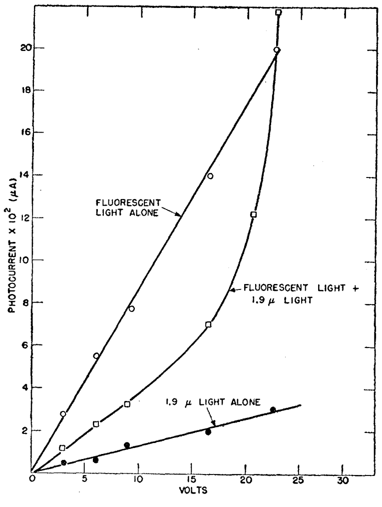

FIG. 4. Curve of dc photocurrent *vs* voltage for an *n*-type sample showing quenching; the effect of different modes of illumination are shown.

the usual definition, quenching is the effect by which a photocurrent and/or "dark" current through the specimen is reduced by illuminating the latter with another beam of light. Figure 4 illustrates the effect. It shows the steady-state photocurrent-voltage characteristic for a sample at 77°K when illuminated with a fluorescent lamp, when illuminated with 1.9μ radiation and when illuminated with the fluorescent light and the 1.9μ radiation. Parenthetically, it is worth noting that with the sample at 22°K under the same conditions of illumination, the quenching increased. The illustrated photocurrent could be decreased to about 10–20 percent of its initial value.

Figure 5a shows a typical cycle of response for a sample illuminated with quenching light. It is similar to other reported quench effects.[2] However, it has been observed that whether or not a sample shows a quench effect in the sense described above, depends upon the intensity of quench light and the voltage applied to the sample. This is partially illustrated in Fig. 5b, which shows that at a sufficiently high level of quench intensity, the steady-state photocurrent is positive relative to the background. To include such effects and to include examples of self quenching, the definition of quenching will be generalized by saying that it is exhibited by such samples which show, at some point in the "light-on" response, a negative derivative of conductivity with respect to time.

Figure 6a shows the spectral distribution of a system of quench bands for a particular sample. The figure shows the steady-state photocurrent relative to a photocurrent set by background light. The presence of a band at about 0.66 ev with an additional weaker effect extending to about 0.35 ev seems indicated. As there might be some question as to the shape of the high-energy side of the 0.66-ev band, an entirely different technique was used to observe the quench. Figure 6b shows the spectrum of the ratio, in percent, of the peak transient photocurrent (see Fig. 5b for definitions) minus steady-state photocurrent to the steady state photocurrent, a quantity termed percent "Quench," which should give a measure of the quenching effect. The measurements were made by an oscilloscopic technique. The monochromatic light level was adjusted so as to give the same steady-state photocurrent at each wavelength. It seems quite clear that a high-frequency limit for this quench does exist and that the major effect is properly defined in terms of a band centering at about 0.66 ev.

The spectrum illustrated in Fig. 6a, and in particular the 0.66-ev band, seem to be characteristic of *n*-type specimens for which the gold concentration is estimated to be less than about 1×10^{14} atoms/cc. In some cases, the 0.66-ev band is found without any other structure being observable. In one case, however, the prominent band was found at 0.54 ev with only a weak band at 0.66 ev. The quenching effect at 0.66 ev was found in samples cut from 5 ingots prepared to have the low gold concentration. It was not found in samples for which the estimated gold content exceeded this value. It was first thought that the appearance or nonappearance of these bands might be a sensitive function of the ratio of donor atoms to gold atoms but this seemed not to be the case. For it was found that a sample having the stipulated gold concentration, but for which the number of donors was slightly greater than the number of gold produced acceptor states, (i.e., low resistance at 77°K) showed a quench in the

