Hall and Drift Mobility in High-Resistivity Single-Crystal Silicon

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Room-temperature Hall and drift mobilities have been measured for samples of single-crystal silicon ranging in resistivity from about 10^{-2} ohm cm to nearly intrinsic. The Hall mobility figures indicated for lattice scattering are 1560 and 345 cm²/volt sec for electrons and holes respectively, whereas drift mobility values of 1360 and 510 cm²/volt sec for electrons and holes, respectively, are found.

INTRODUCTION

SINCE no data have appeared in the literature concerning Hall or drift mobilities for charge carriers in single-crystal silicon of resistivity greater than 200 ohm cm, it seems worthwhile to publish the results obtained at our Laboratory for these parameters. This information may contribute to settling the question which is posed by many concerning a historical rise in mobility in silicon analogous to that observed in germanium.[1]

SAMPLES

The single-crystal silicon samples investigated here were obtained by the Czochralski technique utilizing a quartz crucible and argon plus 10% hydrogen atmosphere. The lower resistivity samples were doped with either phosphorus (*n* type) or boron (*p* type). Many of the higher resistivity crystals were undoped. Very high resistivity samples could sometimes be cut from the neighborhood of *p*-*n* junctions in undoped crystals.

Hall samples were generally in the form of rectangular thin plates with dimensions approximately 0.5×4×10 mm with lapped surfaces. Drift mobility specimens were generally in the form of small bars of dimensions 0.5×0.5×10 mm with etched surfaces.

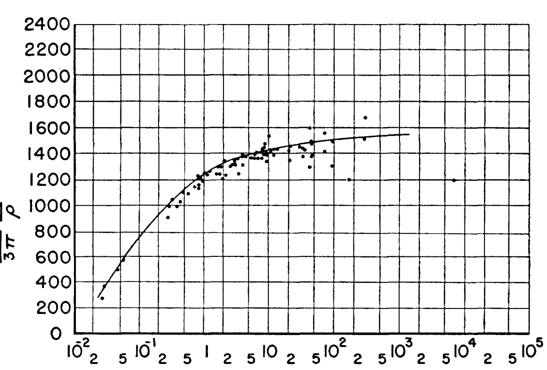

FIG. 1. Plot of Hall mobility $(8/3\pi)(R/\rho)$ (cm²/volt sec) *versus* resistivity ρ(ohm cm) for *n*-type single-crystal silicon at room temperature (25°C).

EXPERIMENTAL PROCEDURES

Hall mobility was obtained by combining potential traverse measurements of resistivity with Hall coefficient measurements utilizing a permanent magnet with a field strength of 3000 gauss. The voltages and currents in each case were obtained from the trace of a Brown vibrating-reed recording electrometer having a 10^{11}-ohm input resistor. Correction for "end shorting" was made using the calculations of Isenberg *et al.*[2]

Drift mobility values were obtained using the Lawrance[3] modification of the Haynes-Shockley[4] drift mobility experiment utilizing a Tektronix 514D oscilloscope to determine both drift velocity and electric field strength. An Electropulse double pulse generator was used to pulse the sweeping field (and in some cases the emitter whisker). Emitter and collector whiskers were electropointed tungsten. The collector whisker was supplied with a constant bias and the signal observed across the collector load resistor. The collector signal pip was extrapolated to zero injection level by reduction of emitter current. Each point on the curves corresponds to an average of six measurements with varying emitter-collector separation and reversal of pulse travel

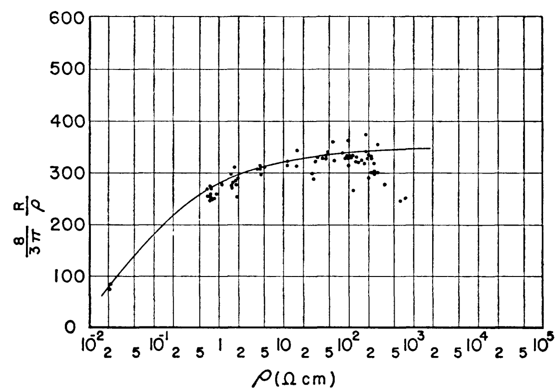

FIG. 2. Plot of Hall mobility $(8/3\pi)(R/\rho)$ (cm²/volt sec) *versus* resistivity ρ(ohm cm) for *p*-type single-crystal silicon at room temperature (25°C).

[1] W. Shockley, *Holes and Electrons in Semiconductors* (D. Van Nostrand Company, Inc., New York, 1950), p. 338.

[2] Isenberg, Russel, and Greene, Rev. Sci. Instr. **19**, 685 (1948).

