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Stimulated emission from optically excited $Cd_xHg_{1-x}Te$ structures at room temperature

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ABSTRACT

Main requirements for the optimization of $Cd_xHg_{1-x}Te$ (MCT) structures with a view to increasing the wavelength of stimulated emission under optical pumping are discussed. A 2–2.5 μm stimulated emission from optimized MCT structures is observed experimentally at room temperature. The measured values of the gain in the active medium amount to 50 cm^{-1} at a 2 μm emission wavelength.

1. Introduction

Investigation of $Cd_xHg_{1-x}Te$ (MCT) material and MCT solid-state films and structures has been historically associated with the development of infrared (IR) range photodetectors (see, for example, Refs. [1,2]). However, not many works are devoted to the application of this material for the development of IR lasers. There have been reports mainly on low-temperature (well below room temperature) observation of stimulated emission from bulk MCT samples (see Refs. [1,3–7]). No substantial advancement into the long wavelength range of stimulated emission has been attained at room temperature, which seems to be associated with insufficient quality of the samples and with the use of non optimal samples for the laser emission. Besides, it was not clear whether it is possible to obtain stimulated emission from bulk MCT samples in the long wavelength range at high temperatures because of the important role of Auger recombination in MCT (see Ref. [1]).

Coherent photoluminescence in $Cd_xHg_{1-x}Te$ crystals for the first time was observed at 12 K in the wavelength range from 3.8 to 4.1 μm in samples optically pumped by GaAs diode pumping laser [3] (see also Ref. [1]). Bulk $Cd_xHg_{1-x}Te$ samples were grown by the Bridgman method. The thickness of the samples was about 25 μm and the length of the Fabry–Perot cavity was typically 120 to 150 μm. Development of optically pumped pulse lasers with operating wavelengths ranging from 1.25 to 2.97 μm at a temperature of 77 K was described in Ref. [4]. There was also a report of continuous laser emission at a 2.97 μm wavelength at $T=12$ K. Typical dimensions of the used samples were $0.15\times0.2\times2$ mm^3. Bulk samples with typical thickness values of 4 to 8 μm have been investigated at low temperatures in Ref. [5]. There was a report on tunable picosecond MCT lasers with operating wavelength $\lambda=1.2$ μm at temperature $T=5$ K; $\lambda=2.0$ μm at $T=5$ K and $\lambda=1.82$ μm at $T=70$ K. Stimulated emission from MCT films ($x=0.46$, thickness 0.6 μm) was observed at 2.42 μm in a 12–40 K temperatures range in Ref. [6]. The samples in this work were fabricated on a semi-insulating CdTe substrate by the molecular beam epitaxy (MBE). An Nd:YAG laser with the power of 3 to 4 kW/cm^2 was used for optical pumping of bulk samples. Similar results were obtained in Ref. [7] at temperatures $T=12$–77 K. The value of threshold intensity for those structures was about 7.2 kW/cm^2 at $T=77$ K and $\lambda=2.32$ μm.

There have been reports [8–10] on laser oscillation in thick (not quantum size) CdHgTe layers grown by metalorganic chemical vapor deposition (MOCVD). Laser emission was observed at temperatures $T=12$ K–160 K in the wavelength interval $\lambda=2.5$–3.3 μm. The typical film thickness was about 1.5–4 μm. Application of the MBE method made it possible to fabricate high quality samples with nearly micron thickness [11,12] and quantum-size structures [13]. Double-heterostructure laser in Ref. [11] operated under pulsed current at temperatures varying between 40 and 90 K. The emission wavelength was 2.86 μm at 77 K with a linewidth of 0.3 meV, and the pulsed threshold current density was 625 A/cm^2. Similar devices were also reported in Ref. [12].

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The stimulated emission wavelengths for these lasers at $T=77$ K were 2.9, 3.4 and 4.4 μm. Operation at 5.3 μm was demonstrated at 60 K. High-power capability of CdHgTe optically pumped laser in samples with quantum wells has been reported in Ref. [13]. The author therein observed laser emission at a 3.2 μm wavelength. The highest operation temperature was 154 K. Low threshold injection lasers based on CdHgTe were fabricated in Ref. [14,15]. The laser double heterostructure was grown by molecular beam epitaxy on (111) CdZnTe substrate. Laser emission at $\lambda=3.4$ μm and $\lambda=3.56$ μm was obtained at 78 K under pulsed current conditions. The thickness of the active layer was about 1 μm and the width of the laser stripe was 35, 45 or 55 μm. It should be noted that there is no essential difference in the way the laser is pumped. We believe that the optical pumping is simpler and more convenient for investigation of stimulated emission.

The latest achievements with regard to infrared stimulated emission in CdHgTe samples are associated with the vertical-cavity surface-emitting lasers (see, for example, Ref. [16]) based on quantum heterostructures. The reported results include laser emission at $\lambda=2.63$ μm at operating temperature $T=80$ K–190 K. It was demonstrated before that lasing can be fabricated in this material in a wide range of wavelengths 2–5.3 μm at temperatures up to 160 K. Our research objective is to fabricate MCT bulk films that would be optimal (in terms of geometrical sizes and chemical content) for obtaining stimulated emission. We would also like to find the upper limit of wavelength, at which stimulated emission (or laser emission) from MCT can be obtained at room temperature.