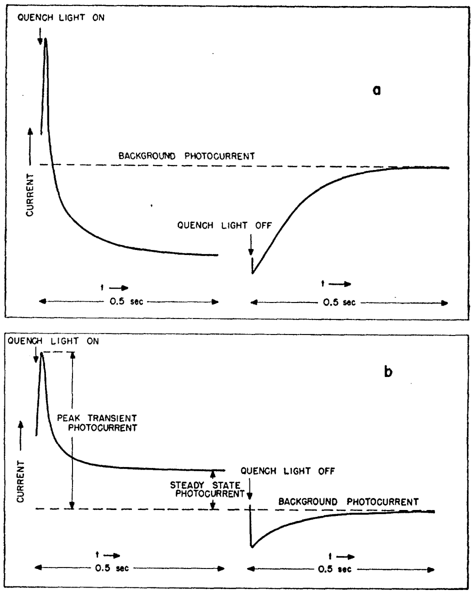

FIG. 5. A time-response pattern of a sample showing quenching when illuminated with quench light (1.9μ); the effect of different levels of quench intensity is shown in (a) and (b). The level in (b) is 3 times that in (a) (from an oscillogram).

same way as the high-resistance samples conventionally studied for which the ratio of the two concentrations is presumably reversed. It would, therefore, appear that the presence or absence of the 0.66-ev quench band is determined largely by the gold concentration.

In some *n*-type samples with gold concentrations higher than about 1×10^{14}, an example of self-quenching was observed. When light of appropriate wavelength in the fundamental region was turned on, the initial photocurrent decayed to a lower steady-state value. The curves observed with an oscilloscope resembled those of Fig. 5b. Since in this case, the radiation apparently produces an appropriate type of photocurrent as well as exciting the quenching, no additional background radiation source was required. Figure 7 shows spectral distributions of the percent "Quench" (defined above) for this quenching effect. Measurements, as in those displayed in Fig. 6b, were taken with the light level adjusted to give a fixed steady state photocurrent for each curve at all wavelengths. There appears to be a band centered at about 0.8 ev followed by a sort of continuum at energies higher than about 0.9 ev. The figure shows that the effect is decreased at increasing photoconductive levels. At a level about 5 times higher than the highest shown, no quenching was observable.

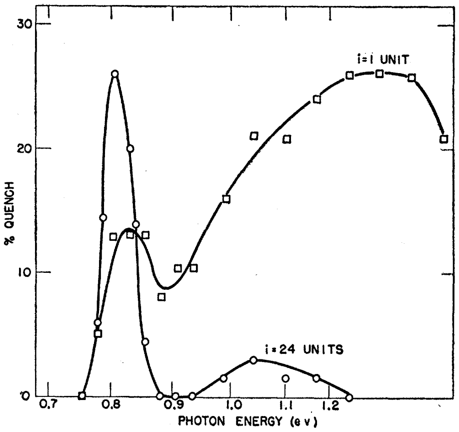

FIG. 7. Spectral response of an *n*-type sample showing self-quenching at 0.80 ev, using transient response as described in text. Effect of different levels of photocurrent (*i*) are shown.

In other *n*-type samples with high gold concentration, the band at 0.8 ev was present but the continuum was too weak to be effectively measured. However, in all cases for which the 0.8-ev band was present, the 0.66-ev band was absent and vice versa. It was of extreme interest to note the apparent existence of a band at an energy exceeding the forbidden gap in germanium. The situation here is complex in that for this energy the radiation is not uniformly absorbed. Consequently, the possibility exists that a purely surface effect is being observed. The effect seemed, however, independent of surface treatment in that for a given sample the effect was present with a ground surface and with an etched surface.

