E-beam longitudinal pumped semiconductor laser based on ZnCdS/ZnSSe type-II multi quantum well structure

M R Butaev[1,2], V I Kozlovsky[1,2], D A Sannikov[2] and Y K Skasyrsky[2]

[1]National Research Nuclear University «MEPhI».Kashirskoe highway 31, 115409 Moscow, Russia
[2]P.N. Lebedev Physical institute, 53 Leninsky pr., 119991, Moscow, Russia

E-mail: mbutayev@mail.ru

Abstract. A ZnCdS/ZnSSe multi quantum well structure was grown by metal-organic vapor phase epitaxy on GaAs substrate. The structure is consisted of the 45 ZnCdS layers of 5 nm in thickness separated by the 100 nm thin ZnSSe barrier layers and was the type-II heterostructure. A microresonator was produced from this structure for scanning electron beam longitudinal pumping. Lasing with output power up to 2W at 478 nm was achieved at room temperature.

1. Introduction

The ultimate goal of the authors is, to create a semiconductor disk laser with optical pumping operating at the fundamental frequency in the blue-green spectrum range [1]. Effective intracavity generation of the second harmonic in such as laser makes it possible to master the actual average ultraviolet range of the spectrum. For this, it is necessary to use resonant-periodic structures of wide-gap compounds as the active medium of the laser. Currently, one of the most popular and widely studied compounds, radiating in the blue-green region of the spectrum is the InGaN compound. Laser and light-emitting structures are usually grown on sapphire substrates by epitaxial methods. In the classical scheme of the semiconductor disk laser is used a high-reflecting Bragg mirror embedded in the epitaxial structure. Despite the great advances in nitride epitaxial technology, such a mirror cannot yet be obtained. In the new scheme of a semiconductor disk laser of the "membrane" type, all resonator mirrors are removed from the epitaxial structure [2]. For this, the active epitaxial structure is transferred to another substrate, and the growth substrate is removed. However, nitride heterostructures cannot be separated from the sapphire substrate, maintaining the optical quality of both surfaces of the heterostructure, and this is practically impossible due to the high chemical resistance of sapphire.

Other known compounds are wide-gap II-VI compounds. These compounds at the end of the last century were considered as the most promising compounds for blue-green spectrum lasers. The blue laser on structures based on ZnSe was implemented much earlier than on structures based on GaN [3]. However, the problem of degradation in lasers based on II-VI compounds has not yet been solved. In addition to the degradation factors inherent in injection lasers, in which it is necessary to create a pn junction and reliable contacts, the insufficient strength of chemical bonds of metal atoms of the second group with selenium and internal elastic stresses in quantum wells were also mentioned [4]. In optically pumped lasers, only the latter factors can play a significant role in degradation.

In this connection, in this report we consider a relatively new heterostructure with quantum wells ZnCdS/ZnSSe grown on a GaAs substrate as a potential active structure of semiconductor disk laser [5]. At a certain composition in quantum wells and barriers, all layers of the heterostructure can be fully consistent in the parameters of the crystal lattice with the GaAs substrate, which significantly reduces internal stresses. On the other hand, these structures can be easily transferred to another substrate due to the presence of selective GaAs etchants relative to II-VI compounds. However, the proposed heterostructures refer to heterostructures with zone discontinuities of the second type, which leads to the spatial separation of charge carriers generated by the pump, which in turn lowers the rate of radiative recombination and can lead to an increase in the lasing threshold. In this work, we present results that indicate that the latter observation is not essential and the proposed structure is promising for semiconductor lasers. So far, we're looking at a laser with a microresonator and an electron beam pump.

2. Experimental

Heterostructures were grown by vapor-phase epitaxy from metal-organic compounds in a hydrogen flow at atmospheric pressure in a quartz reactor. Dimethyl selenide $(CH_3)_2Se$, dimethyl cadmium $(CH_3)_2Cd$, diethyl sulfide $(C_2H_5)_2S$ and diethyl zinc $(C_2H_5)_2Zn$ were used as starting compounds. The growth was carried out on GaAs substrates oriented by 10^0 from plane (001) to plane (111)A. To prevent the interaction of Se with GaAs, after a high-temperature breakdown of the oxide from the substrate, its temperature decreased to 350 ^{0}C, and a low-temperature buffer ZnSSe layer was born. Then the substrate temperature gradually increased to a growth temperature of 450 ^{0}C. An interruption of 3-5 s was made between the layers, which improved the sharpness of the heterojunctions.

