Photoluminescence of $Hg_{0.3}Cd_{0.7}Te$ and $Hg_{0.7}Cd_{0.3}Te$ epitaxial films

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The results of a study of photoluminescence (PL) of epitaxial films of $Hg_{0.3}Cd_{0.7}Te$ and $Hg_{0.7}Cd_{0.3}Te$ solid solutions grown by molecular beam epitaxy are presented. A comparison of PL data with the results of optical transmission measurements and structural and microscopic studies showed that in terms of the degree of disorder of the solid solution, the studied $Hg_{0.7}Cd_{0.3}Te$ films are not inferior in quality to the material synthesized by other methods. For $Hg_{0.3}Cd_{0.7}Te$ films, PL data revealed significant composition fluctuations and the presence of acceptor states, which indicates the need to optimize the technology

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1. Introduction

Solid solutions (SS) $Hg_{1-x}Cd_xTe$ (MCT) are widely used for the development of infrared photoelectronics devices. In photodetectors based on MCT, both traditional materials of small composition $x \approx 0.2-0.3$ [1,2] and wider-band compositions $x \approx 0.5-0.7$ [3,4] are currently used; the latter are also in demand in the manufacture of waveguide layers of laser structures [5]. Due to the high degree of ionicity of the chemical bond, MCT SS exhibit significant disorder, which manifests itself, among other things, in fluctuations of the chemical composition and the appearance of corresponding tails in the density of states. The actual scale of disorder in MCT samples of different compositions remains a subject of debate [6,7]. Using the photoluminescence (PL) method, we conducted a comparative study of the properties of the $Hg_{0.3}Cd_{0.7}Te$ and $Hg_{0.7}Cd_{0.3}Te$ SS layers; these data were supplemented by optical transmittance measurements and microscopic and structural studies.

2. Experiment procedure

The layers were grown by molecular-beam epitaxy (MBE) on GaAs ($x \approx 0.3$ and $x \approx 0.7$) and Si(013) ($x \approx 0.3$) substrates at the A.V. Rzhanov Institute of Semiconductor Physics SB RAS [8]. The x value was monitored using *in situ* ellipsometry and *ex situ* optical transmittance (OT) measurements at the $T = 300$ K temperature using an InfraLUM-801 spectrometer. PL spectra were obtained at $T = 4.2-300$ K using a MDR-23 monochromator. The PL signal was excited with a semiconductor laser with the wavelength of $1.03\,\mu$m and recorded with the InSb or HgCdTe photodetectors (for the layers with $x \approx 0.3$) or Ge photodetector (for the layers with $x \approx 0.7$). Microscopic studies were carried out on a TESCAN MIRA 3 electron microscope with an Ultim® Max 100 attachment for energy-dispersive X-ray spectroscopy (EDXS). Structural studies included taking X-ray diffraction patterns using a DRON-8 unit in a slit configuration with a BSV-29 high-focus tube with a copper anode and a NaI(Tl) scintillation detector.

3. Results and discussion

According to X-ray diffraction (XRD) data, the studied layers were characterized by a crystalline structure. For example, in the diffraction pattern of sample 0720 with $x = 0.32$ (substrate Si), the peak at $2\theta \approx 97.8^\circ$ with half-width $1038''$ was dominant. For sample 0417 with $x = 0.74$ (GaAs substrate), the main diffraction peak from the MCT layer was the peak at $\theta = 102.3^\circ$ with half-width $358''$.

Figure 1 shows the OT spectra for a number of samples of the compositions $x \approx 0.3$ (Figure 1, *a*) and $x \approx 0.7$ (Figure 1, *b*). Most of the studied samples (in particular, all samples with $x \approx 0.3$ (Figure 1, *a*)) were characterized by a sharp edge of the OT. The OT spectrum of sample 1003 turned out to be similar to that of a [9] multilayer structure, which indicated the heterogeneity of the layer in composition (Figure 1, *b*). For all samples, in the low-energy area, a fringe pattern was observed in the spectra, indicating good planarity of the epitaxial structures.

EDXS data on the chemical composition of the material confirmed the results of determining the composition based on ellipsometry and OT data, which allowed to reliably determine the composition of the SS for interpreting the results of the PL study.