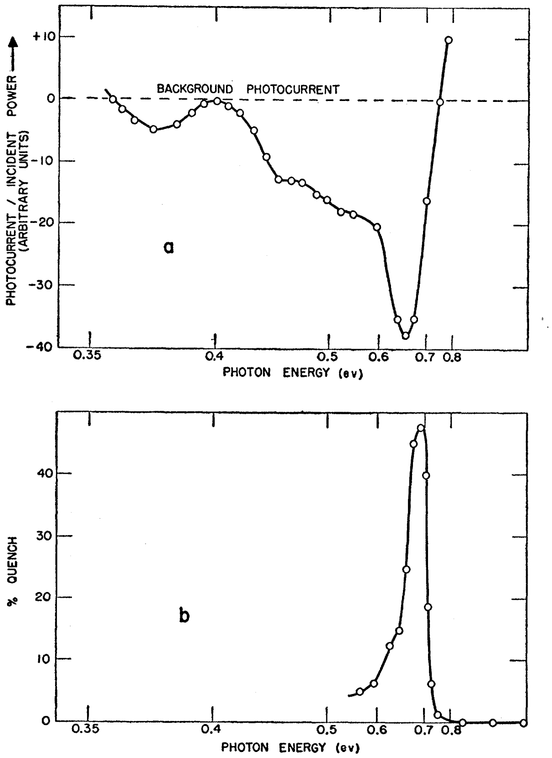

FIG. 6. Spectral response of an *n*-type sample showing a strong quenching at 0.66 ev: (a) measurement of dc steady state photocurrent relative to the background; (b) measurement using transients as described in text.

It was also worth noting that at 22°K several samples showed slight quenching at energies exceeding about 0.85 ev which showed no corresponding effect at 77°K.

As was mentioned above, whether a sample shows a negative steady-state photoconductivity (relative to the background) depends upon the voltage applied to the sample and the amount of quenching radiation impinging on it. This is illustrated by Fig. 8 which shows a series of curves relating total dc photocurrent produced by a fluorescent light plus the quench light (1.9μ) to the intensity of the latter and to the voltage.

The complexity of these curves can be reduced to a certain extent. The response to quenching light is the sum of a normal photoconductive component linear with respect to voltage and intensity and a quenching component. The voltage and intensity behavior of the normal component may be determined by observing the response of the sample in the absence of any background light. An example of the current-voltage characteristic for the normal component is shown in the curve marked "1.9μ light alone" in Fig. 4. This normal component can then be subtracted from the total effect observed with the quench light plus the background photocurrent employed. One can then, presumably, observe the effect of the quench component alone,

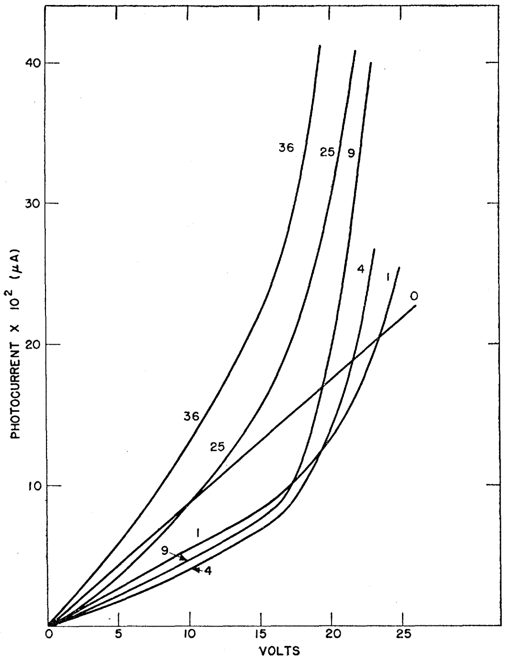

FIG. 8. Curves of dc photocurrent *vs* voltage for a constant level of background and different relative intensities of quench light (1.9μ) as indicated by the labels.

assuming that the two components are independent of one another. Data corrected in this way are shown in Figs. 9 and 10. Figure 9 shows the effect of the intensity of the quench component on different levels of background photocurrent. The ordinate, as in that of Fig. 10, is the total dc photocurrent minus the normal photocurrent produced by 1.9μ light at the same voltage and monochromatic light intensity. The apparent saturation of the quench effect with quenching intensity and the decreased fractional effect at higher background current levels are to be noted. Figure 10 shows the effect of different applied voltages on the quenching.

