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Anisotropy of light emission from the surface LED based on the type-II ZnSe/BeTe heterojunction

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Abstract. Electroluminescence (EL) spectra are studied in the type-II ZnSe/BeTe light emitting diode (LED) based on a single heterojunction. The light emitted from the surface exhibits a strong in-plane linear polarization along [1$\bar{1}$0] crystal axis. The polarization is stable in respect to an increase of the applied voltage and temperature up to 300 K. The experimental data are discussed in the framework of a tight-binding model taking into account a type-II band alignment and lack of common atom in the ZnSe/BeTe heterosystem.

Introduction

It has been shown recently that a single heterojunction on the (001) atomic plane between two zinc-blend semiconductors has to reveal an optical anisotropy in the interface plane due to the lack of the point symmetry of the bulk matherials. The effect was demonstrated for number of type-I heterostructures [1]. The experimental results and theoretical calculations show that in the type-I structures the optical anisotropy may reach 20% in absorption and emission spectra. In a recent time similar effects have been observed for symmetrical quantum well structures under external electric field [2] for semiconductors system with type-I band alignment. The effect was called *Quantum Confined Pockels Effect*.

Semiconductor heterostructures with type-II band alignment, where electrons and holes are separated spatially in the alternating layers, have obvious advantages for the optical study of interface-related phenomena. In our papers [3, 4] we studied spatially indirect transitions in the type-II ZnSe/BeTe heterostructures such as superlattices and/or double-barrier structure and found that in this case the PL spectra are almost totally linearly polarized. In the present paper we perform further investigations of the optical transitions at the heterointerface ZnSe/BeTe. In particularly we measured polarization characteristics of the photoemitting diode based on the single type-II heterojunction ZnSe/BeTe.

Experimental details and results

The type-II heterosystem ZnSe/BeTe allows to fabricate a new type of light emitting diode (LED) which contains only a single ZnSe/BeTe interface. The emission of such a device can be adjusted between 640 nm and 515 nm [5]. The light emission occurs because of a spatially indirect carrier recombination between the ZnSe conduction band and BeTe valence band. Normally such devices based on a type-II heterostructures possess a very low radiative efficiency. However due to the strong carrier confinement at the interface at which the recombination of electrons and holes occurs efficiencies of 0.5% were achieved.

The devices were grown by molecular-beam epitaxy on p-type doped GaAs (100) substrates, which were covered by a thin GaAs buffer layer. In order to reduce the stacking

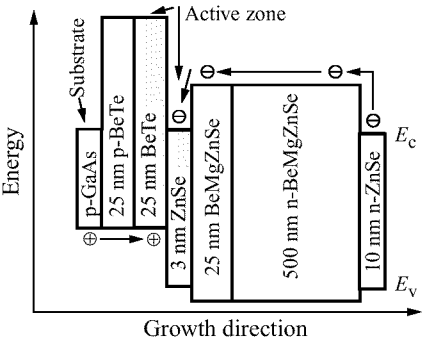

Fig. 1. Sketch of the band structure of a ZnSe/BeTe type-II LED.

fault density, 4 monolayers of BeTe were deposited before the growth of the diode. The growth was continued with 25 nm of 5×10^{18} cm^3 p-type BeTe. For the doping we used a nitrogen plasma at 300 W at partial pressure of 3×10^{-5} Torr. Then the plasma was switched off and 25 nm undoped BeTe was grown followed by 3 nm of ZnSe acting as a quantum well for electrons. After a spacer of 25 nm undoped BeMgZnSe 500 nm lattice matched n-BeMgZnSe doped with ZnI_2 to 5×10^{17} cm^{-3} resulting in bandgaps ranging from 2.85 eV to 3.35 eV respectively were grown. The structure was completed by 10 nm of n-ZnSe with an electron concentration of 10^{19} cm^{-3} for the ohmic metal contact. The scheme of the structure is presented in Fig. 1.

Figure 2(a) shows electroluminescence emitted from the surface of a typical LED at room temperature. The emitted light is strongly (is about 70%) linearly polarized in the direction [1$\bar{1}$0]. The line-width (FWHM) of the spectra was about 100 meV that is 3 times higher than in conventional ZnSe LED's with ZnCdSe quantum wells. By narrowing the ZnSe quantum well the emission wavelength can be shifted towards shorter wavelengths, for a well thickness of 1 nm luminescence light of 515 nm is emitted while the polarization degree remains the almost constant. The total output was measured in an Ulbricht sphere. For a voltage of 4 V and a current of 15 mA the power was 0.3 mW, which corresponds to an external quantum efficiency of 0.5%. This high efficiency of optical emission in the type-II structures can be explained by a carrier confinement at the interface. Degradation experiments did not show any decrease of efficiency after 1000 hours. Figure 2(b) demonstrates the angle dependence of the LED emission in polar coordinates.

