

LD 泵浦 $\text{Er}^{3+}/\text{Yb}^{3+}:\text{Lu}_2\text{Si}_2\text{O}_7$ 晶体 kHz 微型激光器

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摘要: 目前 $1.5\ \mu\text{m}$ LD 泵浦的钇镱共掺玻璃/晶体被动调 Q 微型激光器广泛应用于激光测距、激光雷达等领域。随着激光器输出能量和重频的增加, 玻璃面临突出的热效应问题, 晶体的热导率是玻璃的 10 倍以上, 有望能够实现比玻璃基质更大脉冲能量和更高重频的激光输出。文中报道了一种采用 LD 脉冲端面泵浦、钇镱共掺焦硅酸镨晶体为增益介质的 $1\ 537\ \text{nm}$ 被动调 Q 微型激光器。通过优化泵浦光斑大小、输出镜透过率与调 Q 晶体初始透过率相匹配, 实现激光输出重频与泵浦重频一致。最终实现了输出重频为 $1\ \text{kHz}$ 、单脉冲能量 $35\ \mu\text{J}$ 、脉冲宽度 $7\ \text{ns}$ 、峰值功率为 $5\ \text{kW}$ 、光束质量因子 $M^2=1.33$ 的激光输出。以及输出重频为 $10\ \text{kHz}$ 、单脉冲能量 $10\ \mu\text{J}$ 、脉冲宽度 $10\ \text{ns}$ 、峰值功率为 $1\ \text{kW}$ 、光束质量因子 $M^2=1.51$ 的激光输出。结果表明, $\text{Er}^{3+}/\text{Yb}^{3+}:\text{Lu}_2\text{Si}_2\text{O}_7$ 晶体是实现高重频 $1.5\ \mu\text{m}$ 激光输出的优良介质。文中研究结果对 LD 脉冲端面泵浦的 kHz 钇镱共掺晶体被动调 Q 人眼安全微片激光器具有重要的参考意义。

关键词: 微片激光器; 被动调 Q ; 高重频; $\text{Er}^{3+}/\text{Yb}^{3+}:\text{Lu}_2\text{Si}_2\text{O}_7$ 晶体; 脉冲泵浦

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0 引言

$1.5\ \mu\text{m}$ 波段激光位于大气传输窗口, 对大气穿透能力强, 处于人眼安全波段, 对人眼的损伤阈值高, 成为人们研究人眼安全激光器的热点波段^[1]。LD 直接泵浦的钇镱共掺玻璃/晶体激光器具有体积小、结构简单、成本低等优点, 广泛应用于激光测距、激光雷达、光通信、医学等领域^[2-5]。对于 LD 端面泵浦的 $\text{Er}^{3+}/\text{Yb}^{3+}$ 共掺磷酸盐玻璃激光器, 增益介质上能级寿命长, Er^{3+} 、 Yb^{3+} 离子之间能量转移效率高, 能够同时满足高功率、转换效率高等要求, 是获得 $1.5\ \mu\text{m}$ 波长输出微型激光器的有效方式^[6-8]。国内外对 LD 端面泵浦 $\text{Er}^{3+}/\text{Yb}^{3+}$ 共掺磷酸盐玻璃被动调 Q 激光器进行了不断地开发探索。2016 年, 俄罗斯 Vitkin 等人实现了重复频率 $1\ \text{Hz}$ 、单脉冲能量 $0.7\ \text{mJ}$ 、脉宽 $10.5\ \text{ns}$ 的脉冲激光输出^[9]。2017 年, 蔡瑾鹭等人得到重复频率为 $10\ \text{Hz}$ 、单脉冲能量约为 $210\ \mu\text{J}$ 、脉宽 $2.8\ \text{ns}$ 、光束质量

因子 $M^2=1.2$ 的 $1\ 535\ \text{nm}$ 激光输出^[10]。2018 年, 北京工业大学郭娜等人采用增益预泵浦方式, 实现重频 $1\ \text{kHz}$ 、单脉冲能量 $40\ \mu\text{J}$ 、脉宽 $5.09\ \text{ns}$ 、峰值功率 $7.85\ \text{kW}$ 、光束质量因子 $M^2=1.4$ 、波长 $1\ 535\ \text{nm}$ 的激光输出^[11]。目前 $\text{Er}^{3+}/\text{Yb}^{3+}:\text{glass}$ 作为增益介质的 LD 端面泵浦微型激光器重频最高可达 kHz 量级。在利用激光进行测距时, 激光的重频越高、单脉冲能量越大, 测量速度越快、精度越高、距离越远^[11]。但是 $\text{Er}^{3+}/\text{Yb}^{3+}:\text{glass}$ 的热导率低, 随着激光器输出能量和重频的增加, 增益介质面临突出的热效应问题, 容易到达介质膜及玻璃的损伤阈值, 影响激光器的使用寿命。与玻璃基质对比, 晶体材料具备良好的热性质, 易于实现较高重复频率。但是目前常用于产生 $1.5\ \mu\text{m}$ 激光的晶体由于声子能量较小, Er^{3+} 离子 ${}^4\text{I}_{11/2}$ 能级的寿命相对较短, 荧光量子效率低等问题, 使得此种激光器存在泵浦利用率低, 阈值较高, 输出单脉冲能量小, 激光器整体转

