DETERMINATION OF THE CURRENT-CARRIER CONCENTRATION FROM THE IMPEDANCE OF A SEMICONDUCTOR DISK IN A STRONG MAGNETIC FIELD

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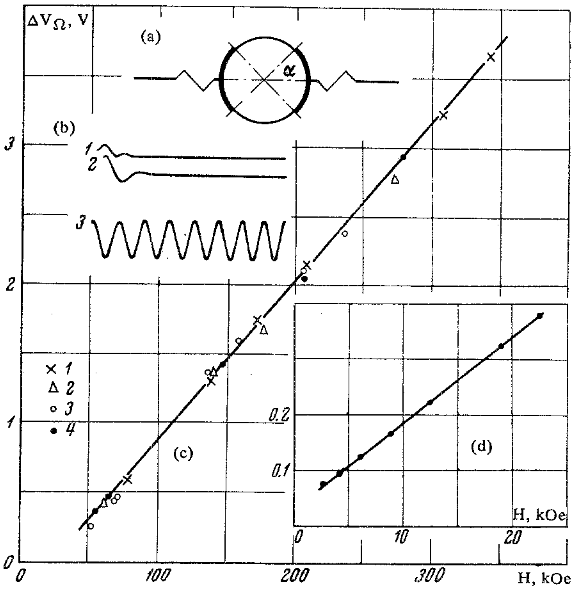
The potential and current distributions in an isothermal isotropically conducting circular semiconductor wafer were found from the solution of a Riemann-Hilbert boundary-value problem for the specific case of extrinsic conduction [1]. It was shown that the general expression for the impedance Ω(H) of the two-terminal network under study, located in a strong magnetic field ($\mu H/c \gg 1$), can be greatly simplified when the aperture of the symmetrically placed electrodes forms a right angle. With this arrangement of the current electrodes (Fig. 1, a) the general expression for Ω(H) (which is independent of the disk radius) can be represented as

$$\Omega(n, e, h, H) = \Omega_0 + \Delta\Omega \approx \frac{H}{ench} = R_\infty \frac{H}{h}, \left(R_\infty = \frac{1}{enc}\right), \quad (1)$$

where h is the disk thickness, Ω_0 is the impedance of the semiconductor disk in the absence of H, and R_∞ is the Hall coefficient as $H \to \infty$.

If we measure $\Omega = f(H)$ for circular specimens in strong magnetic fields ($\mu H/c \gg 1$) we can directly determine (as we see from expression (1)), from the slope of the experimental lines $d\Omega/dH = R_\infty/h$, values of R_∞ which are free of the indeterminacies related to the Hall factor. The values of R_∞ so determined permit precise determination of the current-carrier concentration in the semiconductor. As was shown in [2], the exact values of the Hall coefficient which correspond to R_∞ cannot be obtained directly from $R_x = f(H)$ for strong magnetic fields $\mu H/c \gg 1$, because rigorous saturation of $R_x = f(H)$ is not achieved in fields that do not also give rise to quantization, and in stronger fields H (when $h\omega \gg kT$), the classic theory of the Hall effect is not applicable.



The theory developed in [1] was checked by its authors in the absence and in the region of weak magnetic fields. The aim of this report was to describe an experimental test of expression (1) (and, therefore, of the applicability of the theory [1] for high H), as well as to determine some possibilities for practical application of this expression.

We measured $\Omega = f(H)$ (at J = const and T = 300° K) in strong pulsed magnetic fields (at ±J and ±H) with the use of oscillograms. Typical results of the latter are shown by curves 1, 2, and 3 in Fig. 1, b. To increase measurement accuracy, the signal under study ΔV_Ω and the field signal ΔV were interpreted (with the aid of sine-wave voltage, curve 3) according to the extremes of curves 1 and 2, respectively. In addition, to eliminate inductive noise and phenomena that develop on the contacts, the measurements were made for both signs of H and J, and then the results were averaged in the usual way. A typical example of $\Delta V_\Omega = J\Delta\Omega$ obtained at T ≈ 300° K for a specimen with ρ ≈ 11.6 ohm/cm is shown in Fig. 1, c, where the exes and traingles show the results for + H and ± J and the white and black circles show the results for −H and ± J. Similar lines were obtained for other specimens, with ρ = 0.6, 1.3, 10.2, and 21.9 ohm/cm, in fields up to 450 kOe.

Specimen No.	ρ	R_∞^Ω	R_e	n_e^Ω	$n_e^{R_e}$
			300°K		
1	21.9	$9.1 \cdot 10^4$	$8.57 \cdot 10^4$	$6.85 \cdot 10^{13}$	$6.7 \cdot 10^{13}$
2	11.6	$4.77 \cdot 10^4$	$4.25 \cdot 10^4$	$1.31 \cdot 10^{14}$	$1.33 \cdot 10^{14}$
3	1.3	$5.11 \cdot 10^3$	$4.63 \cdot 10^3$	$1.23 \cdot 10^{15}$	$1.2 \cdot 10^{15}$
4	0.603	$2.05 \cdot 10^3$	$1.92 \cdot 10^3$	$3.05 \cdot 10^{15}$	$2.91 \cdot 10^{15}$
			77°K		
1	3.48	$1.057 \cdot 10^5$	$8.87 \cdot 10^4$	$5.91 \cdot 10^{13}$	$5.89 \cdot 10^{13}$
2	1.45	$4.74 \cdot 10^4$	$3.92 \cdot 10^4$	$1.32 \cdot 10^{14}$	$1.32 \cdot 10^{14}$
3	0.215	$5.27 \cdot 10^3$	$4.53 \cdot 10^3$	$1.18 \cdot 10^{15}$	$1.15 \cdot 10^{15}$
4	0.123	$2.18 \cdot 10^3$	$1.91 \cdot 10^3$	$2.87 \cdot 10^{15}$	$2.92 \cdot 10^{15}$

The measurements at T = 77° K were made in static magnetic fields, since the criterion $\mu H/c \gg 1$ in this case is satisfied with H as low as about 3–10 kOe, depending on the impurity concentration in the specimen. As is apparent from Fig. 1, d, these results also agree with expression (1).

From the slope of the rectilinear segments of $\Delta V_\Omega = J\Delta\Omega$ we found R_∞, by means of which we determined the current-carrier concentrations at 300 and 77° K. For the same specimens, we found n_e from measurements of the Hall coefficient R_0 in weak magnetic fields with strict allowance for the concentration dependence of the Hall factor in accordance with [2]. The n_e values (for the depletion region) obtained by measurement of the impedance of a semiconductor disk in strong magnetic fields and by measurement of the Hall coefficient R_0 in weak magnetic fields (Table) are in good agreement with one another. This allows the proposed method to be used for exact determination of the current-carrier concentration of n-type germanium.

As can be seen from expression (1), the impedance of a circular specimen increases linearly with the magnetic field. Therefore, this dependence of Ω on H can also be used in the calibration of electromagnets over a wide range of magnetic fields which satisfy the condition $\mu H/c \gg 1$ but do not result in quantization.

REFERENCES

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