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ESR STUDY OF THE MAGNETIC PROPERTIES OF THE CdTe/CdMnTe MULTI QUANTUM WELLS

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The results of electron spin resonance investigations of bulk $Cd_{1-x}Mn_xTe$ and of molecular beam epitaxy grown CdTe/CdMnTe single 2 μm thick layer and multi quantum well with Mn concentrations of about $x = 0.10$ are compared. The Mn^{2+} electron spin resonance spectrum of the MQW CdTe/CdMnTe shows severalfeatures different from those observed in the CdMnTe bulk sample.The Mn^{2+} resonance shows a small anisotropy of position and widthwith the anisotropy axis normal to the heterointerface. The temperature dependence of the width of the electron spin resonance line is also different from that observed for the bulk and for the thick single layer.

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1. Introduction

The purpose of this work was to compare magnetic properties ofbulk and multi quantum well (MQW) ternary CdMnTe compound with Mn fraction of 9.5% for the bulk sample and 10% for the two-dimensional (2D) system. The molecular beam epitaxy grown CdTe/CdMnTe MQW system (CT411) was grown on (100) CdTe with 6000 Å thick CdMnTe buffer and consisted of 6 CdTe quantum wells of different thicknesses (6, 12, 18, 28, 60 and 100 Å) separated by 500 Å $Cd_{1-x}Mn_xTe$ barriers and was covered with 1000 Å thick CdMnTe upper layer. The CT608a sample consisted of a single 2 μm CdMnTe layer grown on (100) CdTe substrate separated by 2000 Å CdTe buffer.

2. ESR experiments

The Mn^{2+} electron spin resonance (ESR) spectrum of CT411 and CT608a samples was relatively weak and broad (22 mT (CT411) and 20 mT (CT608a) at 100 K). For the CT411 sample the ESR signal was observed for low temperature below 110 K. The ESR signal of the CT411 sample was at 100 K about 5 mT broader than that for the 9.5% CdMnTe bulk sample. This indicates some inhomogeneous broadening of the Mn resonance in the MQW system, which we relate tentatively to Mn diffusion at the CdTe/CdMnTe interfaces. We have also observed a 5% anisotropy of the ESR signal width. Figure 1 shows the temperature dependence of the ESR spectra of the bulk and of the two MBE samples. The

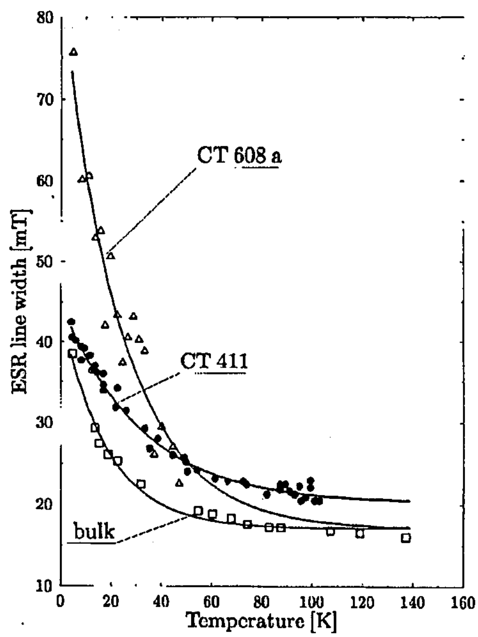

Fig. 1. Temperature dependence of Mn^{2+} ESR signal of the two MBE-grown samples: MQW system (CT411), single thick layer (CT608a), and of the bulk CdMnTe. Solid lines present a fit to the experimental data with semiempirical formulae described in the text.

$\Delta H_{pp}(T)$ dependence of the MQW sample is different from those observed for the bulk and the single layer sample. For the two latter samples the signal width was the same at room temperature but the dependence spreads at low temperatures, due to larger line width of the Mn resonance in the CT608a MBE layer. The temperature dependence for an MQW sample is weaker, which probably is also due to the Mn diffusion at the CdTe/CdMnTe interface.