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换效率低等缺点^[12]。Lu₂Si₂O₇(LPS)晶体的上能级荧光寿命可以与玻璃相比拟,热导率比玻璃高 10 倍以上,是实现大能量高重频 1.5 μm 脉冲激光的优良增益介质^[13]。2020 年,陈雨金等人用 LD 连续泵浦 Y-切 Er/Yb:LPS,在泵浦功率为 6.1 W 时,获得了重频为 1.32 kHz,单脉冲能量为 45.5 μJ,脉宽 25 ns 的 1 537 nm 波段激光输出^[14]。同年该课题组连续泵浦 Z-切 LPS 晶体,在泵浦功率 3.4 W 时,获得重频 0.84 kHz,单脉冲能量 26.9 μJ,脉宽 4.3 ns 的 1 537 nm 激光输出^[15]。目前,LPS 晶体的泵浦方式主要为连续泵浦,输出重频会随泵浦功率和热效应变化,重频不稳定不利于测距等实际应用;另外,连续泵浦造成的晶体内部的热积累,会降低激光输出的能量及光束质量。为了获得稳定的输出重频,并且减小热效应带来的影响,文中采用脉冲泵浦方式,Er³⁺/Yb³⁺:LPS 晶体作为增益介质,通过优化泵浦光斑大小、输出镜透过率与调 Q 晶体相匹配,实现激光输出重频与泵浦重频一致,获得输出重频稳定在 1 kHz 和 10 kHz 的 1.5 μm 激光输出。

1 实验装置

实验装置如图 1 所示。泵浦源为中心波长为 976 nm,装有快轴准直镜的二极管激光器。LD 在信号发生器的调制下可在脉冲模式下连续调节脉冲宽

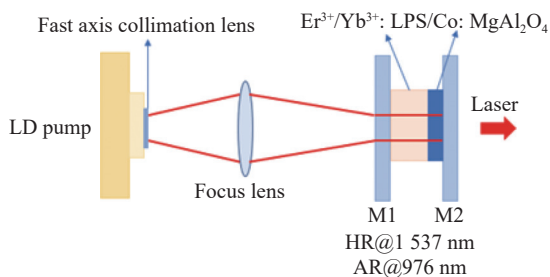
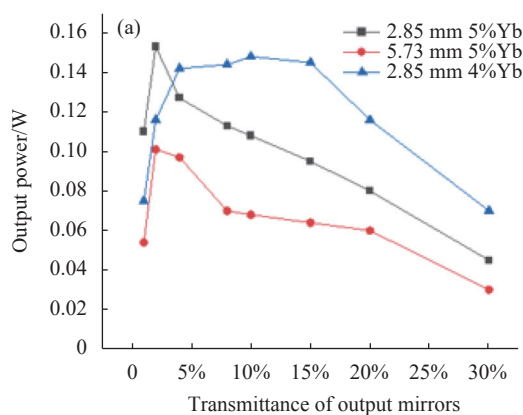


图 1 实验装置图

Fig.1 Experimental device



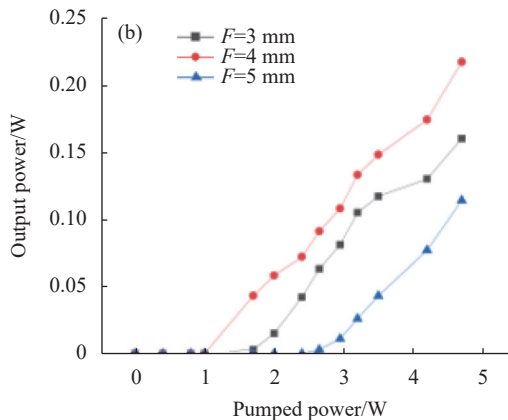
度和周期,发光面的宽度为 100 μm,经快轴准直后的发散角为 8°,峰值功率为 12 W。增益介质采用 Z-切的 Er³⁺/Yb³⁺:LPS,晶体尺寸为 3 mm×3 mm×2.85 mm。可饱和吸收体采用 Co²⁺:MgAl₂O₄,泵浦光经聚焦透镜聚焦后入射到激光晶体上。后腔镜镀有 976 nm 增透膜和 1 537 nm 全反膜,输出耦合镜镀有 1 537 nm 部分反射膜,本实验采用了一组 1 537 nm 透过率为 2%~30%的输出耦合镜。为了有效降低热透镜效应,将增益介质包裹在铜箔中,并放置在通有冷却水的铜块中。