The PL spectra of all studied layers with $x \approx 0.3$ at $T = 4.2$ K contained one line with a half-width from 6 to 9 meV. At $T = 95$ K, the half-widths of the spectra ranged from 14 to 19 meV, at $T = 300$ K — from 40 to 55 meV. The PL spectrum of a sample of a bulk crystal studied for comparison, and grown by vertically directional solidification with replenishment from the solid phase, at $T = 4.2$ K also contained one line with a half-width of 6 meV. At $T = 85$ K, the half-width of this line was 15.7 meV, at $T = 300$ K — ~ 49 meV. Similar values

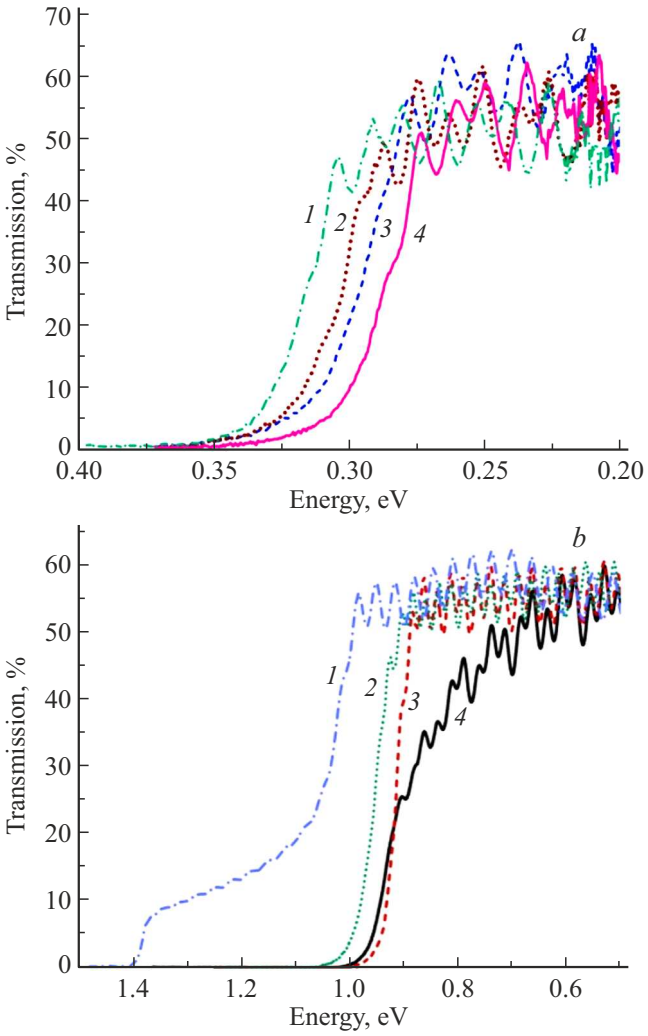

Figure 1. Optical transmission spectra of MCT layers of composition $x \approx 0.3$ (substrate Si): 0303 ($x = 0.31$) — *1*, 0124 ($x = 0.30$) — *2*, 0423 ($x = 0.30$) — *3* and 0219 ($x = 0.29$) — *4* (*a*), and $x \approx 0.7$: 1003 ($x = 0.69$) — *1*, 1227 ($x = 0.71$) — *2*, 1224 ($x = 0.72$) — *3*, 1222 ($x = 0.73$) — *4* (*b*) at $T = 300$ K. (The colored version of the figure is available on-line).

