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Design of Optically Pumped PbS-Based Mid-Infrared Surface Emitting Lasers

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1. Introduction

Tunable mid-infrared lasers are useful for spectroscopic applications such as trace gas analysis, high speed gas detection. A high nonradiative Auger-recombination probability and large free carrier absorption proportional to λ^2 are making difficult to prepare midinfrared semiconductor lasers. Lead salt IV-VI materials such as PbTe, PbSe, and PbS have direct gaps at L-points of Brillouine zone and have almost symmetric band structure between conduction and valence bands. Thus the Auger recombination probability is much smaller than that of III-V and II-VI materials, and relatively higher temperature laser operations have been obtained in the IV-VI materials[1,2]. Optical pumped lasers are useful to decrease optical losses by free carrier absorption, and vertical external cavity surface emitting lasers (VECSELs) are useful in tunable laser operation[3]. We recently prepared optically pumped PbS based double heterostructure (DH) and multiple quantum well (MQW) structure VECSELs[4,5]. The MQW laser operated in high efficiency and high power at -70°C with external quantum efficiency of 16% and maximum pulsed output power of 2W. We describe here a design of optically pumped PbS-based tunable VECSEL.

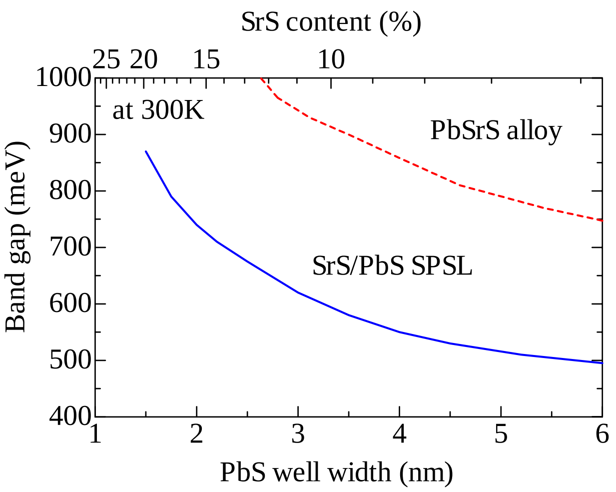

Fig.1 Band gaps of SrS/PbS SPSL with monolayer SrS and PbSrS alloy with the same SrS content.

2. SrS/PbS SPSL and quantum wells

SrS/PbS short-period superlattices (SPSLs) with monolayer SrS are useful for the optical excitation layers and barrier layers in the MQWs. The SPSL has higher carrier mobility compared with PbSrS alloy owing to smaller alloy scattering, and the higher mobility is useful to decrease free carrier absorption[4,5]. Figure 1 shows the band gap of the PbSrS SPSL, and the band gap of PbSrS alloy with the same SrS content. The band gap of the SPSL increases with the decrease of PbS layer thickness.

Figure 2 shows density of states and gain for PbSrS/PbS (111) MQW with 12nm PbSrS barrier and 8nm PbS well. The gain was calculated under the injected carrier concentration of 6×10^{18}cm^{-3}. Figure 3 shows dependence of optical gain on injected carrier concentration for the PbSrS/PbS MQW active layer from 80 to 300K with 20K step. Maximum gain per one quantum well is about 0.007, and optical intensity can be increased about 3.5% when the light passes through the five quantum wells under no optical loss. In surface emitting laser application, a multiple mirror with reflectivity as high as 99% is necessary, and optical loss caused by free carrier absorption should be decreased within few percent for one way of the vertical cavity. Significant free carrier absorptions exist in both PbS quantum well layer and PbSrS excitation layers in both side of active layer, and the free carrier absorption in the PbSrS excitation layer is decreased by decreasing the band gap to the direction of PbS quantum well.

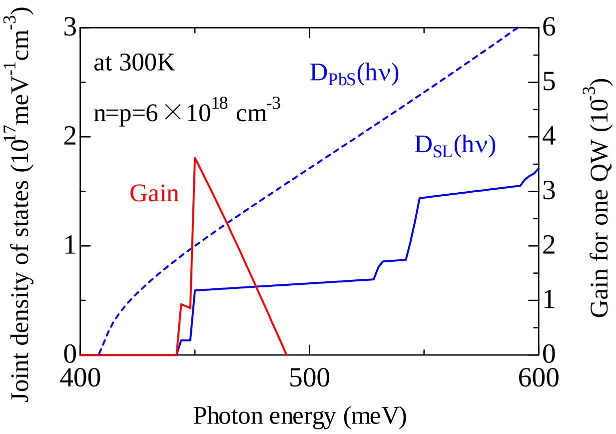

Fig.2 Density of states and gain for PbSrS/PbS (111) MQW with 12nm PbSrS barrier and 8nm PbS well. Small and large steps in the density of states correspond to [111] and other <111.> oblique valleys.