By now we have done a fairly good research into the possibilities for producing stimulated emission from the MCT structures (see, for example, Ref. [17–19]). However, all our earlier results have been obtained for samples that were not optimized for this purpose (their thicknesses were very large so that the samples could not be efficiently "pumped" by the optical pumping). An essential part of this paper is devoted to the problem of optimizing MCT samples to effectively obtain stimulated emission.

2. Samples and experimental setup

For sample optimization we suggest two schemes of the spatial distribution of composition and, hence, the band structure. The first structure is shown in Fig. 1a; it has a relatively thin MCT homogeneous layer. Thickness d of the structures should be as small as about 0.6–1 μm to secure the penetration of the optical pumping field into the sample. This condition makes it possible to "pump" the MCT layer well by optical pumping (in samples with the thickness of several microns, used in our earlier experiments, the active medium is apparently formed by the diffusion of carriers). The use of thin samples should result in a substantial decrease of the pumping intensity threshold for the stimulated emission. Yet, the active layer should not be too thin to ensure suitable electrodynamic conditions for the emitted wave and, hence, smaller the values of the electrodynamics dissipation. The presence of the surface wide gap passivation layer may increase the lifetime of nonequilibrium carriers.

In view of the above condition it would also be interesting to study the samples with a sufficiently thick surface "coating" layer that is transparent for the optical pumping wave. A structure of this type is shown in Fig. 1b. The surface layer thickness h is apparently not considerable, if it is transparent for the pumping wave. The important thing here is to make the width of the intermediate layer between the surface layer (with thickness h) and active MCT layer (with thickness d) as narrow as possible.

When carrying out this research, we fabricated MCT samples with the composition profile shown in Fig. 2a. At our disposal were different structures: right after growth, after growth with subsequent annealing at 260 °C for 3 h, and after growth with subsequent annealing at 290 °C for 1 h. We have studied samples with a covering CdTe layer (about 0.1 μm, see the scheme in Fig. 2b) and without it. The width of the gap for the active MCT layer (in the central "well") in these structures corresponds to the emission wavelength 2.81 μm (it was determined at $T=300$ K by the threshold of photoconductivity). Stimulated emission from these structures at $T=300$ K has been observed at the wavelength 2.5 μm (somewhat lower or higher, depending on the intensity of optical pumping) and only from the structures that had been annealed at 250 °C for 3 h. The after-growth structures (without annealing) produced only spontaneous emission at room

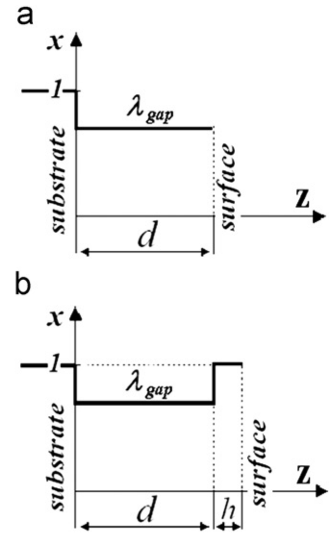

Fig. 1. Geometry of cross-section composition for the MCT samples optimization: (a) without the covering layer, and (b) with covering layer on a free surface; d is the thickness of MCT layer and z is the coordinate in the direction perpendicular to the film (z is counted from the buffer layer); h is the thickness of the surface wide gap passivation layer.

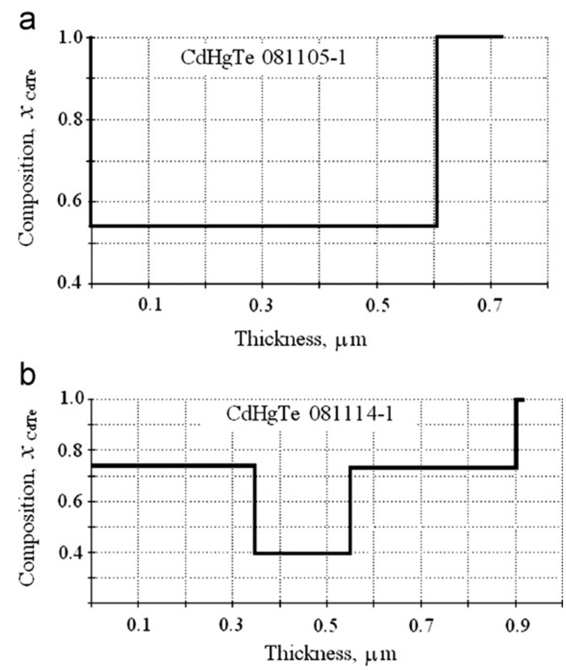

Fig. 2. Spatial profiles of the structures. Composition variation x versus film thickness: (a) MCT 0811085–1 and (b) MCT 081114–1. The coordinate is counted from a buffer CdTe layer deposited on the substrate.