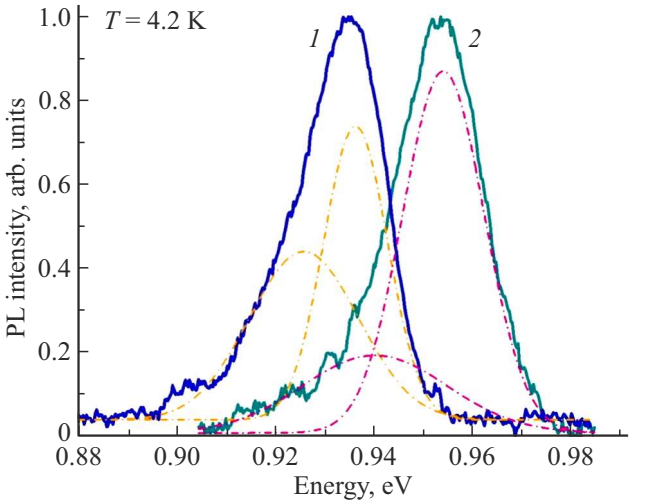

Figure 2. Normalized PL spectra of MCT epitaxial layers with $x \approx 0.7$ at $T = 4.2$ K: *1* — sample 1223 ($x = 0.71$), *2* — sample 1222 ($x = 0.73$). The dash-dot lines show the decomposition of the spectra.

were reported for layers with $x \approx 0.3$ grown by liquid-phase epitaxy (LPE) and for a number of layers grown by MBE and studied previously [10]. Thus, in terms of their optical properties, layers with $x \approx 0.3$ grown by MBE were close to the material grown by other methods. Let us also note that the spectra of the studied layers grown on Si substrates did not contain lines associated with acceptor states, typical of material with $x > 0.35$ grown using this technology. This result indicates a well-developed technology for MBE films of small composition for both GaAs and Si substrates.

Figure 2 shows examples of low-temperature PL spectra of layers with $x \approx 0.7$. The spectra had a pronounced asymmetric shape and were well approximated by two Gaussians with a distance between them of 12–18 meV. The half-widths of high-energy (HE) lines at $T = 4.2$ K ranged from 15 to 19 meV, low-energy lines, from 30 to 45 meV. The latter were traced in the spectra up to a temperature of ~ 50–60 K; they can be attributed to transitions to acceptor states in the band gap. The half-widths of the HE PL lines at $T = 4.2$ K in the studied layers turned out to be $\sim 50\%$ greater than in layers of similar compositions grown by the LPE method (9–13 meV, [11]).

Figure 3 shows the temperature dependences of the position of the high-energy PL peaks for layers with $x \approx 0.3$ (Figure 3, *a*) and $x \approx 0.7$ (Figure 3, *b*). A common feature, regardless of the composition of the solid solution, is the significant difference between the energies of the E_{PL} peaks and the temperature dependences of the $E_g(T)$ band gap calculated according to the work [12]. At $T < 100$ K $E_{PL} \ll E_g$; this is explained by the fact that optical transitions in MCT at low temperatures are determined by the recombination of excitons localized on composition fluctuations [12–14]. For layers with $x \approx 0.3$, the difference between E_{PL} and E_g at $T = 4.2$ K was ~ 40 meV; the slopes