2 实验结果及分析

晶体掺杂浓度、泵浦光束直径、可饱和吸收体的初始透过率和输出耦合镜的透过率等是影响 LD 端面泵浦被动调 Q 激光器输出的主要因素。文中将研究上述因素对激光输出的影响。

2.1 增益介质掺杂浓度及长度优化

对于钕镱共掺的 LPS 晶体,当增益介质长度一定时,Yb³⁺离子的掺杂浓度越高,泵浦的吸收系数就越高,此时会造成严重的再吸收。为了减小再吸收损耗,提高激光的产生效率,在增益长度为 2.85 mm 时,通过对比不同输出镜透过率下自由振荡的输出功率大小,得到 Yb³⁺离子的最佳掺杂浓度。实验结果如图 2(a) 所示,当 OC 透过率从 4~30% 变化时,0.5 at.%Er³⁺/4.0 at.%Yb³⁺:LPS 晶体的输出功率总是高于 0.5 at.%Er³⁺/5.0 at.%Yb³⁺:LPS 的输出功率。并且当增益介质长度增加时,自由振荡的输出功率也呈下降趋势。根据实验结果,最终选择 L=2.85 mm 的 0.5 at.%Er³⁺/4.0 at.%Yb³⁺:LPS 的晶体进行下述的调 Q 实验。另外还对 0.5 at.%Er³⁺/4.0 at.%Yb³⁺:LPS 晶体的斜效率进行测量,实验结果如图 2(b)~(d) 所示,通过优化泵浦光斑尺寸,输出镜透过率等参数,最终获得的斜效率为 5.8%,这也为之后的调 Q 实验提供参考。



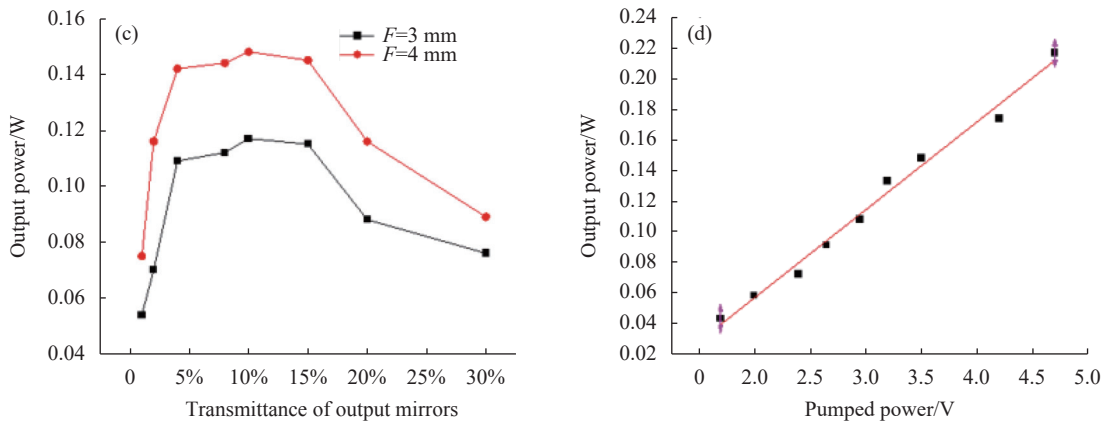


图 2 自由振荡优化结果。(a) 不同输出镜透过率下的自由振荡输出功率; (b) 不同泵浦光斑下的输出功率; (c) 不同输出镜透过率下的输出功率; (d) 斜效率拟合图

Fig.2 Free oscillation optimization results.(a) Free oscillating output power at different transmittance of output mirrors; (b) Comparison of output power under different pump spots; (c) Output power at different transmittance of output mirrors; (d) Fitting plot of slope efficiency

2.2 调 Q 实验结果

泵浦光斑尺寸、可饱和吸收体的初始透过率、输出耦合镜透过率等参数共同影响输出激光的重频、能量及脉宽。为了实现激光输出重频与泵浦重频一致,获得输出重频稳定在 1 kHz 和 10 kHz 的 1.5 μm 激光输出,采用控制变量法,使泵浦光斑大小、输出镜透过率与调 Q 晶体初始透过率相匹配,并通过对比输出重频及单脉冲能量的大小,来获得最佳的实验参数。