Ideally, the data of Figs. 9 and 10 should have been obtained with two monochromatized light beams. As this could not be readily arranged, a fluorescent lamp which has a negligible output in the quenching region was used as the exciting source. To insure that the effects were not surface phenomena, it was ascertained that essentially equivalent data were obtained when radiation reached the sample either directly or after passing through a germanium filter. Since only a limited range of background current could be obtained using a filter, the data of Fig. 9 were obtained without a filter.

The quenching process is characterized by a relatively slow decay of the photoconductivity from some peak value, when the quench light is turned on, down to a lower steady-state value. Similarly, when the quench light is turned off there is usually a negative dip followed by a slow rise to the conductivity set by the background. These transients seem describable as simple exponentials. The time constants at 22°K for a given sample for the two processes are illustrated in Fig. 11 as a function of the intensity of the quenching light (1.9μ). It is seen that the decay time in the quench light is a function of intensity whereas the recovery time in the "dark" (no quench light) is not. The "light on" decay time is also sensitive to the background level whereas the "dark" recovery time is not. For example, the former increased about a factor of two for a fourfold increase in background. It is also important to note that the dark recovery time, which seems a suitable descriptive parameter, only decreased by about a factor of two, in warming a sample from 22°K to 77°K. In some other samples "dark" recovery times of order 1 sec at 22°K were observed. The "dark" recovery time for samples showing the 0.8-ev quench were of order 0.1 to 0.5 sec at this temperature.

DISCUSSION

A satisfactory explanation of all the effects reported above, particularly those related to quenching, has not been forthcoming. However, it is felt that for heuristic purposes tentative hypotheses may be of value.

An analysis of the spectral dependence of normal photoconduction seems straightforward. The photoconductive response at photon energies, greater than about 0.7 ev, is, of course, the intrinsic photoconductivity. For the condition that (absorption coefficient)$^{-1}>$sample thickness, the response will be proportional to the absorption coefficient. The spectral shifts in the low energy tail of the intrinsic photoconduction with temperature, therefore, mirrors the corresponding change in the absorption coefficient.

At energies below about 0.7 ev, the impurity photo-

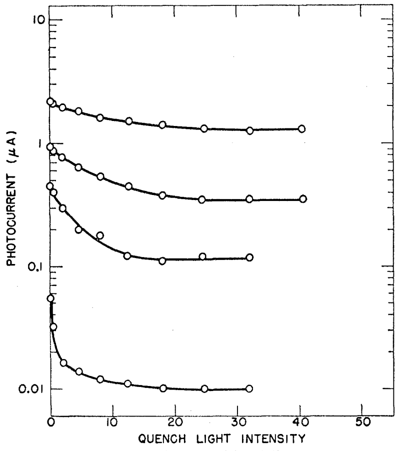

FIG. 9. Curves of dc photocurrent at a constant voltage (6 v) *versus* the intensity of quench light (1.9μ). The effects on different levels of background are shown. The effect of the normal component of response to the quench light has been subtracted (see text).

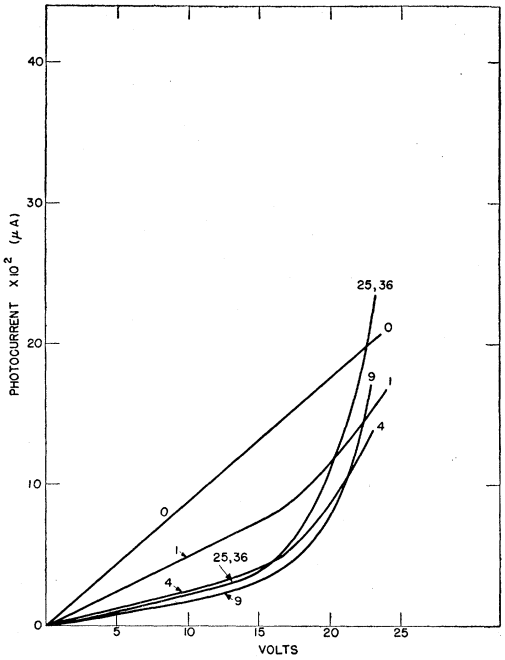

FIG. 10. Curves of dc photocurrent *vs* voltage at a given background level showing the effect of different relative intensities of quench light (1.9μ), as indicated by labels. The effect of the normal component of response to the quench light has been subtracted (see text).

conductivity is, presumably, dominant. Since the absorption coefficient, due to ionization of the impurity centers, may be estimated to be at most $10^{-1}-10^{-2}$ cm^{-1} (atom fraction$\times 10^6$), the photoresponse should give a measure of its spectral dependence.

