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硕 士 学 位 论 文

Cr,Yb:YAG 双掺中间层对 Yb^{3+}:YAG/Cr^{4+}:YAG 复合晶体激光性能影响的研究

Study on Effects of a Cr,Yb:YAG Codoped Interface Layer on Passively Q-Switched Laser Performance of Yb^{3+}:YAG/Cr^{4+}:YAG Composite Crystals

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摘要

激光二极管泵浦的被动调 Q 激光器是一种可产生高光束质量、高峰值功率脉冲激光的固体激光器。激光二极管泵浦的被动调 Q 激光器在激光加工、激光测距、激光点火、远程遥感及环境污染监测等领域有极其广泛的应用，因此，一直以来关于该类激光器的研究都是固体激光器研究领域的一大热点。复合晶体由于具有缓解热效应及缩短腔长等优势，被广泛的应用于高转换效率、高峰值功率的小型化被动调 Q 激光器的研制中。然而，通过热键合技术制成的复合晶体其键合面存在一层双掺中间层，而这层双掺中间层对复合晶体激光性能的影响仍未被系统地研究清楚。

本文通过采用“三明治”结构将 Cr,Yb:YAG 双掺晶体放置在 Yb^{3+}:YAG 晶体和 Cr^{4+}:YAG 晶体中间模拟 Yb^{3+}:YAG/Cr^{4+}:YAG 复合晶体的构造，利用微片激光器的方式进行了 Cr,Yb:YAG 双掺中间层对复合晶体激光性能影响的实验和理论研究。研究结果表明，Yb^{3+}:YAG/Cr^{4+}:YAG 复合晶体中存在的 Cr,Yb:YAG 双掺中间层对输出激光的平均输出功率、转换效率以及单个脉冲的能量和峰值功率有负面影响。而且 Yb^{3+}:YAG/Cr^{4+}:YAG 复合晶体中存在的 Cr,Yb:YAG 双掺中间层会加剧纵模间的模式竞争，导致纵模个数减少、纵模间隔增大，进而导致输出激光脉冲序列稳定性变差。

除实验研究之外，本文在被动调 Q 激光器速率方程基础上修订获得了可用于计算含双掺中间层在内的复合晶体被动调 Q 激光器输出激光性能的被动调 Q 速率方程，建立了复合晶体被动调 Q 激光器的速率方程模型。通过理论计算获得了包括双掺中间层在内的 Yb^{3+}:YAG/Cr^{4+}:YAG 复合晶体被动调 Q 微片激光器的激光性能，对比分析了模拟结果和实验结果，发现模拟结果能与实验结果很好地吻合。

在此基础上，本文通过改变双掺中间层的厚度从理论上研究了 Cr,Yb:YAG 双掺中间层厚度对 Yb^{3+}:YAG/Cr^{4+}:YAG 复合晶体被动调 Q 微片激光器的输出脉冲宽度、脉冲能量、峰值功率、重复频率以及平均输出功率的影响。理论研究结

果表明 Cr,Yb:YAG 双掺中间层厚度变化对 Yb^{3+}:YAG/Cr^{4+}:YAG 复合晶体被动调 Q 微片激光器的输出脉冲宽度、脉冲能量、峰值功率、重复频率以及平均输出功率的影响极其微弱，但有可能对输出激光的纵模模式造成影响。通过合理的热键合工艺形成的双掺中间层有助于复合晶体被动调 Q 激光器工作在单纵模激光模式，从而实现输出激光脉冲序列的稳定化。

本论文的研究成果对于研制新型 Yb^{3+}:YAG/Cr^{4+}:YAG 复合晶体实现高峰值功率、高光学转换效率激光输出具有重要的理论和实践指导意义。

关键词：固体激光器；被动调 Q；微片激光器；双掺中间层；复合晶体

Abstract

Laser diode pumped passively Q-switched lasers can obtain laser pulses with high beam quality and high peak power, and have wide applications in laser processing, laser range finders, engine ignitions, remote sensing and environmental pollution detection, and so on. Therefore, development of high peak power passively Q-switched microchip lasers has become a highlight in the solid-state laser field. Composite crystals fabricated with thermal diffusion bonding technology have many advantages, such as alleviating the thermal effect and shortening the cavity length, and they have been widely used in constructing compact passively Q-switched miniature lasers with high optical-to-optical efficiency and high peak power. However, there is an interface layer through ion diffusion between the gain medium and the saturable absorber in the composite materials, which has strong effects on laser performance of composite crystals. Up to now, the effect of the interface layer formed in the composite crystal on the laser performance has not been investigated.

In this thesis, by using combinations of Yb^{3+}:YAG/Cr,Yb:YAG/Cr^{4+}:YAG laser crystals to simulate a Yb^{3+}:YAG/Cr^{4+}:YAG composite crystal with a Cr,Yb:YAG interface layer, the effect of the Cr,Yb:YAG interface layer on the laser performance of the Yb^{3+}:YAG/Cr^{4+}:YAG composite crystal has been investigated. The experiment results show that the formation of the Cr,Yb:YAG crystal interface layer in the Yb^{3+}:YAG/Cr^{4+}:YAG composite crystal has a negative impact on the average output power, the optical efficiency, as well as the single pulse energy and the pulse peak power. In addition, the Cr,Yb:YAG crystal interface layer in the Yb^{3+}:YAG/Cr^{4+}:YAG composite crystal also leads to a strong mode competition,

resulting in the decrease of the longitudinal mode number, the widening of longitudinal mode separations, and the poor stability of laser pulse trains.

Besides, in this thesis, rate equations, which are applicable to passively Q-switched lasers structured by composite crystals with codoped interface layers, were estabished by modifying the passively Q-switched rate equations. The analytic solutions of the modified rate equations have been obtained，and the analytic solutions can be used to directly calculate the pulse energy, the peak power, the pulse width, the repetition rate and the average output power of passively Q-switched lasers structured by composite crystals with codoped interface layers. By comparing and analyzing the experiment results and the simulation results, it shows that the simulation results are in good agreement with the experiment results.

Afterwards, the effects of the thickness of a codoped interface layer on the passively Q-Switched laser performance of composite crystals were investigated through the simulation method. The simulation results show that the change of the thickness of the codoped layer has little effect on the pulse width, the pulse energy, the peak power and the repetition rate, as well as the average output power. However, the codoped interface layer in a composite crystal has a great influence on the laser longitudinal modes. The single-longitudinal-mode oscillation can be achieved in Yb^{3+}:YAG/Cr^{4+}:YAG composite crystal passively Q-switched microchip laser by adjusting the thickness of the interface layer with proper thermal diffusion bonding parameters. The single-longitudinal mode oscillation in passively Q-switched microchip laser is benefical for stabilizing pulse trains.

The results of this study are of theoretical and practical importance to develop novel Yb^{3+}:YAG/Cr^{4+}:YAG composite crystals that could be used to obtain laser pulses with high peak power and high optical efficiency.

Key word: Solid-state laser; Passively Q-switched; Microchip laser; Codoped Interface Layer; Composite Crystal

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