Tilted Field Magnetotransport Experiments on Germanium Bicrystals

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1. Introduction

Previous magneto-transport experiments on p-type space charge layers adjacent to the grain boundary of Ge-bicrystals revealed the existence of a quantized, 2-dimensional system. Shubnikov-de Haas (SdH) experiments allowed the identification of two electric subbands, which can be attributed to light and heavy holes [1]. The background magnetoresistance suggested that the g-factor of the holes should be much larger than 2. The determination of the g-factor of a 2D-system is sometimes possible by studying quantum oscillations in tilted magnetic fields [2]. Because the Landau splitting depends on the normal component of the magnetic field and the spin splitting on the total field, the relative magnitude of the splittings varies with the tilt angle and gives rise to interference effects. These were actually observed in previous experiments [3], although no spin splitting of individual SdH peaks was found due to level broadening. Results of recent SdH- experiments in fields up to 23 T on high quality bicrystals produced in Würzburg are in good agreement with previous subband calculations [1]. Again interference effects were found in tilted magnetic fields. They can be explained on the basis of numerical model calculations. The reason for the interference effects is that spin splitting, even if unresolved, gives rise to amplitude variations as a function of the tilt angle. The assigned g* factors of the light and heavy holes are considerably larger than 2, they are close to 6.

2. Experimental

Germanium bicrystals were grown using the Czochralski pulling technique. The starting point for the crystal growth was two [100] seeds cut from a high quality germanium single crystal and tilted along the [001] axis. The tilt angle Θ between the two seeds was 15 degrees. From simple geometrical considerations, dislocation pipes perpendicular to the pulling direction are supposed to be formed with a distance $D = a/2\sin(\Theta/2)$ where $a$ is the lattice constant. Two kinds of samples with parallel or with perpendicular dislocation pipes were prepared (see fig.1). The magnetotransport experiments in the temperature range from 1.5K to 4.2K were performed in magnetic fields up to 23 Tesla.
3. Subband Calculations

To obtain detailed insight into the band structure of the p-type inversion layer in a bicrystal, self consistent calculations were performed [4]. Contrary to the well-known situation in MOSFETs, the Hartree potential shows inversion symmetry and the spin degeneracy of the bulk states is not lifted. Fig.2 shows the calculated Hartree-potential for a total carrier concentration of $4 \times 10^{12}\text{cm}^{-2}$. For this concentration two occupied subbands are expected.

4. Experimental Results

The magnetoresistance for different tilt angles $\theta$ between the normal vector of the 2D-plane and the magnetic field is shown in fig.3. On top of a strong background magnetoresistance two SdH-oscillations with low and high frequency are superimposed. As expected for 2D-systems, the SdH-extrema are shifted to higher magnetic fields following a $B/\cos(\theta)$ law for tilt angles $0^\circ < \theta < 20^\circ$. However, the amplitudes of the SdH-oscillations vanish at distinct angles ($\theta = 25^\circ$ and $57.5^\circ$ for the high and $\theta = 58^\circ$ and $72^\circ$ for the low frequency oscillation).

5. Discussion

From theoretical considerations and from the observed, relatively low mobilities, it is clear that the Landau levels formed in a magnetic field are broadened quite substantially in the bicrystal system. To understand the angular dependence of the SdH-amplitudes, it is essential to consider the shape of the density of states (DOS). In a tilted magnetic field, where the Landau splitting $\Omega_c = \hbar eB/m_c$ depends on the normal component of the magnetic field and the spin splitting on the total field, the relative magnitude of