Abstract

In the late 90s, zinc oxide (ZnO) was "rediscovered" and introduced as an interesting alternative to gallium nitride (GaN). Considering the fact that the introduction of Cd into the wurzite ZnO lattice reduces the band gap energy of the material from the UV to the visible range, the ternary compound ZnCdO appears to be an interesting candidate to play the role of InGaN. However, the production of high-quality ZnCdO has encountered many technological challenges. An interesting and novel alternative for creating a ternary alloys is therefore the fabrication of quasi-ternary materials: short-period $\{ZnO/CdO\}_n$ superlattices (SLs). Such superlattices had not previously been reported in the scientific literature.

This doctoral dissertation focuses on undoped and Eu-doped superlattices based on ZnO and CdO layers. Doping of these quantum structures with Eu ions was carried out during layer growth "*in situ*" using plasma-assisted molecular beam epitaxy (PA-MBE). Undoped $\{ZnO/CdO\}_n$ SLs, as well as $\{ZnO/CdO\}_n$, $\{ZnCdO/ZnO\}_n$ and $\{ZnCdO/ZnMgO\}_n$ SLs doped with Eu ions were obtained and described for the first time in this study. Comprehensive characteristics of structures obtained in this thesis was performed using X-ray diffraction (XRD), secondary ion mass spectrometry (SIMS), transmission electron microscopy (TEM) and scanning electron microscopy (SEM), as well as photoluminescence (PL) and cathodoluminescence (CL) measurements.

In the first part of the doctoral dissertation, the growth conditions for undoped $\{ZnO/CdO\}_n$ SLs deposited on sapphire (Al_2O_3) substrates by the PA-MBE method were investigated to achieve high-quality structures. It was demonstrated that the best quality of the crystal structure of the $\{ZnO/CdO\}_n$ SLs was obtained using *m*-plane Al_2O_3 substrate. The quality of the layers was confirmed by XRD and TEM measurements. It has been shown that regardless of the thickness of the sublayers, ZnO crystallizes in the hexagonal wurtzite structure, while CdO layers have the cubic rock salt structure. The study also investigated the effect of growth temperature on the quality of $\{ZnO/CdO\}_n$ SLs deposited on *m*-Al_2O_3 substrates. It was shown that the growth temperature affects the structural and optical properties of the superlattices. Increasing the substrate temperature during growth degrades the quality of the studied superlattices. The thesis also considers the issue of diffusion in $\{CdO/ZnO\}_n$ superlattices. For this purpose, the structures were annealed after growth. Using a combination of SIMS and CL depth profiling methods, it was found that the uniformity of Cd distribution after rapid thermal annealing proces of $\{ZnO/CdO\}_n$ SLs at high temperatures depends on the thickness of the CdO sublayers.

The second part of the dissertation is devoted to studies on *in situ* Eu doped $\{ZnO/CdO\}_n$ and $\{ZnCdO/Zn(Mg)O\}_n$ SLs. It was shown that it is possible to obtain high-quality periodic structure of $\{ZnCdO/Zn(Mg)O\}_n$ SLs doped with Eu with sharp interfaces between sublayers. It has been proven that Eu ions are incorporated into Zn(Cd,Mg)O layers directly during growth proces (*in situ*) by molecular beam epitaxy with a plasma oxygen source, without causing second phase or phase separation and occupying strictly defined sublayers. Next, the work investigated the effect of annealing the $\{ZnO/CdO\}_n$ and $\{ZnCdO/Zn(Mg)O\}_n$ SLs on the thermal activation of Eu ions. The study demonstrated increased efficiency in an increase in the efficiency of red emission associated with the presence of Eu ions. It was found both that the Zn(Mg)O barrier height and the (Zn,Cd)O

quantum well thickness directly affect the emission intensity. Reducing the thickness of the CdO and ZnCdO quantum wells increases the efficiency of Eu ion excitation, which was confirmed by CL measurements.

Thanks to the development of the growth of superlattices based on ZnO and CdO by the PA-MBE method, control of the crystallographic properties of the sublattices and their thickness, which in turn made it possible to modificate energy band gap, a quasi-ternary material was obtained that represents an alternative to random ZnCdO alloys. The introduction of Eu ions to these quantum structures also allowed for generation of red emission and investigating the influence of the barrier and quantum well composition on the intensity of this emission in the $\{ZnO/CdO\}_n$ and $\{ZnCdO/ZnMgO\}_n$ structures. Understanding aspects of diffusion in the studied structures related to the growth temperature or annealing temperature has significantly knowledge in this area. Studies of undoped and Eu-doped $\{ZnO/CdO\}_n$ and $\{ZnCdO/Zn(Mg)O\}_n$ SLs presented in this thesis confirm that these modern structures have the potential to be used in the design of contemporary optoelectronic devices.