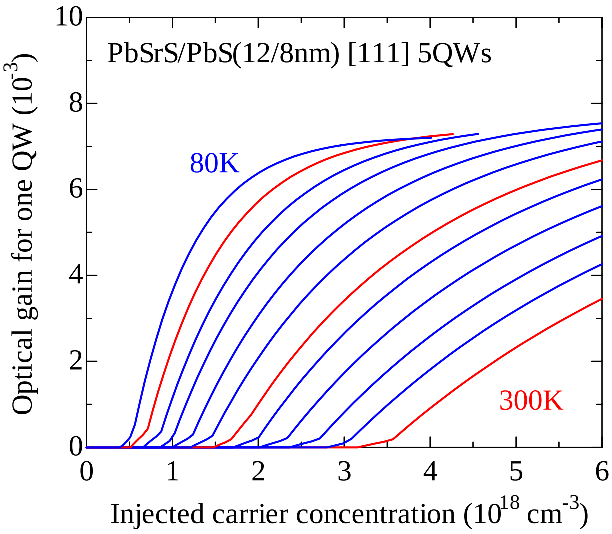

Fig.3 Dependence of optical gain on injected concentration for PbSrS/PbS MQW from 80 to 300K.

3. Multiple mirrors and design for tunable laser

There are various combinations of materials for the multiple mirrors of the VCSEL or VECSEL in PbS-based lasers. PbSrS/SrS, ZnTe/BaF_2, and PbSrS/BaF_2 multiple mirrors are expected for the multiple mirrors with a wide reflection band. Refractive index of PbSrS, SrS, ZnTe, and BaF_2 are 4, 2, 2.6, and 1.4, respectively. Figure 4 shows theoretical reflectance spectra of the PbSrS(170nm)/SrS (360nm), ZnTe(260nm)/ BaF_2(480nm), and PbSrS(170nm)/ BaF_2(480nm) multiple mirrors. High reflectivity mirrors exceeds 99% with wide reflection bands are obtained for the mirrors.

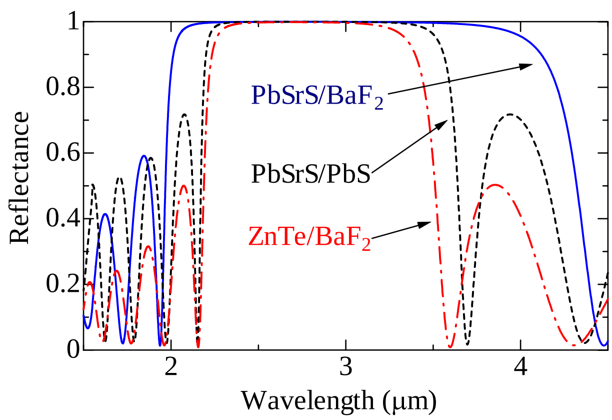

Fig.4 Theoretical reflectance spectra of the PbSrS/SrS (5.5 periods) , ZnTe/BaF_2 (5.5 periods), and PbSrS/BaF_2 (3.5 periods) multiple mirrors. Thicknesses of the PbSrS, ZnTe, SrS, and BaF_2 layers are 170nm, 260nm, 340nm, and 480nm, respectively.

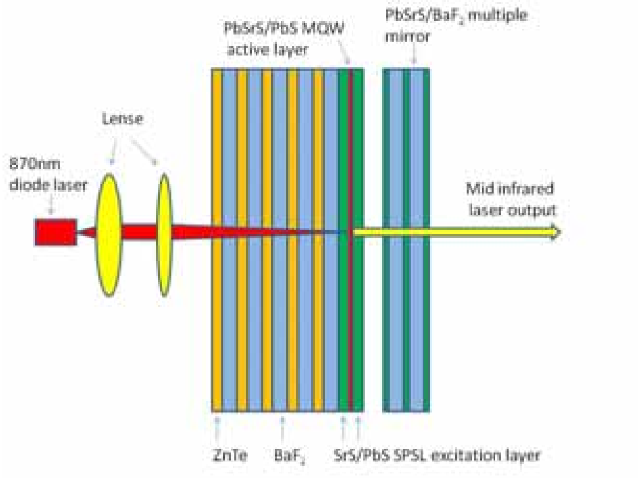

Fig.5 An optically pumped laser structure.

Figure 5 shows an optically pumped tunable mid-infrared laser structure. Tunability is obtained by slightly modulating the space w between the two mirrors (w < 0.1mm)[4]. A high power diode laser is available for excitation source in near infrared region, and mid-infrared laser optically pumped with the near infrared light has a high potential for the tunable laser application. Since the ZnTe/BaF_2 multiple mirror can be designed to be transparent for the near infrared light, the optically pumped VECSEL is designed with the combinations of the ZnTe/BaF_2 and PbSrS/BaF_2 multiple mirrors.

4. Summary

PbS-based VECSEL is useful for tunable diode laser applications around 3μm mid-infrared region. Laser designs of the active region and multiple mirrors for the VECSEL were discussed.

References

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