may be differentiated and written in the form

$$dc/dP=-[(8\pi)^{1/2}e^4/(kT)^{3/2}m^{1/2}K^2]$$
$$\times\{2[K^{-1}(dK/dP)]+\tfrac{1}{2}[m^{-1}(dm/dP)]\}.$$

The terms in the bracket are of comparable magnitude and opposite sign, and the capture coefficient is therefore approximately independent of pressure. For this reason the change in excess carrier lifetime with pressure may be attributed almost entirely to a change in the energy of the recombination level.

The analysis of the data for the p-type sample is complicated by the fact that a trapping center exists in conjunction with a recombination center. This situation results in a loss of information in the low-temperature region about the capture coefficient, and hence a determination of the type of centers (donor or acceptor) is impossible. The recombination level lies 0.13 eV from one of the band edges, and approaches that band edge as the pressure increases. If the recombination level results from a chemical impurity, Table I shows that there are three impurities having ionization energies close to 0.13 eV: Au, 0.15 eV; Ag, 0.14 eV; and Mn, 0.16 eV. Lacking any more definitive information about the parameters of this recombination center, it is not constructive to speculate further about its specific character.

The slope of the lifetime–temperature curve in the low-temperature region indicates that the trapping center is close to one of the band edges, thus confirming its behavior as a trap. However, no other information is available concerning the nature of the trap.

VII. SUMMARY

Measurements of the excess carrier lifetime as a function of temperature and pressure have been made on n- and p-type germanium.

The 14-Ω cm n-type sample contains a donor-type recombination level 0.18 eV from the valence band, as determined from the temperature variation of the lifetime utilizing the Shockley–Read theory. Measurement of the pressure dependence of the lifetime up to 10 000 kg/cm^{-2} indicates that this recombination level approaches the valence band at the rate of 1.2×10^{-6} eV cm^2 kg^{-1}. From the behavior of the lifetime under hydrostatic pressure, it was inferred that the level is associated with an interstitial impurity. Low-temperature ($\sim$240°K) data indicate that the electron and hole capture coefficients are independent of pressure.

The 5-Ω cm p-type sample contains a recombination level 0.13 eV from one of the band edges, and a trap level 0.05 eV from one of the band edges. Pressure measurements on the recombination level showed that it approaches the nearest band edge at a rate of 1.5×10^{-6} eV cm^2 kg^{-1}.

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[7] The distinction between the recombination center and the trap is governed by the relative probability of capture of the opposite type carrier and the thermal emission of a carrier back to its respective band. If, for example, a flaw captures an electron and the next most probable event is the subsequent capture of a hole, the flow is acting as a recombination center. On the other hand, if the next most probable event is the emission of that electron back to the conduction band, the flaw is acting as a trap.

[8] Using $m_n^*=0.25m_0$, $m_p^*=0.40m_0$, where m_0 is the free electron mass, and using an average value of the majority carrier density n_0 over the temperature range covered in Region II of 1.4×10^{-14} cm^{-3}.

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[15] In view of the possibility of thermal migration of impurity atoms during the growth process, and the possibility of their interaction with vacancies and dislocations, it is not entirely clear that significant concentrations of interstitial atoms may result from normal crystal growth. Under the circumstances, this suggestion should be regarded as tentative and qualified, but it is not inconsistent with the evidence now available. It should also be noted that concentrations of recombination centers much smaller than those normally associated with substitutional doping impurities may be quite significant in affecting excess carrier lifetime in germanium crystals.