Our results indicate a different spectral response for *n*- and *p*-type gold doped samples. Using Dunlap's model, it might be expected that the response of *p*-type samples would be simplest to understand. For the process in this case should involve only the ionization of a hole from the impurity center with a threshold at about 0.15 ev. This seems borne out by the data. The form of the curve is of the type expected for a simple ionization process. That is, as the energy decreases, the response should slowly rise to a maximum and then sharply fall off as the ionization limit is reached. There is an uncertainty in the point at which the ionization limit should be defined. By analogy to the intrinsic case, a point where the response is 10^{-3} of peak might be arbitrarily chosen. Extrapolating our data, it is found that this corresponds to an energy of 0.13 ev. The response at 0.15 ev, the thermal activation energy, is about 10^{-2} of peak.

In the impurity region, the photoconductivity data taken at 77°K and at 22°K for a given sample differ only by a constant scale factor (3 for the data shown). This factor will reflect the changes in carrier lifetime and mobility with temperature. For the accuracy of our data, the shape of the photoconductive curves do not change in the 77°K–22°K interval. If a model employing a Coulombic potential is applicable, this is not surprising since the energy levels will only involve the dielectric constant as a variable. On this basis it would probably require at least a 2 percent change in dielectric constant or in turn approximately a 1 percent change in specific volume to observe a temperature effect.

Returning to Dunlap's model, one might expect that the response of *n*-type samples might be more complex. Here at least two ionization processes are possible. First, ionization of impurities which have but one excess electron and second, ionization of the second excess electron of impurities having two excess electrons. The form of the *n*-type response is perhaps suggestive of a superposition of two photoconductive spectra. In any event, the lowest energy threshold is compatible with the thermal activation energy reported by Dunlap. That is, a point about 10^{-3} down from the slowly changing section of the curve corresponds to an energy of 0.20 ev.

Conventional theories of quenching[3,4] (e.g. for the sulfides) center about the concept of a trapped hole which is freed by the quench light and subsequently recombines with a conduction electron to reduce the conductivity. It is presumed that the probability of recombination of a trapped hole and a free electron is small.

This theory has attractive possibilities for the present case. (The subsequent discussion will refer largely to measurements made on the 0.66-ev quenching effect.) In the dark the hole concentration and hence the concentration of trapped holes must be small in the *n*-type samples and little or no quenching is actually observed. The effect of background light is to increase the number of electrons in the conduction band and the number of free and trapped holes. If now the function of the quench light is to empty the hole traps,

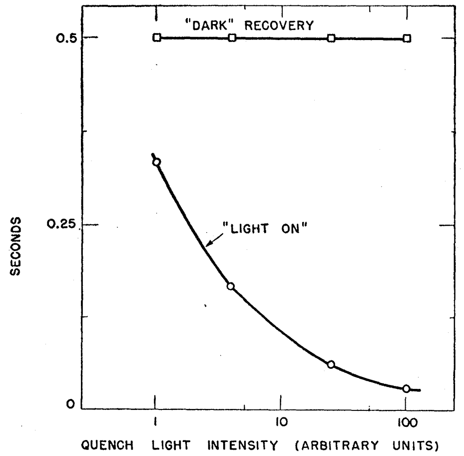

FIG. 11. Time constants for quenching at 22°K as a function of quench light intensity.

