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Gold as a Donor in Silicon

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Resistivity-temperature data show gold produces a donor level 0.33 ev above the occupied band in silicon.

GOLD has been found to cause deep-lying energy levels in p-type silicon. From resistivity-temperature data, such as those shown in Fig. 1, there is at least one well-defined thermal activation energy for the holes of 0.33 ev. Curve 1 of Fig. 1 is for undoped p-type silicon which, as determined from the resistivity, contains 10^{15} carriers per cc. Curves 2, 3, 4, 5 are for p-type silicon containing increasing concentrations of gold. At liquid air temperature, resistivities much greater than 10^{10} ohm cm are readily realized. The data have been obtained using single-crystal silicon drawn according to the Czochralski technique.

The effect of the concentration of gold in silicon may be seen from the curve of Fig. 2 in which the resistivity at room temperature is plotted along the length of a single crystal. The gold, by rejection from the solid during growth, is concentrated toward the bottom of the crystal. It is observed that the resistivity increases rapidly if the gold concentration exceeds a certain value. The resistivity of undoped p-type silicon decreases slightly down the length of a grown crystal.

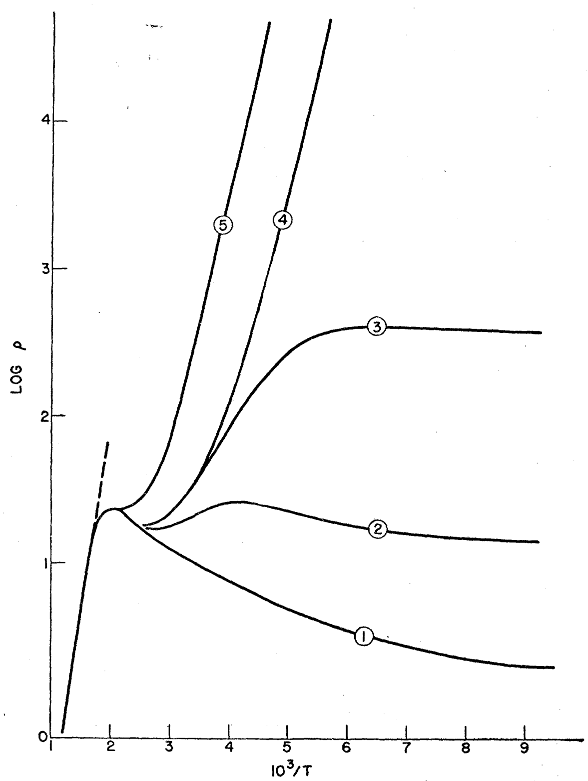

FIG. 1. Temperature-resistivity plot for gold-doped p-type silicon.

If we consider a model in which each gold atom accepts one hole, it is possible to determine the ratio of gold atoms to holes from the data of Fig. 1. Thus, curve 2 may be shown to indicate a gold atom to hole ratio of about 0.8 and curve 3 about 0.99. Since the hole concentration is given by the expression $N=1/\rho e\mu_p$, where ρ is the resistivity before adding gold, the concentration of gold may be evaluated by combining this expression with that for the ratio of gold atoms to the number of holes. From the concentration of gold atoms at various points in the crystal, it is possible to estimate a distribution coefficient for gold in solid and liquid silicon (C_s/C_1). Using 370 cm²/volt/sec[1] for μ_p, we obtain a value for (C_s/C_1) of about 3×10^{-5} averaged from the data for several gold-doped silicon crystals.

Of principle interest at this time is that whereas Dunlap[2] has reported gold as an acceptor in germanium, in silicon it is a donor whose effect is most conveniently seen on holes in initially p-type samples.

Acknowledgment is gratefully made of the profitable discussions with Dr. L. Apker and Dr. W. C. Dunlap in the course of these studies.

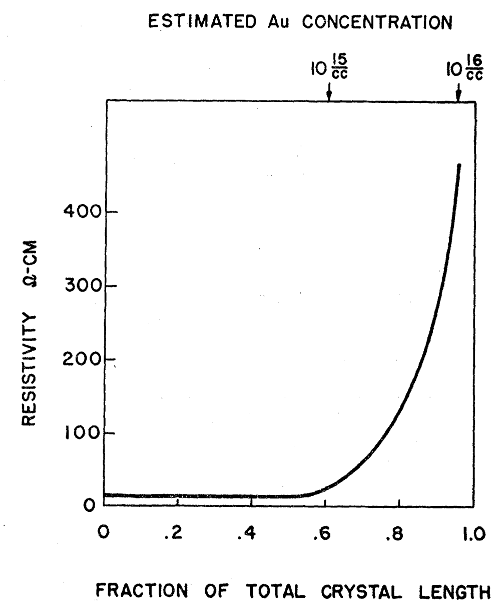

FIG. 2. Resistivity of gold-doped p-type silicon at room temperature.

[1] E. J. Ryder, Phys. Rev. **90**, 766 (1953).
[2] W. C. Dunlap, Jr., Phys. Rev. **91**, 208, 1282 (1953).