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MBE growth and characterization of a II–VI distributed Bragg reflector and microcavity lattice-matched to MgTe

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ABSTRACT

We present the realization and characterization of a 20-fold, fully lattice-matched epitaxial distributed Bragg reflector based on (Cd,Zn)Te and (Cd,Zn,Mg)Te layers. We also present a microcavity based on (Cd,Zn,Mg)Te containing a (Cd,Zn)Te quantum well. Reflectivity spectra, photoluminescence imaging in real space and in far field are presented.

1. Introduction

In III–V semiconductor compounds, the lattice-matching between GaAs and AlAs allows for the growth of monolithic structures and the realization of devices for optoelectronics [1,2]. For II–VI compounds, the challenge in designing and realizing epitaxial distributed Bragg reflectors (DBRs) and microcavities relies on the compromise between opposite constrains: the lattice-matching and a high refractive index contrast. Lattice-matched DBRs based on II–VI compounds have been reported so far for four substrates (or buffers): GaAs [3], InP [4], ZnTe [5], and (Cd,Zn)Te [6,7]. For the last one, the substrate was $Cd_{0.88}Zn_{0.12}Te$ and DBR was based on (Cd,Mg)Te and (Cd,Mn)Te layers grown on the (Cd,Zn)Te buffer. In such a structure, the presence of Mn, which has strong magnetic properties, in the DBRs layers can be a disturbance if one wants to explore magneto-optical effects related to quantum wells [8–13]. We present here the realization of unstrained DBR lattice-matched to MgTe, based on the stack of (Cd,Zn,Mg)Te layers with various Mg contents. Enhancements in the design of the DBR led us to the realization and characterization of a monolithic, optically active microcavity containing a lattice-matched $Cd_{0.86}Zn_{0.14}Te$ quantum well (QW) surrounded by good quality DBRs.

As shown in Fig. 1, our choice of a structure lattice-matched to MgTe is justified by the possibility of tuning the refractive index and the bandgap of the layers independently on the lattice parameter, depending only on the Mg content. With this concept, the whole structure including DBRs and QW can be lattice-matched.

The DBR, microcavity and QW were grown by a molecular beam epitaxy (MBE) technique. The MBE machine provided by SVT Associates consists of two growth chambers (for III–V and II–VI semiconductor compounds), each equipped with a reflectivity setup for in situ measurements. Monitoring the reflectivity spectra during the growth allows us to verify the growth rate and thickness of the layers, which is a crucial parameter for the growth of microcavities or DBRs [14–17].

The structures are grown on a GaAs:Si substrate (100) at the temperature of 346°. A $Cd_{0.86}Zn_{0.14}Te$ buffer about 800 nm thick is grown to relax the strain due to the lattice mismatch with GaAs. The lattice parameter and the composition of the buffer were estimated in situ from streaks spacing on the RHEED (reflection high energy electron diffraction) pattern.

2. Distributed Bragg reflector

The DBR containing 20 pairs of low and high refractive index layers was designed so that the center of the stopband is at a wavelength of $\lambda_0 \approx 900$ nm. The layers of the DBR are made of $\lambda/4n$ layers of $Cd_{0.86}Zn_{0.14}Te$ for the high refractive index and a 20-fold $Cd_{0.86}Zn_{0.14}Te$/MgTe superlattice for the low refractive index. The growth times of the superlattice layers are set to have an effective concentration of 50% Mg in the resulting digital alloy. The grown structure was observed by a scanning electron microscope (SEM) imaging. As presented in Fig. 2 the layer thicknesses are regular and the interfaces are smooth.

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The results of reflectivity measurements compared to the simulation by the transfer matrix method [18] are presented in Fig. 3. The DBR exhibit a maximum reflectivity above 95%. The stopband width measured is ≈ 70 nm which allows us to evaluate the refractive index contrast using the formula [18] given in Eq. (1), where $\Delta\lambda$ sets for the stopband width, λ_0 the center of the stopband, $\tilde{n}$ the average refractive index

$$\frac{\Delta\lambda}{\lambda_0} = \frac{4}{\pi}\sin^{-1}\left(\frac{|n_2 - n_1|}{n_1 + n_2}\right) \approx \frac{2}{\pi}\frac{\Delta n}{\tilde{n}} \quad (1)$$

Considering that the average refractive index [19] is $\tilde{n} \approx 2.8$, the refractive index contrast is $\Delta n \approx 0.34$.

X-ray diffraction measurements and simulation show that the whole structure (except the substrate) is matched to the lattice constant of MgTe [20] (see Fig. 4). This result comes from the comparison of the angular positions of the measured and calculated peak positions. Calculation assumes that the 1 μm thick $Cd_{0.84}Zn_{0.16}Te$ buffer is 98.4% relaxed to its natural lattice constant which is equal to the MgTe lattice constant. The other thin layers constituting the DBR are assumed to be 100% relaxed and lattice matched to MgTe.

3. Quantum wells

In order to obtain a fully lattice-matched microcavity, we designed a $Cd_{0.86}Zn_{0.14}Te$ QW with $Cd_{0.77}Zn_{0.13}Mg_{0.1}Te$ barriers.