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[4] A. Rose, RCA Rev. **12**, 362 (1951).

than at the steady state there will be fewer uncombined electrons and holes and the background photocurrent will be quenched. (The argument could probably be reversed regarding holes and electrons except for the fact that quenching has been found for *n*-type samples having low resistance at 77°K which probably implies that any trap which was deep enough to be effective for this mechanism would already be saturated.)

If the procedure for dividing the effect of the quench light into normal and quench components is valid, then further evidence for the hypothesis is forthcoming. Presumably, the number of hole traps is a constant for a sample. It then seems reasonable that the quenching effect should saturate with increasing quenching intensity for a given background photocurrent. At a quench light level determined by the background, effectively all the traps will be emptied and no further changes in conductivity will occur. Similarly, a saturation should occur with respect to the background photoconductivity. That is, since the total number of hole traps is fixed, an upper limit should exist to the amount of conductivity that can be quenched; the fraction of the total conductivity that can be quenched should decrease with increasing conductivity. Also, at least at low background levels, the intensity of quench light necessary to produce a given fractional effect should increase more or less linearly with the background. Effects in qualitative agreement with these predictions are indicated by the data of Fig. 9.

We have no explanation to offer for the voltage characteristics of the quench curves. By the simple theory discussed above, the current-voltage characteristic should be linear. The fact that the characteristic for normal photocurrents is linear would seem to rule out the effects of contacts or inhomogeneities as the origin of the nonlinearity of the quenched photocurrents. The data suggest a decreasing efficiency for the quench process with increasing voltage.

If the hole trap mechanism is correct, one is faced with the problem of determining the nature of the traps. The striking thing about the spectrum of quenching is, of course, the presence of well defined bands. This would suggest that the optical transitions involved are "line to line" with some subsequent process communicating the effect to the continuous electronic states of the germanium. The insensitivity of the time constant to temperature (in the 22°K to 77°K range) would seem to rule out thermal activation from a discrete level to a continuous band as the time-limiting "subsequent process."

Without specifying a mechanism in detail, one can set up a model in which the discrete spectrum, and the effects of quench light intensity and background light intensity on time constant can be included. Suppose, for simplicity, that H holes produced by background radiation be trapped. Suppose further that the hole trap has a ground state occupied by h trapped holes and an excited state occupied by h' trapped holes. If the optical transition between them is allowed, then equilibrium between the states will be rapidly reached in any given radiation field. Suppose further that in the excited state the hole can ionize (perhaps by a multistep process) to a state p which can subsequently rapidly recombine with an electron. We assume that the process of ionization is the rate determining step.

Now, just after the quench light is turned on, since the $h' \leftrightarrows h$ equilibrium is rapidly established and the $h' \rightleftarrows p$ equilibrium is not, one can show that

$$h' = HB\rho/(2B\rho + A),$$

where B is an appropriate Einstein radiation constant, ρ the radiation density, and A a term which is the Einstein A plus a term describing any radiationless transition between h and h'. Similarly, under the aforementioned restrictions, the initial rate for the production of free holes will be of the form

$$dp/dt = k_{h'\rightarrow p}(h') + k_{\text{thermal}} + k_{\text{optical}}I - k_{p\rightarrow h'}(p) - p/\tau,$$

where the k's represent rate constants for the processes indicated in the subscripts, I is the intensity of background light and τ is the recombination lifetime. Substituting the expression for h' and assuming I large enough so that $p \sim k_{\text{opt}} I \tau$, in the absence of quench light, one then gets

$$\frac{dp}{dt} = k_{h'\rightarrow p}\left(\frac{HB\rho}{2B\rho + A}\right) - k_{\text{optical}} I \tau k_{p\rightarrow h'}.$$