Discussion

To explain the experimental results in [3, 4] authors assumed that PL signal of the spatially indirect transition related to the certain interface in the type-II ZnSe/BeTe heterostructures is almost totally polarized. Using structures with single heterojunction we clearly experimentally shown that this assumption is correct. In the ZnSe/BeTe system the conduction- and valence-band offsets amount to 2 eV and 1 eV, respectively, and the penetration depth of the electron wavefunction into the BeTe layer or for a hole into the ZnSe layer is about 3 Å.

Therefore, in type-II direct-gap ZnSe/BeTe heterostructures the wavefunctions of an electron and a hole participating in the spatially indirect optical transition overlap substantially only over few atomic planes. In this case the calculation of the interband matrix elements requires the knowledge of the microscopic behavior of the wavefunctions at the interfaces which can be obtained by using the pseudo-potential or tight-binding method.

The calculation based on tight-binding method shows that the strong polarization of

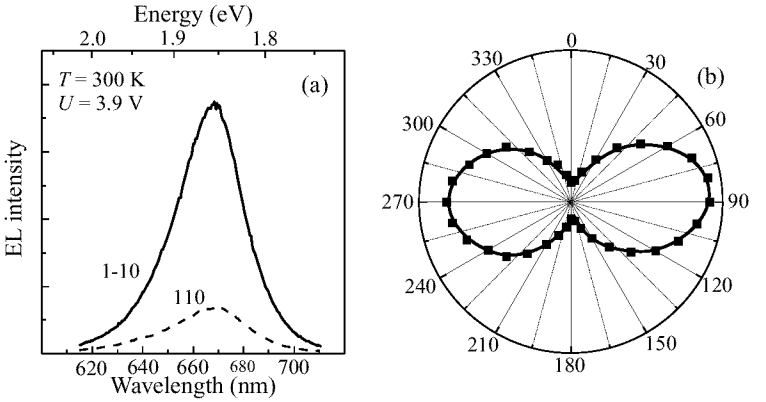

Fig. 2. (a) Surface emitted electroluminescence signal detected in two linear polarizations along the [1$\bar{1}$0] and [110] crystallographic axis. (b) EL angle dependence, polar coordinates.

the spatially indirect transition at the type-II heterojunction may be explained by the fact that contribution of only one atomic plane dominates in the matrix elements [3, 4]. The polarization of the light radiated by the one atomic plane is totally polarized along the chemical bonds lying at the plane. We mentioned here that so strong localization of the optical transition area is an absolutely new result, which is following from the polarization experiment, described above and developed theory.

We also analyze the influence of the interface disorder on the polarization degree. It may be shown that monomolecular fluctuations on the interface don't lead to remarkable changes in the polarization. On the other hand, the interfacial disorder connected with admixture of chemical bonds or any rearrangement of chemical bonds at the interfaces should be followed by dramatic variation of the polarization.

The reported effect of the optical anisotropy has a potential to become a powerful tool for investigation of the microscopic structure of heterointerfaces with monolayer resolution by means of non-destructive optical methods. We also mentioned here that the effect play an important role for designing any optical devices based on the type-II optical transition.

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References

[1] O. Krebs and P. Voisin, *Phys. Rev. Lett.* **77**, 1829 (1996).

[2] O. Krebs, D. Rondi, J. L. Gentner, L. Goldstein and P. Voisin, *Phys. Rev. Lett.* **80**, 5770 (1998).

[3] A. V. Platonov, V. P. Kochereshko, E. L. Ivchenko, G. V. Mikhailov, D.R. Yakovlev, W. Ossau, F. Fisher, A. Waag and G. Landwehr, *Phys. Rev. Lett.* **83**, 3546 (1999).

[4] D. R. Yakovlev, E. L. Ivchenko, V. P. Kochereshko, A. V. Platonov, S. V. Zaitsev, A. A. Maksimov, I. I. Tartakovskii, V. D. Kulakovskii, W. Ossau, M. Keim, A. Waag and G.Landwehr, *Phys. Rev. B* **61**, 2421 (2000).

[5] G. Reuscher, M. Keim, H. J. Lugauer, A. Waag and G.Landwehr, *J. Cryst. Growth* (2000) in press.