CONDUCTIVITY OF GRAIN BOUNDARIES AND DISLOCATIONS IN SEMICONDUCTORS

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Introduction

In spite of the high perfection that can be achieved in the production of monocrystalline Silicon, the working horse of the semiconductor industry, many devices are and will be made in the future of compound as well as of elemental semiconductor material which is not so perfect, either for economic or technological reasons. This material contains dislocations and grain boundaries (GB-s). Consequently, the investigation of the electronic properties of these defects will continue to be of interest from a practical point of view.

Beyond this, dislocations and GB-s can be also of fundamental interest as one- and two-dimensional electronic systems. Two-dimensional conductivity at surfaces has lead to the famous von Klitzing effect and some one-dimensional conductors exhibit transport by charge density waves (CDW), a phenomenon related to superconductivity, and a Peierls phase transition due to a strong coupling between Bloch-waves and standing lattice waves.

All these interesting effects can in principle be studied in GB and dislocations as well and these extended defects are potentially even more ideal than other known systems of reduced dimensionality. Thus, for instance, localised states in one dislocation core can be perfectly decoupled from other dislocation cores, while in so-called "one-dimensional"crystalline conductors there is always a small but
finite overlap between Bloch functions and also a Coulomb interaction between CDW-s on different chains.

Furthermore, the investigation of the conductance along extended defects can provide also information on their other electronic properties which is difficult to obtain by other means.

In this work new results on the two-dimensional conductivity of grain boundaries in Ge are compared with measurements of the conductance across the boundary. Former discrepancies between the two sets of results are resolved. Direct evidence for one-dimensional conduction along dislocations in Ge is obtained from DC-measurements for the first time. A Peierls transition and a Peierls gap of 22 meV are observed. The I-V-characteristics are strongly nonlinear and formally fit the theoretical expression for charge density waves, although with a negative threshold field. No evidence has been found so far for one- or two-dimensional conduction at extended defects in Si.

Conduction perpendicular and parallel to GB-s

Most experiments on the conductivity along GB-s have been performed so far in Ge-bicrystals. In earlier measurements low angle GB-s with tilt angles up to $15^0$ and a (100) tilt axis were investigated in n-Ge $^{1,2,3}$. The results were interpreted by G. Landwehr et al in terms of an effective mass calculation based on the following model $^3$: Associated with the GB is a sheet of acceptor states with a strongly localised charge. This charge is neutralised by an equal number of holes in two dimensional bands that split from the valence band. The hole states are localised with a half width of roughly $40\,\AA$. The screened potential in the neutral state which is obtained from a Hartree calculation has the same range. The density of bound holes is high enough for complete degeneracy. In n-type material the number of holes is of course somewhat reduced because electrons are trapped in the GB states, but the degeneracy persists.

This model was confirmed by all transport experiments, including Schubnikov-de Haas measurements that allowed to determine the effective mass of the bound holes. It is represented in its simplest possible form in figure 1. The horizontal axis in this figure is a coordinate perpendicular to the GB. The vertical bar whose width is