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Combined (ZnSe/MgS)/ZnCdSe Bragg Reflectors Grown Using ZnS as a Sulphur Source

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We report on MBE growth and study of optical and structural properties of (ZnSe/MgS)/ZnCdSe distributed Bragg reflectors with $\lambda = 520$ nm and $R_{\max} = 97\%$. The samples were grown pseudomorphically on GaAs substrate using ZnS as a sulphur source. Scanning electron microscopy, X-ray diffraction, and optical measurements showed good optical and structural characteristics of the Bragg reflectors.

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1. Introduction

Semiconductor microcavities have been attracting strong scientific interest for almost 20 years [1]. Their main characteristic feature is an effective interaction of photons and excitons, which results in formation of a quasi-particle called exciton–polariton [2]. The strength of this interaction is especially large in II–VI semiconductors [3], which are therefore possible candidates for manufacturing polaritonic devices capable of operating at room temperature. It is of great importance to grow the whole structure using II–VI materials only.

There have been several recent attempts to use zinc-blende MgS — the lowest refractive index material nearly lattice-matched to GaAs — for optical structures. For example, Suemune et al. have grown a 5-period ZnSe/(ZnSe/MgS) distributed Bragg reflector (DBR) with a 92% reflectivity by metal-organic vapor phase epitaxy [4]. Kruse et al. have demonstrated 17-period DBR of the same type with 99% reflectivity, grown by molecular beam epitaxy (MBE) using a valved cracker cell as a sulphur source [5].Earlier Bradford et al. have suggested

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to employ ZnS as a sulphur source to grow MgS/ZnSe quantum wells (QWs), using the efficient Mg–Zn exchange interaction which is due to the much stronger Mg–S binding energy as compared to the Zn–S one, although they have not applied this technique to DBRs [6]. This paper reports on the studies of novel design (ZnSe/MgS)/ZnCdSe DBRs grown by MBE using ZnS as a sulphur source.

2. Bragg mirror design

We have developed an MBE technique of growing MgS-containing II–VI DBRs, using ZnS as the sulphur source. The middle of the stop-band was chosen to correspond to a standard ZnCdSe QW wavelength, which is ≈ 520 nm. It has been pointed out by Bradford et al. [6] that pseudomorphic growth of zinc-blende MgS on GaAs is only possible under low temperatures and is limited by a certain critical thickness depending on the temperature. These constraints do not allow growing of a pure MgS/ZnSe DBR with $\lambda/4$-thick layers. Therefore, we used an MgS/ZnSe superlattice (SL) as a low index material and ZnCdSe solid alloy with Cd $= 3\%$ as a high index material.

The refractive index dispersion curves of MgS, ZnSe, and ZnCdSe have been calculated using modified single effective oscillator model [7] (values $E_0 = 7.5$ eV, $E_{\mathrm{g}} = 4.5$ eV, and $E_{\mathrm{d}} = 27$ eV, taken from [8], were used to describe MgS in this model).

The design was optimized in order to obtain stress compensation in the whole superlattice, while keeping the refractive index contrast high enough. This optimization yielded the design presented in Fig. 1. The nested SL consists of four MgS layers of 10 nm and four ZnSe layers of 3 nm, providing approximately 75% of average MgS content. The high-index ZnCdSe layer with Cd $= 3\%$ is of a 45 nm thickness. The composite multilayer structure consists of 15 periods, having a total thickness of 1450 nm. Such structure should provide at least 95% reflectivity at the center of the stop-band.

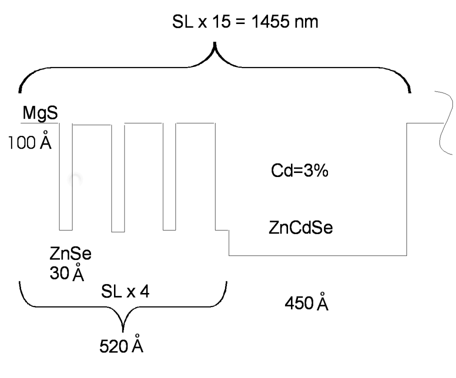

Fig. 1. Design of the combined superlattice of the DBR.

3. Experiment

The samples were grown pseudomorphically on a GaAs (001) substrate in an EP-1203 (home made) MBE setup equipped with elemental sources of Zn, Cd, Mg, Se (the latter is a valved cracker cell) and a ZnS compound source. The growth temperature of 250°C allows one to grow MgS layers of necessary thickness without transformation to a rock-salt phase [6].