[3] R. Lawrance and A. F. Gibson, Proc. Phys. Soc. (London) **B65**, 994 (1952).

[4] J. R. Haynes and W. Shockley, Phys. Rev. **81**, 835 (1951).

direction. Correction for diffusion and drift[5] as well as pulse/group[6] difference was made.

RESULTS

At room temperature (25°C), the results (Figs. 1 to 4) of Hall and drift mobility measurements agree reasonably well with the literature,[7–10] all of which refers to crystals having a resistivity less than 200 ohm centimeters. The indicated lattice scattering mobilities would seem to be as shown in Table I.

TABLE I.

Hall mobility ($\mu=(8/3\pi)(R/\rho)$)				Drift mobility			
	Author	D-K[a]	M-M[b]	Author	L-W[c]	Prince[d]	D-K[a]
μ_n	1560	1610	1450	1360	1350	1500	1610
μ_p	345	360	298	510	480	500	360

[a] See reference 8.
[b] See reference 7.
[c] See reference 9.
[d] See reference 10.

The electron Hall mobility corresponding to lattice scattering (1560 cm^2/volt sec) is somewhat higher than that obtained by Morin and Maita[7] but somewhat lower than found by Debye and Kohane.[8] The same relationship holds for the hole Hall mobility corresponding to lattice scattering except there is a more serious discrepancy with Morin and Maita's value.

The drift mobility results are quite close to those obtained by Ludwig and Watters[9] who used crystals with resistivity less than 200 ohm centimeters. The electron mobility is somewhat lower than Prince[10] extrapolated for material with resistivity less than 30 ohm cm, although the measured values are in substantial agreement with the values which he quotes, namely, 1200 and 500 cm^2/volt sec.

The values disagree widely with those quoted by Debye and Kohane.[8]

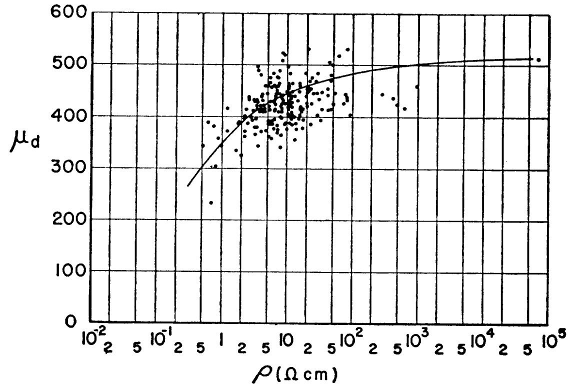

FIG. 3. Plot of drift mobility μ_d(cm^2/volt sec) *versus* resistivity ρ(ohm cm) for *n*-type single-crystal silicon at room temperature (25°C).

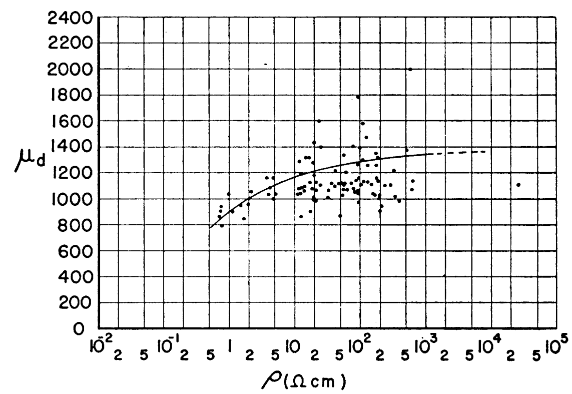

FIG. 4. Plot of drift mobility μ_d(cm^2/volt sec) *versus* resistivity ρ(ohm cm) for *p*-type single-crystal silicon at room temperature (25°C).

A statistical study between Hall and drift mobilities for adjacent specimens cut from the crystals yielded only doubtful correlation (correlation coefficient ≈ 0). Most of the observed scatter of the values probably results from either sample inhomogeneities or random experimental error.

ACKNOWLEDGMENT

My thanks are here expressed to Mr. W. Thompson for performing the measurements described here.

[5] H. N. Leifer and R. L. Watters (private communication).
[6] M. B. Prince, Phys. Rev. **91**, 271 (1953).
[7] F. J. Morin and J. P. Maita, Phys. Rev. **96**, 28 (1954).
[8] P. P. Debye and T. Kohane, Phys. Rev. **94**, 724 (1954).
[9] G. W. Ludwig and R. L. Watters, Phys. Rev. **101**, 1699 (1956).
[10] M. B. Prince, Phys. Rev. **93**, 1204 (1954).