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STIMULATED AND LASER EMISSION IN CdZnTe/CdMnTe DOUBLE QUANTUM WELL HETEROSTRUCTURES‡

L. Kowalczyk, G. Karczewski, T. Wojtowicz and J. Kossut

Institute of Physics, Polish Academy of Sciences
Al. Lotników 32/46, 02-668 Warszawa, Poland

Stimulated emission by optical excitation has been investigated in CdZnTe/CdMnTe quantum well heterostructures. Laser action has been achieved at 4.2 K and at 77 K with relatively low threshold values of the excitation intensity. Photoluminescence excitation spectra of the stimulated emission were obtained indicating that the optical gain involves exciton–exciton inelastic scattering.

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The physics of lasers based on II–VI wide gap semiconductor heterostructures operating in the visible range of the spectrum have been the subject of increasing interest in the last few years. Independently of the issues related to doping of this materials (in order to form *p–n* junctions) the lasing of II–VI quantum well (QW) heterostructures was studied by optical excitation. The photo pumping was shown to lead to a pulsed laser action in CdTe/CdMnTe at 760 nm [1] and in CdZnTe/ZnTe multi quantum well (MQW) structures at the red part of the visible spectrum [2]. The room temperature lasing in the blue-green region has been obtained in optically pumped MQW and single QW structures of ZnCdSe/ZnSe [3, 4]. Achievement of lasing by optical pumping led to the subsequent success of the diode laser when *p*-type doping become available [5]. Recently, most of the attention has been devoted to studies of lasing mechanisms in selenium based heterostructures [6, 7]. In this paper we report on a study of stimulated emission from optically excited CdZnTe/CdMnTe QW heterostructures operating in the red-yellow range of the visible spectrum. A point of particular interest in this ternary heterostructure is a possibility of reducing the lattice mismatch by varying the alloy composition. The investigated structures were grown on (100)GaAs substrates by molecular beam epitaxy. A thick CdTe buffer was deposited prior to the heterostructure growth. The active region consisted of two ZnCdTe quantum wells, each 100 Åwide, separated by a 100 Å barrier made of CdMnTe.

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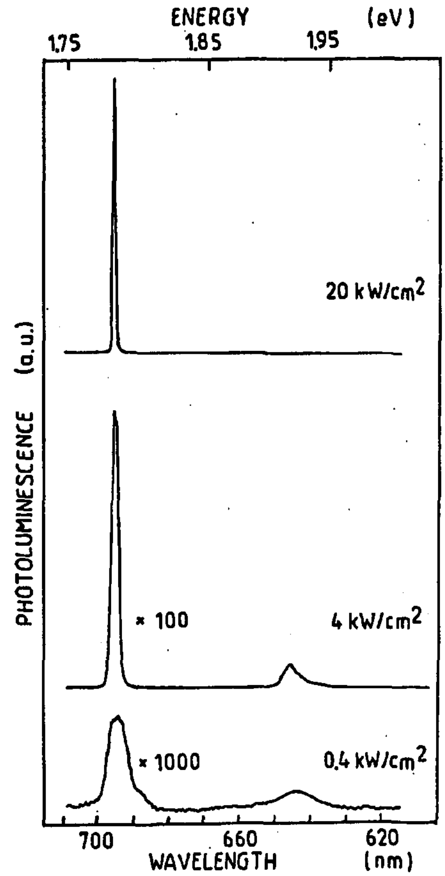

Fig. 1. Edge emission spectra of $Cd_{0.75}Zn_{0.25}Te/Cd_{0.77}Mn_{0.23}Te$ quantum well SCH at 4.2 K for three excitation power levels. The energy of the pumping photons was equal to 2.33 eV.

In order to optimize the device performance, a series of structures with different compositions of the barrier and/or well material was grown and characterized. In all samples investigated the lattice mismatch between the barriers and the wells did not exceed 0.6%. The optical confinement in the investigated samples was assured by embedding the active structure in a material having a smaller index of refraction. This was either made in an abrupt fashion (separate confinement heterostructures — SCH), or gradually (GRINSCH structures). As the cladding layer we used either cubic MnTe or $Cd_{1-x}Mn_xTe$ with a high molar fraction of Mn ($x = 0.9$).

In order to obtain a lasing action in the investigated structures the substrates were thinned to about 300 μm and the samples were cleaved into bars of approximately 1×0.5 mm^2. The reflective mirrors were formed by the natural facets of the cleaved samples. The samples were optically pumped edge-to-edge with a second harmonic pulsed Nd:YAG laser (532 μm). The pulse duration was