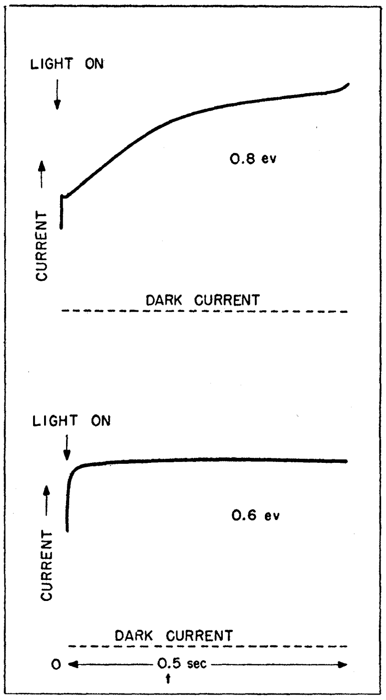

FIG. 12. Time dependence of response at 77°K of a sample showing quenching to 0.6-ev and 0.8-ev radiation. No background light present (from an oscillogram).

By the model, the rate of production of free holes is the rate of the quenching process. The above then indicates that the initial rate of quenching would show a linear increase with the intensity of quench light at low levels. Similarly, it should show a decrease with increased background level. Although no detailed confidence is placed in the model, it is of interest to note that the "light on" time constant curve of Fig. 11 resembles the predictions of the model at least at low quench intensities. Likewise, the "light on" time constant was observed to increase with background level. The time constant for recovery in the "dark" would be determined by the rate of the $p \rightarrow h'$ process, which should be independent of the previous quench light intensity.

A consequence of the hole trap model is that to the extent that the traps are involved, the fundamental photoconductivity should show long time constants identical with "dark" recovery times corresponding to the rate for trapping of free holes. On the other hand, for impurity photoconduction in the same sample, the long time effects need not be present. Figure 12 gives some confirmation of this view. It shows the "light on" response for a sample which exhibits quenching when illuminated with light in the fundamental region (0.8 ev) and when illuminated in the impurity region (0.6 ev), without any other radiation source present. Since the complete light on–light off cycle for the fundamental photoconduction does not show complete symmetry, presumably, some effects are involved which are even more complex than those discussed here. However, the major point seems to be established.

If a trapping process is involved in the quenching effect, the precise origin and nature of these traps remains unspecified. It is, for example, not completely established that the quenching explicitly involves the added gold. However, subsequent to the measurements described here, cases have been found where the interrelationships between quenching and trapping effects are more clearly brought out. The quenching spectra in these cases differ for that found for the gold and seem specific to the doping materials. The work will be presented in the near future.

It is a pleasure to acknowledge the assistance at various times of E. A. Taft. W. C. Dunlap, Jr., and L. Apker performed as sympathetic sounding boards for the author's ideas as well as offering many of their own. I am grateful to Professor Harvey Brooks for his criticism of this manuscript.

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High-Frequency Resistance of Thin Films*

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Measurements of high-frequency (hf) resistance of thin films have been performed. It is shown that the relatively small decrease of resistance with frequency occurring for uniform resistance is due to self-capacitance; the simple transmission line theory of this effect, originally presented by Howe, is incorrect. Additional decrease of hf resistance beyond that due to self-capacitance has been found to be due to the presence of nonuniform regions in the resistor and not to the presence of intercrystallite barriers in the frequency range considered. Properly interpreted, hf measurements can give information concerning the presence of gross inhomogeneities in films.

I. INTRODUCTION

When a resistor is subjected to alternating current, the value of resistance decreases as the frequency increases. Several theories have been proposed to explain this behavior, but none has been satisfactory.

The extensive use of photoconductive cells in recent years and the search for a mechanism of photoconductivity in these cells has led to renewed activity in high-frequency (hf) measurements. The results of these measurements in cells have been used by many observers to substantiate their theories of photoconductive behavior; again there has been considerable disagreement concerning the significance of experimental results.

Hence it seems desirable to examine critically past data in order to obtain a mechanism that will explain observed results and to obtain information about the nature of thin conducting films.

The earliest reported investigations on high-frequency measurements of resistors were those of Boella[1] in Italy who observed additional high-frequency conductance

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[1] Mario Boella, Alta Frequenza 3, No. 2 (April, 1934).