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Abstract

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V. N. VERZNER and L. N. MALAKHOV

APPLICATION OF THE SHADOW ELECTRON-MICROSCOPIC METHOD TO THE STUDY OF THE POTENTIAL DISTRIBUTION IN p-n JUNCTIONS

(Presented by Academician A. A. Lebedev, 31 VII 1957)

To determine inhomogeneities of the refractive index in light optics, the Foucault-Toepler method (^{1,2}), or the so-called schlieren method, is widely used. By schlieren are meant local disturbances of the density and refractive coefficient of a substance. The possibility of observing a schlieren pattern is determined by the fact that optical inhomogeneities of the specimen cause an anomalous path of rays in the optical system. The schlieren method can be transferred to the field of electron optics, where the causes producing electron deflection are local electric and magnetic inhomogeneities and where, consequently, its application makes it possible to reveal microinhomogeneities in the distribution of electric or magnetic fields.

To obtain quantitative data on the distribution of these fields, an electron-optical shadow method (^{3}) was developed, the principle of which is explained in Fig. 1. A parallel electron beam falls on the lens

Fig. 1. Schematic diagram of the shadow method

L and, in the absence of disturbing electric or magnetic fields on the object S', gives on the screen a shadow image of the obstacle ED, located beyond the focus of the lens L. Such an obstacle may be, in particular, a thin wire. The boundary of the shadow image of the obstacle will be determined by the pair of rays BDB_1 and AEA_1, intersecting at the focus of the lens F. If a voltage is applied to the specimen S', the electron beam will be deflected, and the boundary of the shadow image of the obstacle on the screen will be determined by the deflected rays BDB_1' and AEA_1'. The magnitude of the displacement of the shadow

image of the obstacle on the screen and serves as a measure of the magnitude of

Figure 2

Figure 2: Figure 2

Figure 3

Figure 3: Figure 3

the perturbing field. In a working setup, a metal mesh is usually used instead of a wire, which makes it possible to determine the potential distribution in that part of the object which falls within the field of view of the electron-optical system.

The electron-optical method was first applied, in the case of semiconductors, to study the magnitude of carrier drift from the potential distribution on the surface of lead sulfide photoresistors by V. S. Vavilov (4).

In the present work this method was applied to observe the zone of potential drop at germanium p—n junctions. The electron-optical setup was arranged according to a scheme using a "coordinate mesh" as the indicator of the electric field. The use in the setup of a high accelerating voltage of 50 kV made it possible to observe the objects under study with a sufficiently high resolution, of the order of 0.1 μ. Sensitivity to electric fields was ensured by the high sharpness of the shadow image of the "coordinate mesh," which was achieved by creating a small effective electron source from which it is projected. In our setup the dimensions of this source were of the order of 1—2 μ, which made it possible to use 200—300-fold magnifications of the mesh, realized with the aid of an additional electromagnetic lens. This made it possible, despite the use of fast electrons, to detect a potential of 0.3 V.

Fig. 2. Displacement of the coordinate mesh in the p—n junction region, obtained by the method of "differential photographs" ; 1000×

For increasing the accuracy of readings of mesh displacements, we used the method of "differential photographs," which consisted in taking shadow images of the distorted and undistorted mesh on one and the same photographic plate. This procedure, in addition to increasing the accuracy of the readings, reduced the time during which the specimens remained under the beam, which is of substantial importance for a number of objects.

Fig. 3. Potential distribution in the blocking region

The specimens studied were p—n junctions in a germanium single crystal. For the investigation, a special preparation of the objects was carried out, consisting in the following: from the germanium single crystal, by grinding and polishing, a prism with a sharp edge was made. Electrodes were soldered to this prism and the object was placed in a special holder that allowed the necessary displacements of it to be made. One of the ends of the specimen was grounded, and voltage was applied to the other. Parallel to the edge of the prism a copper wire was stretched, which was at ground potential. Thus, between each point of the specimen and the grounded wire there existed a certain potential difference. By applying voltage to the specimen in the reverse direction and measuring the displacement of the mesh bands, it is possible to determine the location

zones of voltage drop and also, knowing the magnification of the object, to estimate its extent.

Figure 2 shows a photograph typical for a *p*—*n* junction, obtained by the method described above. The character of the potential distribution is conveyed especially clearly by the grid bands located in the image in the region close to the object.

A preliminary study of the width of the zone in which the principal voltage drop occurs, as a function of the magnitude of the applied voltage, showed that the zone, in agreement with theory, decreases as the voltage is reduced. The width of the barrier zone in the germanium specimens studied did not exceed 20μ at voltages of 70-80 V, decreasing as the voltage was reduced (Fig. 3).

We hope that the method developed will make it possible to study in greater detail the physical processes preceding and accompanying breakdown in *p*—*n* junctions.

In conclusion we express our sincere gratitude to V. M. Tuchkevich and A. A. Lebedev for kindly providing specimens for the investigation, and also to Academician A. A. Lebedev for his constant interest and valuable advice in discussing the results of the work.

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Note: Figure translations are in progress. See original paper for figures.