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DEVELOPMENT OF CdTe/$Cd_{1-x}Mg_xTe$ DOUBLE BARRIER, SINGLE QUANTUM WELL HETEROSTRUCTURES FOR RESONANT TUNNELING

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We report the first observation of resonant tunneling through a CdTe/$Cd_{1-x}Mg_xTe$ double barrier, single quantum well heterostructure. Negative differential resistance is observable at temperatures below 230 K, exhibiting a peak to valley ratio of 3:1 at 4.2 K.

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Since the first observation of resonant tunneling in GaAs/AlGaAs double barrier structures [1], the work in this particular field has been almost exclusively confined to III–V material systems [2–5]. Resonant tunneling devices are interesting for high frequency applications. Moreover, they are of considerable interest in basic research [6]. Double barrier structures can be used e.g. for the investigation of interface roughness or band discontinuities.

In II–VI semiconductors, resonant tunneling through double barrier structures had been reported only in the HgTe/CdTe system [7]. It has been shown that CdMgTe heterostructures can be grown by molecular beam epitaxy (MBE) with a high quality [8]. Varying the Mg concentration, the energy gap can be tuned from 1.5 eV (CdTe) to 3.5 eV (zinc blende MgTe) [9]. The valence band offset CdTe/MgTe was determined to be 0.7 eV [10, 11]. Therefore a very high electron confinement of 1.3 eV can be obtained. Recently quantum Hall effect in modulation doped CdTe/CdMgTe single quantum wells has been observed [12], demonstrating that high mobility two-dimensional systems can be fabricated. In optical studies the non-magnetic CdMgTe turned out to be the ideal counterpart for the semimagnetic CdMnTe due to its very similar crystalline and electronic properties [13, 14]. Thus the quaternary system CdMgMnTe provides the unique possibility to alter separately the electronic and magnetic properties in a heterostructure. In addition, this material system is suitable for the fabrication of quantum wires and dots [15]. Photoluminescence intensity from low-dimensional, deep etched structures turned out to be limited by side wall recombination at the etched surfaces. Therefore, resonant tunneling could be an alternative method for the investigation of these low-dimensional structures made of II–VI semiconductors.

In this article we report on the fabrication of CdTe/CdMgTe double barrier structures and the observation of resonant tunneling in this material. Up to now, resonant tunneling devices have not been reported in any wide gap II–VI material.

The CdTe/CdMgTe double barrier structures were grown by MBE on (001) CdTe and n-type (001) CdZnTe:In substrates. Details about the substrate preparation were described elsewhere [16]. The substrate temperature was kept at 260°C. A Cd/Te flux ratio of 2/1 was adjusted to provide a Cd-rich growth regime. Before the growth of the heterostructure a 10 nm thick n-doped CdTe buffer layer was applied at 350°C in order to obtain a smooth substrate surface. For the doping we used CdI_2 which turned out to be the most suitable doping source material for n-type doping [16]. The double barrier structures were embedded in highly doped CdTe layers. Doping levels far above 1×10^{18} cm^{-3} are an important prerequisite for the fabrication of low temperature ohmic contacts. Figure 1 illustrates the layer sequences of one of the investigated tunneling structures. The growth rate was determined by means of RHEED (reflection high-energy electron diffraction) intensity oscillations and yielded 1.2 Å/s for this sample. The error in the layer thickness is assumed to be 3%.

After the MBE growth process, a 400 nm aluminum layer was deposited on top of the sample at room temperature without breaking the vacuum. This was done by means of a metallization chamber equipped with an electron evaporator interconnected with the MBE chamber. This procedure prevents the CdTe surface from being oxidized, avoiding a degradation of the contacts through surface contamination.

After a photolithographical step, mesas were created by etching the structure in a 1% bromine–ethylenglycol solution until the double barrier structure was isolated. Typical mesa sizes were 100 μm × 100 μm. The back contact has been formed by soldering indium onto the etched n-CdTe epilayer surface (see Fig. 1).

Current–voltage (I–V) characteristics of the sample were measured in a helium bath cryostat at different temperatures by the use of a HP-4145B semiconductor parameter analyser.

The I–V characteristics of sample CT1143 with 8 nm thick barriers is shown in Fig. 2. A peak to valley ratio of 3:1 for the first resonance can be determined at 4.2 K. At higher voltages a second resonance shows up which we ascribe to the second subband. From the positions of the resonances on the voltage axes one cannot determine the exact subband energies. This is due to both a significant voltage drop across the collector depletion layer, which is caused by the undoped spacer, as well as an additional voltage drop from the series resistance of the contact layers.

To conclude, resonant tunneling in a CdMgTe/CdTe double barrier structure has been observed. Better resolution can certainly be obtained by optimizing the double barrier structures and — more important — lowering the size of the tunneling diodes. This work has been a further step towards the fabrication of semimagnetic heterostructures for transport measurements.

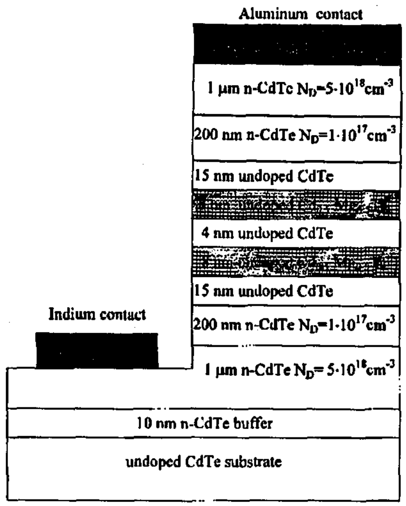

Fig. 1. Layer sequence of a CdTe/CdMgTe double barrier SQW structure. The typical mesa size is 100 μm × 100 μm.

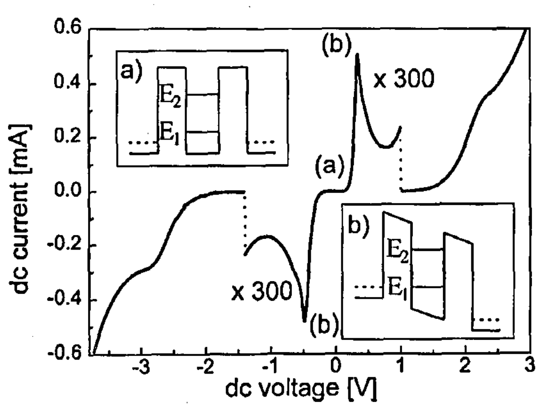

Fig. 2. *I–V* characteristics of a CdTe/CdMgTe resonant tunneling device at 4.2 K. Inset (a) shows the conduction band edge of the double barrier structure at zero applied voltage. In inset (b) the band edge is plotted for applied voltage. There, the Fermi level of the emitter is in resonance with the first bound state in the SQW. The corresponding situations in the *I–V* curve are indicated by (a) and (b), respectively.

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