The Mn^{2+} resonance in the bulk CdMnTe sample is isotropic. This is not the case of the MBE samples, as shown in Fig. 2. The anisotropy observed is a

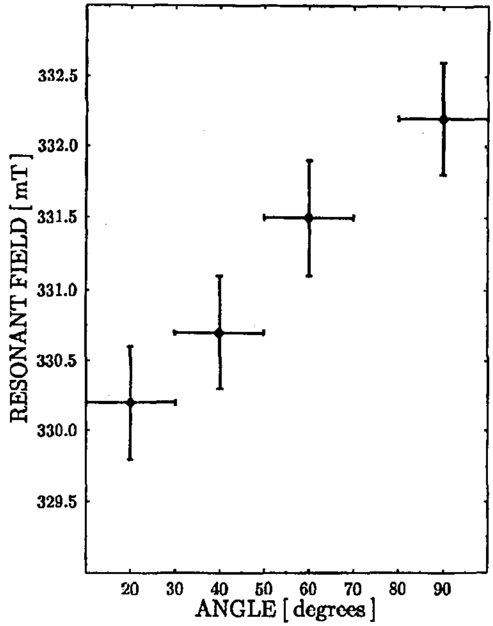

Fig. 2. Anisotropy of the Mn^{2+} ESR signal in the MQW system. The spectra were measured at 12.4 K for the sample rotated between two extreme configurations of the magnetic field versus the interface axis. For 90 degrees the magnetic field was normal to the interface plane.

characteristic feature of heterojunction systems with the lattice constant misfit [1]. This means that even though a thick 6000 Å CdMnTe buffer was used, some residual strain is still left in the MQW structure. The observed signal anisotropy could also come from the Mn^{2+} ions at the well–barrier interfaces. However, in the ESR study of the single CdMnTe layer a similar signal anisotropy was observed, which allows us to reject the alternative explanation.

A residual strain in the structures has also been determined by X-ray diffraction measurements. For that reciprocal space mapping of asymmetric reflections has been performed. A strain parameter Γ has been deduced. $\Gamma = 1$ corresponds to a fully strained layer, whereas $\Gamma = 0$ describes a fully relaxed layer. The strain parameter Γ is given by

$$\frac{(a(\text{layer}) - a(\text{sub}))_{\text{parallel}}}{a(\text{sub})} = (1 - \Gamma)\frac{(a(\text{layer}) - a(\text{sub}))_{\text{relaxed}}}{a(\text{sub})}, \tag{1}$$

where a(layer), a(sub) are lattice constants of epilayer and substrate, respectively. A possible tilt of the substrate and layer orientation has been taken into account for the analysis. For the thick CdMnTe layer CT608, a strain parameter Γ of 0.6 has been measured, which indeed means that the CdMnTe layer is still partly strained.

3. Temperature dependence of the line width

Application of the ESR method to characterization of Mn based ternary compounds was reviewed by Oseroff and Keesom [2]. It was observed by several authors that the ESR signal line width (ΔH_{pp}) increases with decreasing temperature. Three different approaches were proposed to describe signal broadening [3–5]. These were the Huber [3], Dormann and Jaccarino [4] and Bhagat [5] formulae. T_c parameter in each of these formulae was related to the order–disorder critical [3, 4] and spin freezing [5] temperatures, i.e., ESR can be used to estimate magnetic phase transition temperature.

Several authors argued an advantage of a particular description of the ESR data and physical meaning of the parameters [6–8]. However, no consensus was reached which of the approaches is "the correct one" [2]. It is why we used these three formulae to fit the experimental data. The Huber formula gave $T_c \approx 0$ K for the bulk sample, i.e., the critical temperature agrees with the magnetic phase transition temperature. This is in contrary to some earlier statements that the Huber equation describes the data only far above the critical temperature [2]. The similar value of the critical temperature was also obtained from the Dormann and Jaccarino formula. However, the Curie–Weiss temperature of 0.15 K obtained from the fit is too small [6]. Formally the best fit to the data (the smallest standard deviation) was obtained with the empirical Bhagat formula but with the 18.2 K critical temperature. Even though the temperature dependence of the ESR line width of the MQW system looked differently, the fit with two first formulae gave T_c values about 0 K, i.e., the same as for the bulk sample.

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