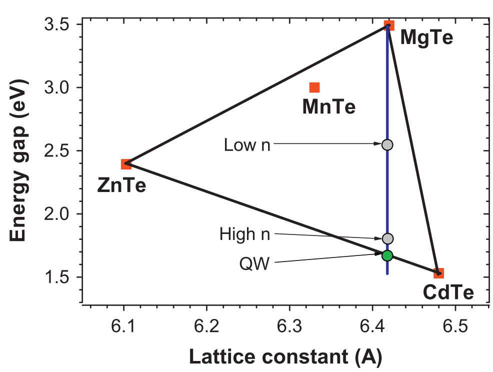

Fig. 1. The choice of having a structure lattice-matched to MgTe allows one to tune the refractive index contrast through the Mg content of the layers without changing the lattice constant. Line, MgTe lattice constant; dots, high and low refractive index layers, QW.

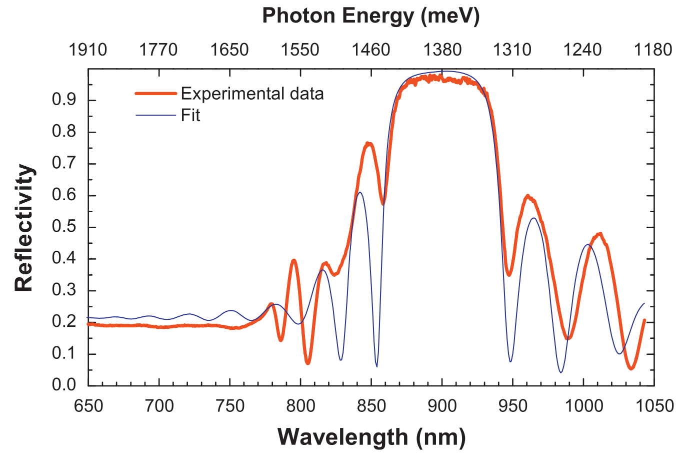

Fig. 3. Reflectivity spectra: measurement and simulation at room temperature. The maximum reflectivity is above 95%, the stopband is ≈ 70 nm wide indicating a refractive index contrast $\Delta n \approx 0.34$.

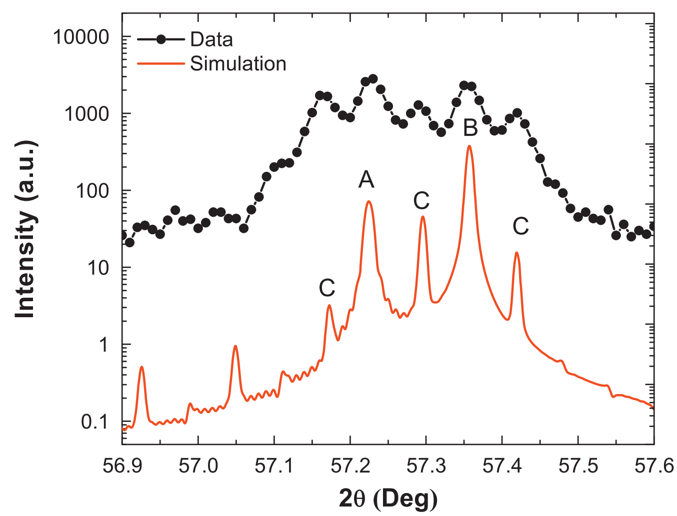

Fig. 4. X-ray diffraction measurement (dots) and simulation (solid line) assuming that the structure is lattice matched to MgTe (red curve). Where A sets for the main diffraction peak from the $Cd_{0.84}Zn_{0.16}Te$ buffer (98.4% relaxed) grown on the GaAs substrate, B originates from the $Cd_{0.84}Zn_{0.16}Te|MgTe$ digital alloy, and the satellites C arise from the 20-fold periodicity of the whole DBR. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

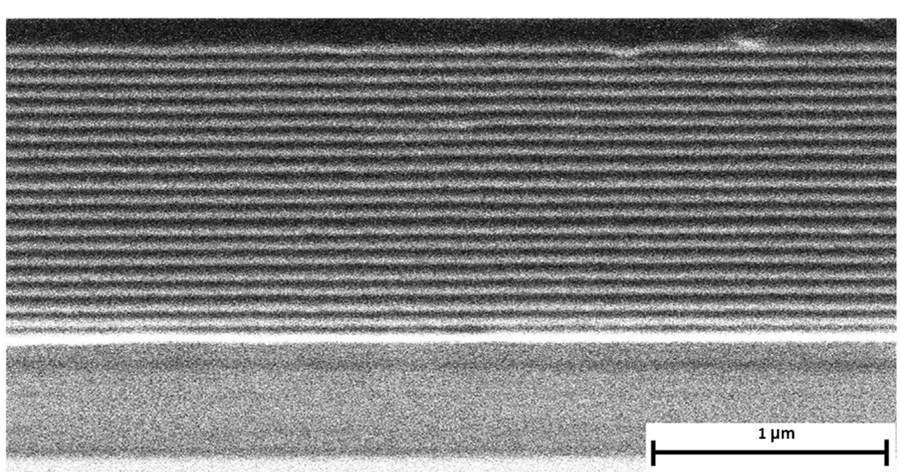

Fig. 2. SEM imaging of the DBR.