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Exhaustion barriers in zinc sulphide

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Summary. The nature of the exhaustion barrier at a metallic contact to a zinc sulphide crystal is considered in the light of the evidence of electroluminescence and of the effect of electric fields on the scintillations produced by alpha particles. The evidence suggests that the donor states whose depletion gives rise to the barrier are concentrated at a single energy level, rather than distributed through the forbidden band.

In a recent paper, Rose (1956) has considered the nature of the exhaustion layer present at the boundary between a metallic electrode and an insulating crystal. The theory proposed by Schottky (1939) considers only electron traps of a single depth near the Fermi level and disregards other trapping states. Rose suggests that for many substances a more realistic theory should consider trapping states distributed in energy throughout the forbidden band. The properties of a space charge layer of this kind differ in important respects from those deduced by Schottky.

Zinc sulphide is a material to which this modified theory might very reasonably be applied. The purpose of this paper is to examine the results of those experiments made on crystalline zinc sulphide in which the properties of the barrier should be particularly important. No systematic study of the electrical properties of zinc sulphide has been carried out, and any evidence is necessarily indirect.

Some evidence arises from the study of electroluminescence. In zinc sulphide the occurrence of electroluminescence can satisfactorily be explained in terms of the excitation of luminescence centres by electrons which have been accelerated in the conduction band by the applied field. The electric field strengths at which electroluminescence first becomes observable can be calculated assuming a uniform potential drop across the crystal. At such field strengths, the probability of accelerating free electrons to sufficiently high energies is inappreciable. Consequently it must be assumed that the field is not uniform, so that a region of high field strength exists in the electroluminescent crystal. The evidence suggests that the high field region may be provided by an exhaustion barrier at the negative electrode.

Attempts to develop a quantitative theory of electroluminescence have assumed the field distribution in the barrier region calculated by SCHOTTKY as mentioned above. Thus, the probability that an electron in the conduction band will gain enough energy E to excite luminescence is proportional to exp (α/F), where F is the local electric field strength and $\alpha = \alpha(E)$.

For a SCHOTTKY barrier, the maximum field strength is

$$F_0 = \text{constant} \cdot V^{\frac{1}{2}}$$

so the electroluminescent brightness B is proportional to exp (α/F). i. e. to exp $(\alpha/V^{\frac{1}{2}})$.

The corresponding expressions for the maximum field strength given by ROSE is

$$F_0 = \text{constant} \cdot V$$

so that now B is proportional to exp (α/V).

Comparison with experiment shows that the former expression for the variation of electroluminescence with applied voltage is the more satisfactory for single crystals (ALFREY and TAYLOR 1955), powder layers (ZALM, DIEMER and KLASENS 1955), or evaporated films (SCHWERTZ and FREUND 1955).

In the absence of a recognized method for making ohmic contact to zinc sulphide crystals, direct electrical investigation of the properties of a single barrier layer is not possible. The barrier region can, however, be probed by the use of a beam of alpha particles. These are used in preference to other nuclear radiations because their range in the crystal is comparable with the barrier thickness, so giving rise to a large ionisation density in that region of the crystal where the field strength is high. The scintillations produced are observed with a photomultiplier and the height of the output pulses measured.

We have investigated the effect of electric fields on scintillations produced by alpha particles entering the crystal through a thin metal electrode evaporated onto one surface. The crystal is supported on a plate of conducting glass which forms the other electrode. When the first electrode is positive, the field is without effect on the pulses, but if this electrode is negative the pulses are reduced in height.

This result confirms the view that there is in fact a region of high field strength in zinc sulphide crystals, and that it is located at the negative electrode.

When the „quenching“ effect of the electric field on the scintillations is considered quantitatively it is found that the results are in agreement with the Schottky theory, according to which the barrier thickness depends on the voltage applied to the crystal. In the type of barrier considered by Rose, the thickness does not change appreciably with applied voltage. Since the results of our experiments cannot be reconciled with the idea of a constant barrier thickness, the theory of Schottky would seem to be more appropriate.

A detailed account of these experiments will be published elsewhere.

Evidence from the luminescent properties of zinc sulphide all points towards the existence of trapping states distributed in energy, but to derive the distribution of these states from, for instance, thermoluminescence data is a problem which has not been satisfactorily solved. Consideration of the nature of the depletion barriers in zinc sulphide provides an opportunity of studying the shallower trapping states by a separate method, and the phenomena we have discussed are concerned with these barriers.

Two simple assumptions may be made about the energy distribution of these traps: either they are concentrated at a single energy level, or are uniformly distributed. The evidence we have discussed shows that the first of these assumptions is the more satisfactory n the case of zinc sulphide.

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