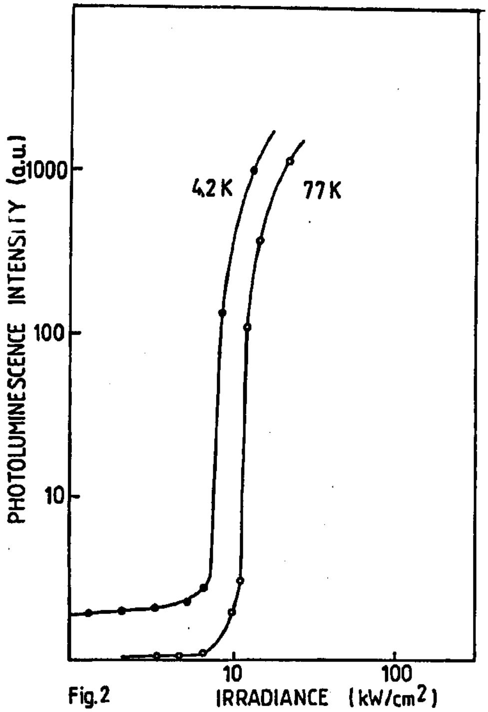

Fig. 2

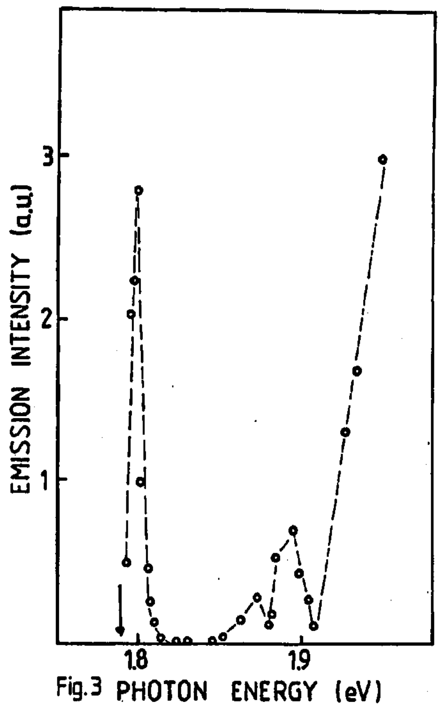

Fig. 3

Fig. 2. Integrated edge emission intensity vs. excitation power density for $Cd_{0.75}Zn_{0.25}Te/Cd_{0.77}Mn_{0.23}Te$ SCH.

Fig. 3. Photoluminescence excitation spectrum for $Cd_{0.75}Zn_{0.25}Te/Cd_{0.77}Mn_{0.23}Te$ SCH detected at the stimulated emission energy (marked by the arrow). The line is to guide the eye.

5 μs, which is much longer than the recombination time in the material, so that the excitation was quasi-steady.

Emission spectra from $Cd_{0.75}Zn_{0.25}Te/Cd_{0.77}Mn_{0.23}Te$ SCH collected from the cleaved edge are shown in Fig. 1 for various pumping power densities. The energy of the pumping photon was equal to 2.33 eV. With increasing excitation intensity the emission from the $Cd_{0.75}Zn_{0.25}Te$ layers becomes the dominant feature, with very narrow line characteristics. The photoluminescence related to $Cd_{0.77}Mn_{0.23}Te$ barriers disappears in the topmost spectrum in Fig. 1. This is because of the fact that during the measurement of this spectrum the collecting lens was removed from the experimental setup, so that only the laser radiation emitted from the sample reached the monochromator due to its collimated nature. This very fact is already an indication that at this excitation density we are dealing with light emitted from $Cd_{0.75}Zn_{0.25}Te$ wells in the process of a lasing action.

The integrated photoluminescence intensity from $Cd_{0.75}Zn_{0.25}Te/Cd_{0.77}Mn_{0.23}Te$ SCH at 4.2 K and 77 K is shown in Fig. 2 as a function of the excitation density. The luminescence increases sharply as the exciting power approaches a threshold value for lasing. The threshold is equal to 10 kW/cm² for

77 K and 6 kW/cm^2 for 4.2 K. In order to obtain information concerning the recombination processes responsible for the stimulated emission observed by us, we measured photoluminescence excitation spectra of $Cd_{0.75}Zn_{0.25}Te/Cd_{0.77}Mn_{0.23}Te$ SCH (see Fig. 3). The intensity of the stimulated emission from the cleaved edge of the sample was measured as a function of the excitation energy (the energy of the detected radiation was about 1.786 meV, as marked by an arrow in Fig. 3).We attribute the maximum at 1.8 eV to the heavy hole exciton ground state. The rapid increase of the stimulated emission for exciting light energies greater than the band gap of the barrier material (1.93 eV) is related to the creation of free carriers in the barrier. The stimulated emission is red-shifted from the heavy hole exciton energy by approximately 14 meV. Such a shift is too large to be caused by localization of the heavy hole excitons by fluctuations of the well width, or by chemical or spin fluctuations in the materials comprising the structure (these are approximately 5 meV). The shift is too small to be explained in terms of the phonon interaction (LO phonon energy is equal to 25 meV). On the other hand, the calculated exciton binding energy in the QW under scrutiny is 14.4 meV. Therefore, one of possible explanations for our experimental results is in terms of exciton-exciton inelastic scattering being responsible for the stimulated emission observed in our experiments. This process was proposed by Newbury et al. to account for the emission from ZnSe epilayers [8] and is often invoked now in the context of II-VI lasing SCH. In such a process two excitons are scattered, with one of them recombining (and emitting a photon) and the other being dissociated. The dissociation energy (equal to at least the exciton binding energy) is provided by the lowering of the energy of the emitted photon. In conclusion, we demonstrated optically pumped laser action in the lattice-matched CdZnTe/CdMnTe QW heterostructures.

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