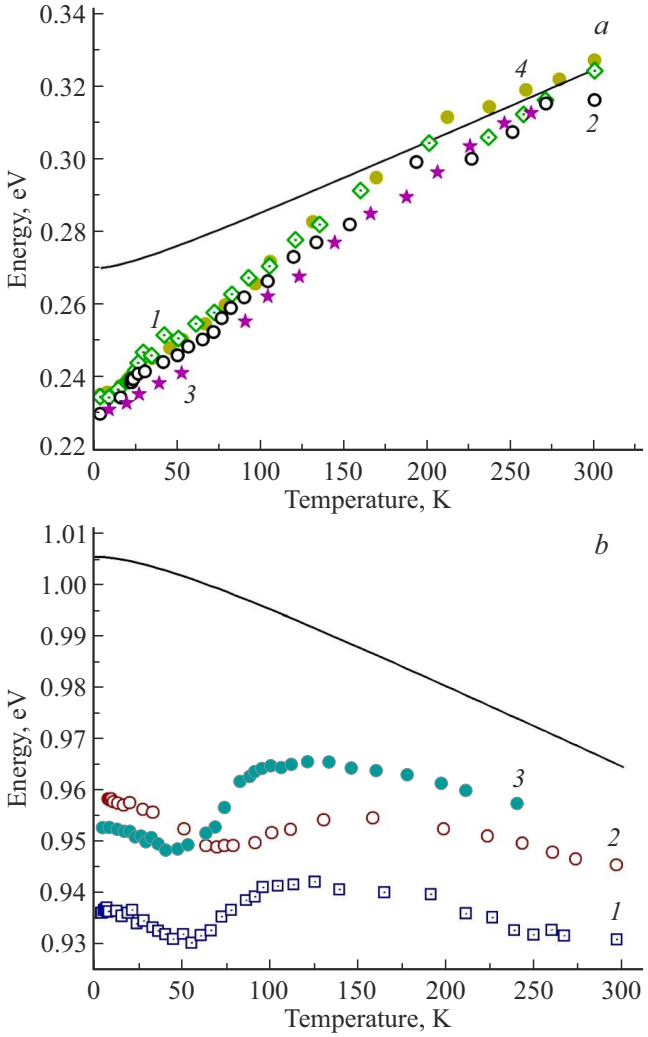

Figure 3. Temperature dependences of the PL peak position for epitaxial layers: *1* — 0303 ($x = 0.30$), *2* — 0219 ($x = 0.31$), *3* — 1202 ($x = 0.30$) and *4* — MCT crystal sample with $x = 0.31$ (*a*), and *1* — 1223 ($x = 0.71$), *2* — 1227 ($x = 0.71$) and *3* — 1222 ($x = 0.73$) (*b*). Solid curves — dependences $E_g(T)$, calculated according to data [12] for MCT with $x = 0.31$ (*a*) and $x = 0.70$ (*b*).

of the $E_{PL}(T)$ dependence were close and did not differ from those for the bulk crystal sample (Figure 3, *a*) and previously studied samples of this composition, grown using this MBE technology [10]. This once again confirms the fact of a well-developed MBE technology for films of small composition, which makes it possible to grow high-quality material, where disorder is due only to the specifics of the formation of SS MCT.

In Figure 3, *b* it is clear that for samples 1223 and 1227 with nominally the same $x = 0.71$ energies E_{PL} differ by ~ 15 meV over the entire temperature range Also, for the studied layers with $x \approx 0.7$, the $E_{PL}(T)$ dependence as a whole is practically absent, i. e. $E_{PL}(4.2\,\text{K}) \approx E_{PL}(300\,\text{K})$, although the $E_g(T)$ dependence should not be observed for MCT with $x = 0.5$ [12]. At $T \approx 50-60$ K, there is a local minimum in the $E_{PL}(T)$ curves, which is a sign of exciton localization. At $T > 100$ K the slope of the $E_{PL}(T)$ curve begins to approach that of the $E_g(T)$. The transition from a „red“ to a „blue“ shift of the PL peak with a further approach to the $E_g(T)$ slope with increasing temperature was previously observed both in layers with $x \approx 0.7$ grown by LPE [11,13] and in bulk MCT crystals of similar compositions [14]. In cases [11,13,14], however, the minimum on the $E_{PL}(T)$ curve corresponded to $T \sim 25$ K. An increase in the temperature at which exciton delocalization begins in the layers studied in this work may be a sign of larger-scale composition fluctuations. Together with the appearance of the acceptor states described above, which are atypical of structures grown by this MBE technology on GaAs [11] substrates, this may be evidence of the need to optimize the technology for the synthesis of MCT of large compositions. Since the optimal modes of MBE MCT with large and small x differ significantly [15], improvement of the synthesis of layers with $x \approx 0.7$ for photodetector and laser (where there are layers with small x) structures should obviously proceed independently.

4. Conclusion

Thus, we conducted a study of the optical and structural properties of the $Hg_{0.3}Cd_{0.7}Te$ and $Hg_{0.7}Cd_{0.3}Te$ layers with an emphasis on PL studies. Studies of layers using OT, XRD and EDXS methods showed good quality of the material. Using PL, it was found that, in terms of the degree of disorder, $Hg_{0.7}Cd_{0.3}Te$ layers grown by MBE are not inferior in quality to material synthesized by other methods. For the $Hg_{0.3}Cd_{0.7}Te$ layers, PL data revealed significant composition fluctuations and the presence of acceptor states, which indicates the need to optimize the technology.

Conflict of interest

The authors declare that they have no conflict of interest.

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