# Nature of an Ohmic Metal-Semiconductor Contact

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A brief discussion is given of various existing models for an ohmic contact between a semiconductor like CdS and a metal. An alternative model is proposed according to which the ohmic nature is brought about by a thin layer of highly conducting *n*-type CdS underneath the electrode.

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VARIOUS models have been proposed for explaining a dc ohmic contact between a metal and a semiconductor. Phenomenologically such a contact is, of course, defined by the fact that it obeys Ohm's law, thus fulfilling the following two requirements: (1) the threshold voltage for zero current is negligible with respect to the applied voltage (2) the proportionality factor between current and voltage (i.e., the conductivity) does not vary measurably with voltage. (1) and (2) must be valid within a certain not too small voltage range, say from about 1 millivolt to several volts.

Neglecting space-charge effects in the bulk,[1] such an ohmic contact will be present if the voltage drop at the electrodes, which is required to supply a number of mobile charge carriers to the semiconductor sufficient to maintain the carrier concentration essentially constant, is small compared with the total voltage drop across the semiconductor.

This will, for example, be the case if the work function of the metal is equal to or smaller than the work function of the semiconductor. Smith and Rose[1,2] thus explained the ohmic contact of In or Ga to CdS. Smith's model, however, cannot explain Butler's[3] experiments, according to which any metal can give an ohmic contact to CdS, provided the CdS surface has previously been exposed to electron or ion bombardment. It is our experience moreover, that, contrary to Smith, even with In or Ga such a bombardment is nearly always required. On the other hand, the model proposed by Butler, according to which no exhaustion barrier at the surface should be present, is not satisfactory, because it is known that such a barrier must always be present if there is a difference between the Fermi levels in the metal and in the semiconductor.

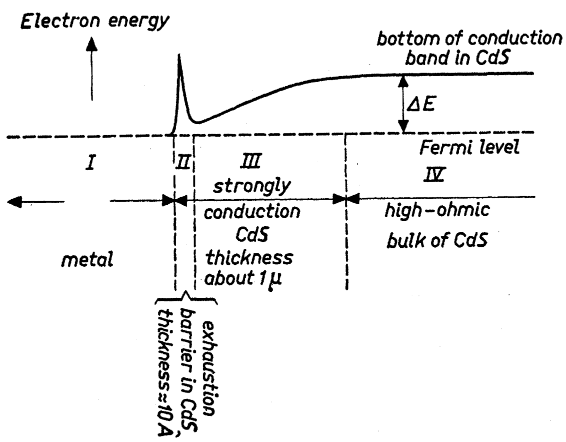


FIG. 1. Proposed band model of an ohmic contact between a highly resistive *n*-type bulk IV and a metal electrode I. III is a thin layer of strongly *n*-type semiconductor, and II is an exhaustion barrier due to the difference in work function between the material III and the electrode I.

The fact that those trivalent elements which are known to diffuse easily into CdS produce ohmic contacts, while elements as Ag and Cu which are incorporated as monovalent ions produce rectifying contacts has suggested to us the following alternative model:

Ohmic contact on a highly resistive *n*-type material is brought about by a rather thin layer of low resistivity (strongly *n*-type) in the semiconductor underneath the electrode. This strongly *n*-type conductivity is, in the case of In or Ga electrodes, induced by diffusion of a certain amount of trivalent metal atoms into the CdS and in Butler's case by the electronic or ionic bombardment, which is known to make CdS superficially highly conductive.[4]

Monovalent elements like Ag, Cu, etc., will produce the opposite effect since their incorporation in the CdS crystal lowers the Fermi level. That diffusion of these elements into a sulfide single crystal can already occur during evaporation of the electrode material onto the crystal has been demonstrated by Diemer.[5]

At the very surface of a highly conductive part of the CdS, adjacent to the electrode, there may exist an exhaustion barrier, which, however, in such a strongly conducting material is so thin that the electrons may easily tunnel through it. The band picture according to our model is schematically drawn in Fig. 1.

The region of strongly conductive CdS acts as a supply of electrons for the highly resistive bulk; the whole system will be ohmic, when an electric field is applied, since only the density of electrons in the conduction band at a height $\Delta E$ above the Fermi-level counts. A slight deviation from ohmic behavior in the thin layer of highly conducting material III and in its exhaustion barrier II will have no measurable influence on the over-all current-voltage characteristic, because of the high series bulk resistance.

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[1] R. W. Smith and A. Rose, Phys. Rev. **97**, 1531 (1955).
[2] R. W. Smith, Phys. Rev. **97**, 1525 (1955).
[3] W. M. Butler and W. Muscheid, Ann. Physik **15**, 82 (1954).
[4] J. Fassbender, Abstracts Physiker Tagung Wiesbaden, 1955; see pp. 36–37.
[5] G. Diemer, Philips Research Repts. **10**, 194 (1955).