In this article we present experimental data on one of the samples. It was investigated by scanning electron microscopy (SEM), optical reflectivity measurements, and X-ray diffraction (XRD). Optical reflectivity was measured using SPECORD M40 double-ray spectral photometer, capable of operating both in UV and visible ranges (185–909 nm). XRD measurements were performed on a double-crystal diffractometer DRON-3M with a Ge(111) monochromator.

4. Results and discussion

The SEM image of the sample is shown in Fig. 2. The periodic structure of the combined (ZnSe/MgS)/ZnCdSe SL is clearly distinguishable. The layers are generally flat. The period of the composite DBR structure is 110 nm, which is within 10% of the intended value. The surface of the sample (not shown) exhibits random nanoscale roughness, which should not affect the reflectivity in the visible range.

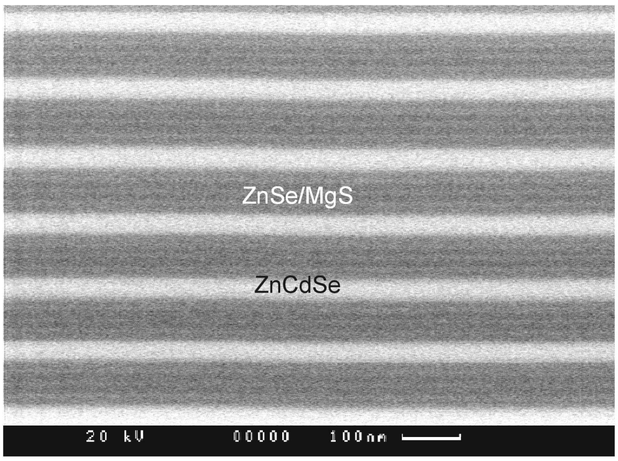

Fig. 2. SEM image of the combined superlattice.

X-ray diffraction curve of the DBR structure is shown in Fig. 3. Besides the narrow GaAs substrate peak, it is dominated by a broad peak shifted to smaller angles. The curve exhibits smooth interference fringes, indicating general flatness of numerous interfaces of the DBR structure. The figure also presents a simulation of the diffraction curve based on the design parameters. One can see that the position of the main broadened peak on the experimental curve corresponds to the position of an average intensity maximum at the simulation curve. However, narrow satellites of the composite DBR structure are not visible on the experimental curve, although the resolution of the apparatus should allow to distinguish them. This indicates that the structure has some deviation from periodicity on large scale, which, however, does not affect strongly its optical properties as will be shown below.

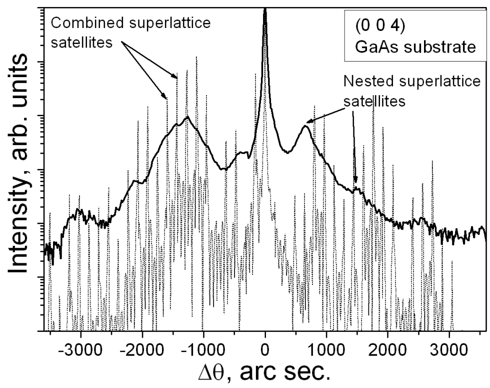

Fig. 3. XRD curve of the DBR structure: experiment (solid curve) and simulation (dotted curve).

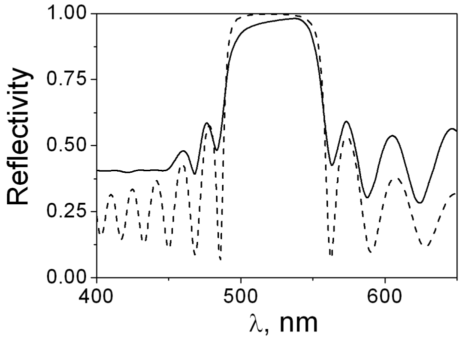

Fig. 4. Reflectivity of the DBR: experiment (solid curve) and simulation (dashed curve).

Figure 4 presents the results of optical measurements and their simulation. The stop-band of the Bragg mirror is very well pronounced. The background reflectivity far from the stop-band is due to the GaAs substrate. The position of the stop-band corresponds to the expected value (it is centered at 520 nm), and its width is consistent with the results of calculations based on transfer matrix method [9]. However, the shape of the experimental curve indicates some gradient in the period of the structure along the growth direction.

5. Conclusions

To conclude, this work has proven the feasibility of MBE growth of MgS-containing distributed Bragg mirrors, using ZnS as the sulphur source. Precise technology, high structural quality, and reflectivity of the mirrors make it possible to fabricate a complete II–VI microcavity with high Rabi splitting.

Acknowledgments

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