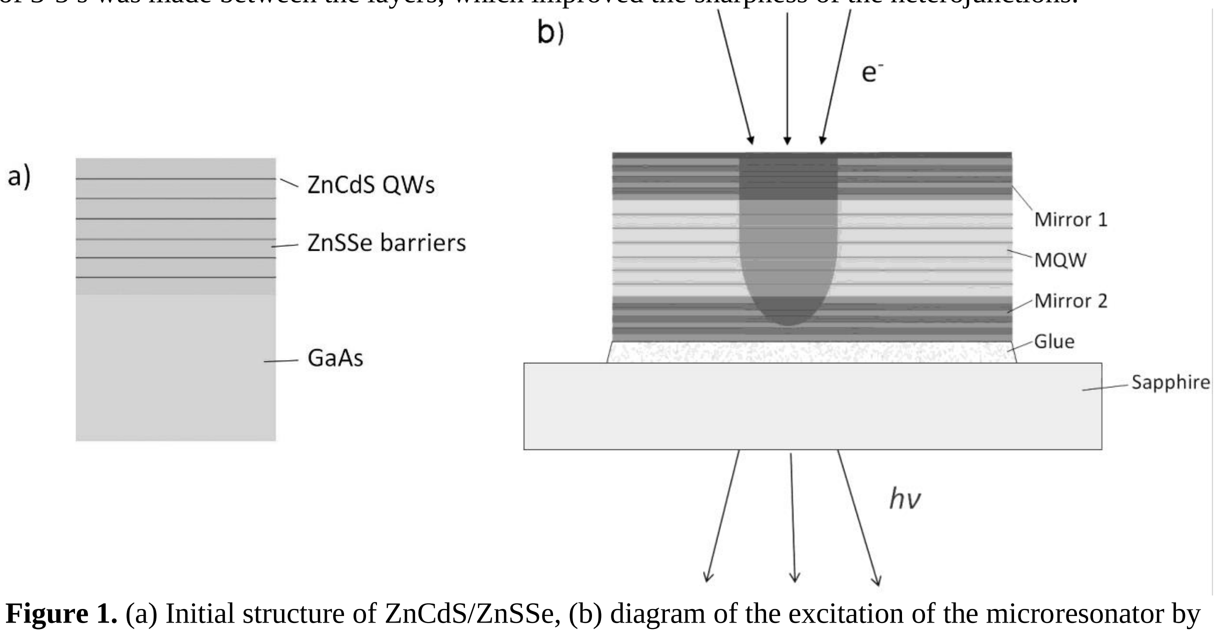

Figure 1. (a) Initial structure of ZnCdS/ZnSSe, (b) diagram of the excitation of the microresonator by the electron beam.

In this paper, we study the structure with 45 Zn0.4Cd0.6S/ZnS0.07Se0.93 QWs. The composition and thickness of the layer were determined by X-ray diffraction analysis. The structure began and ended with ZnSSe layers. All the ZnSSe layers had a thickness of 100 nm, and the ZnCdS layers had 5 nm. The structure is schematically presented in figure 1(a). A microresonator was made of the structure (see figure 1(b)). For this purpose, a mirror of alternating quarter-wave layers SiO_2 and ZrO_2 with a calculated reflection coefficient of 98.4% was applied to the surface of the structure. Further, the structure was glued to the sapphire substrate. First, the GaAs substrate was removed by grinding and then by chemical etching in a selective solution. On the vacant surface of the structure, the second mirror from SiO_2, ZrO_2 layers and an additional Al layer was coated.

The sapphire substrate was the exit window of the vacuum chamber. The structure was excited by a pulsed scanning electron beam with electron energy E_e = 50 keV and current I_e up to 2.5 mA. Diameter of e-beam spot on the structure increased with increasing the current and was about 50 μm at I_e = 2.5 mA.

3. Results and discussion

The spectral characteristics of the ZnCdS/ZnSSe MQW microresonator at room temperature are shown in figure 2. At low e-beam current density, the maximum of the emission spectrum is near 510 nm. It shifts to the short-wave side with increasing the e-beam current density. This shift is typical feature of emission of the MQW structure with the II type zone discontinuities. At I_e = 0.3 mA ($j_e \approx$ 20 A/cm^2), the lasing appears on one of the resonator modes near 478 nm.

