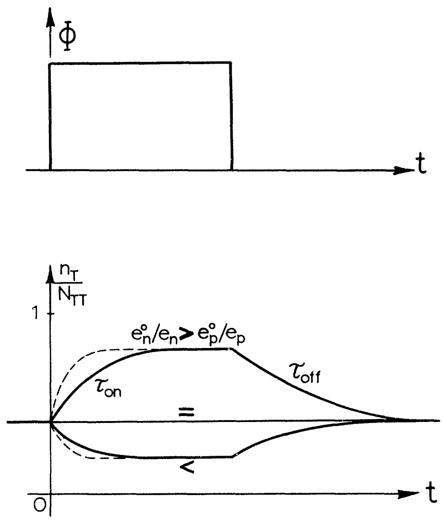

FIG. 2. The chopped-light photon flux (upper figure) and the transient response of the trapped electron concentration, $n_T(t)$, for the three conditions $e_n{}^o/e_n$ greater than, equal to, or less than $e_p{}^o/e_p$. The dashed curves are for a higher light intensity or photon flux.

and e_p+c_pp, respectively, which become spatially dependent.

The solution just obtained shows the following possible experiments on the determination of the parameters of the defect or impurity centers. (1) τ_{off} versus temperature provides σ_n, σ_p, E_T-E_V, and E_C-E_T or E_G. (2) $\tau_{on}{}^{-1}-\tau_{off}{}^{-1}$ versus temperature and photon energy gives the temperature and photon-frequency dependences[5] of the photo cross sections, $\sigma_n{}^O(T,\omega)$ and $\sigma_p{}^O(T,\omega)$. In addition, it provides the data of the photocurrent threshold which may be used to determine the optical-defect level, E_T-E_V or E_C-E_T or both, precisely. (3) By varying the dc reverse bias in a p-i-n structure where the depletion layer width W is independent of voltage, the cross sections may be obtained as a function of the electric field strength. Since the photocurrent is independent of surface leakage, the surface would have little effect on the results.

There are a number of obvious applications of the impurity photovoltaic effect for light-intensity modulation (varying W by modulating the applied junction voltage) and for light detection. In the following Letter, some experimental results are presented to illustrate this effect.

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*Work supported in part by the Advanced Research Projects Agency under Contract No. SD-131, and the U. S. Air Force Office of Scientific Research under Contract No. AF-AFOSR-714-67.

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RECOMBINATION PROPERTIES OF THE GOLD ACCEPTOR LEVEL IN SILICON USING THE IMPURITY PHOTOVOLTAIC EFFECT*

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(Received 29 May 1967)

The method proposed in the preceding Letter[1] is demonstrated in several experiments described below using the gold acceptor level in silicon which is located at $E_C-E_T=0.55$ eV or $E_T-E_V=0.57$ eV in the band gap.[2] This is the only active level in the depletion region of the p-n junction due to the relative values of electron and hole emission rates,[3] although it is well known that the gold impurity also has a donor level located below the midgap

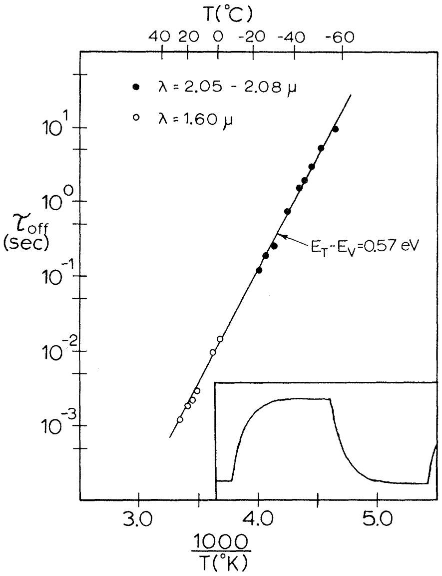

FIG. 1. The measured decay time constant as a function of inverse temperature. The insert shows the observed photocurrent that results when mechanically chopped monochromatic light is incident on the junction.

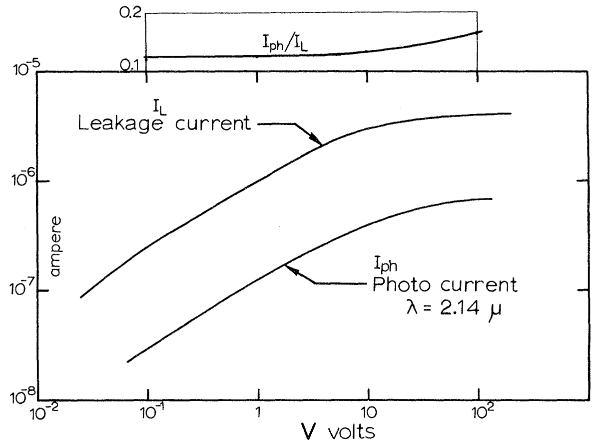

FIG. 2. Leakage current and photocurrent as a function of reverse-bias voltage. The curve at the top of the figure shows the ratio of the two as a function of the reverse-bias voltage.

point at $E_T-E_V=0.35$ eV or $E_C-E_T=0.77$ eV. The two-level or three-charge-condition property of gold centers in silicon offers additional experimentations using the photovoltaic effect which will be described in a subsequent communication.

Diffused and oxide-passivated silicon p^+-n junctions are fabricated with several levels of gold concentration controlled by diffusion at various temperatures to its solid solubility.[4] This is not a critical parameter as we have indicated in the theory, since N_{TT} affects only the magnitude of the photocurrent but not its time dependence. Mechanically chopped monochromatic light is directed to the top surface of the junction and the photocurrent is observed on the oscilloscope, which is shown in the insert of Fig. 1. The observed trace agrees in detail with the theory presented in the preceding Letter. It corresponds to the experimental condition of $e_n{}^o/e_n \gg e_p{}^o/e_p$. This is expected since $e_p \gg e_n$ for the gold acceptor level[3,5] from Fairfield and Gokhale's data using the photoconductivity method, even though the gold acceptor level is near the midgap position, which makes $e_n{}^o \sim e_p{}^o$. In addition, the light level is insufficiently intense to observe any difference of τ_{on} and τ_{off} in the photocurrent transient shown in Fig. 1.

The experiment is performed in a cryostat over a wide range of temperature below room temperature and the measured decay-time constant is plotted in Fig. 1, showing $E_T-E_V=0.57$ eV and σ_p (290°K) $=1.50\times10^{-14}$ cm^2. Since the energy level is sufficiently close to the midgap position and $\sigma_p \gg \sigma_n$ (about 14 at 290°K)[5], it is not possible to detect a change of the slope of the plot of τ_{off} vs $1/T$°K in Fig. 1; hence, σ_n cannot be determined. The cross section determined by the photoconductivity decay of Fairfield and Gokhale is 1.0×10^{-14} cm^2, while that of Bemski[6] is 1.0×10^{-15} cm^2.

In a second experiment, the dependence of the photocurrent on the depletion-layer width W is demonstrated. The photocurrent, the leakage current, and their ratio are plotted in Fig. 2 as a function of the reverse bias applied to the junction. This shows the expected constant ratio of the photo-to-static current over most of the reverse-bias range and the approximately $\sqrt{V}$ dependence of both the current components which conforms with $W \propto \sqrt{V}$ for a p^+-n abrupt junction.

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*Work supported in part by the Advanced Research Projects Agency under Contract No. SD-131, and the U. S. Air Force Office of Scientific Research under Contract No. AF-AFOSR-714-65.

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