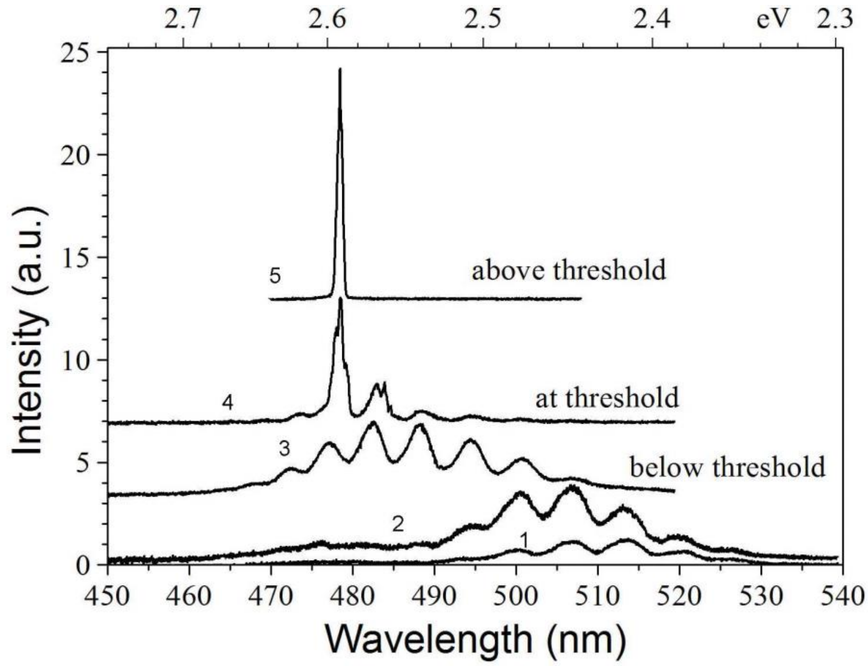

Figure 2. Changes in the emission spectrum of the ZnCdS/ZnSSe MQW microresonator with an increase in the electron beam current density: j_e = 0.001 A/cm^2 (1), 0.01 A/cm^2 (2), 15 A/cm^2 (3), 20 A/cm^2 (4), 100 A/cm^2 (5).

The dependence of the laser power on the power of the electron beam is present on figure 3. The dependence is nonlinear that is not clear until. Maximal laser power was as high as 2 W. Laser efficiency was 1.5 %. We hope that future optimization of cavity and improving of the structure quality allow achieving higher laser efficiency. In the figure 3, the picture of the field in the far zone is also shown. The total divergence angle of the first ring surrounding the central spot was 10^0.

The results obtained indicate that, despite the zone discontinuities of type II, the structure of $Zn_{0.4}Cd_{0.6}S/ZnS_{0.07}Se_{0.93}$ can be used in semiconductor lasers of blue-green spectrum range.

Acknowledgments

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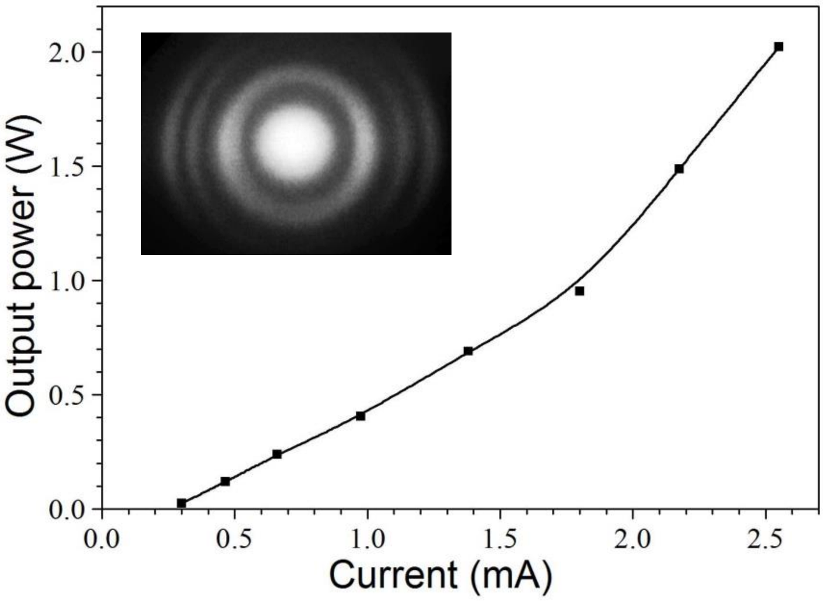

Figure 3. Dependence of the laser power on the e-beam current. The far field pattern of laser radiation inserts.

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