首先,在泵浦重频为 1 kHz 时,在 Co²⁺:MgAl₂O₄ 初始透过率为 95.8%,输出耦合镜透过率 15% 下,对比不同泵浦光斑大小时输出能量的大小,来确定最佳泵浦光斑尺寸。通过改变聚焦透镜的焦距来获得不同大小泵浦光斑,通过 ZEMAX 模拟及实验测量得出,焦距为 3、4、5 mm 时的焦斑直径为 240、300、350 μm。实验结果如表 1 所示,当泵浦光斑直径从 240 μm 增大到 350 μm 时,单脉冲能量先增加后减小,当泵浦光斑直径为 300 μm 时,输出能量最大,为 24 μJ。其次,在最佳泵浦光斑直径为 300 μm,输出耦合镜透过率为 15% 下,优化 Co²⁺:MgAl₂O₄ 的初始透过率。结果见表 2,当 Co²⁺:MgAl₂O₄ 的初始透过率为 94.5% 时,获得最佳输出为 27 μJ。最后,在最佳泵浦光斑和 Co²⁺:MgAl₂O₄ 初始透过率下,对输出耦合镜透过率进行优化,结果见表 3。通过实验发现,当输出镜透过率 <15% 时,由于腔内激光峰值功率过高,晶体极易产生损伤。实验只在输出镜透过率为 20% 和 30% 进行优

化。如图 3 所示,当输出镜透过率增加时,输出能量呈下降趋势,20% 时获得最大输出能量为 35 μJ。

其中, F_{focus} 为聚焦透镜焦距, ω_p 为泵浦光斑直径, f_p 为泵浦重频, T_Q 为 Co²⁺:MgAl₂O₄ 初始透过率,

表 1 1 kHz 泵浦光斑优化

Tab.1 Optimization of pump beam diameter for 1 kHz

$F_{focus}/$ mm	$\omega_p/$ μm	$f_p/$ kHz	T_Q	T_{OC}	$\tau_p/$ μs	$E_p/$ mJ	$f_o/$ kHz	$E_o/$ μJ
3	240							20
4	300	1	95.8%	15%	700	3.5	1	24
5	350							20

表 2 1 kHz Co²⁺:MgAl₂O₄ 的初始透过率优化

Tab.2 Optimization of initial transmittance of Co²⁺:MgAl₂O₄ for 1 kHz

$f_p/$ kHz	T_Q	$\omega_p/$ μm	T_{OC}	$\tau_p/$ μs	$E_p/$ mJ	$f_o/$ kHz	$E_o/$ μJ
1	94.5%	300	15%	700	3.5	1	27
	95.8%						24

表 3 1 kHz 输出耦合镜透过率优化

Tab.3 Optimization of transmittance of output coupling mirror for 1 kHz

$f_p/$ kHz	T_{OC}	T_Q	$\omega_p/$ μm	$\tau_p/$ μs	$E_p/$ mJ	$E_o/$ μJ	$\tau_o/$ ns
1	15%	94.5%	300	700	3.5	27	7.8
	20%					35	7
	30%					30	7.3

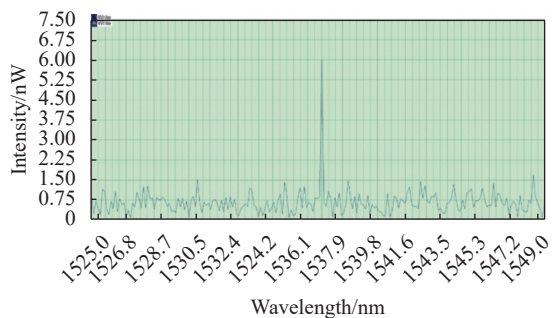


图 3 输出激光光谱

Fig.3 Output laser spectra

T_{OC} 为输出耦合镜透过率, τ_p 为泵浦脉宽, E_p 为泵浦能量, f_o 为输出重频, E_o 为输出单脉冲能量, τ_o 为输出脉宽。

此外, 还对激光输出脉冲性能进行了测试。图 3 为输出激光光谱, 用分光计 (YOKOGAWA aq670c) 测量出在室温下输出激光的中心波长约为 1537 nm。使用 Tektronix DPO-4104B 示波器和 Thorlabs PDA10CF 高速响应光电探测器测量脉冲宽度, 重频为 1 kHz 时脉宽为 7 ns (图 4(a))。泵浦波形和输出激光脉冲序列如图 4(b)~(c) 所示。调 Q 脉冲激光位于泵浦下降边缘附近, 表明泵浦光已被充分利用, 效率最高。用焦距为 100 mm 的凸透镜聚焦输出光束, 用刀口法测量焦点两侧的光斑半径, 最后通过拟合曲线计算光束质量。光斑及光束质量拟合曲线如图 4(d) 所示, 输出激光光斑基本呈圆形, 光束质量在 x 和 y 方向基本一致, 拟合出光束质量因子 $M^2=1.33$ 。

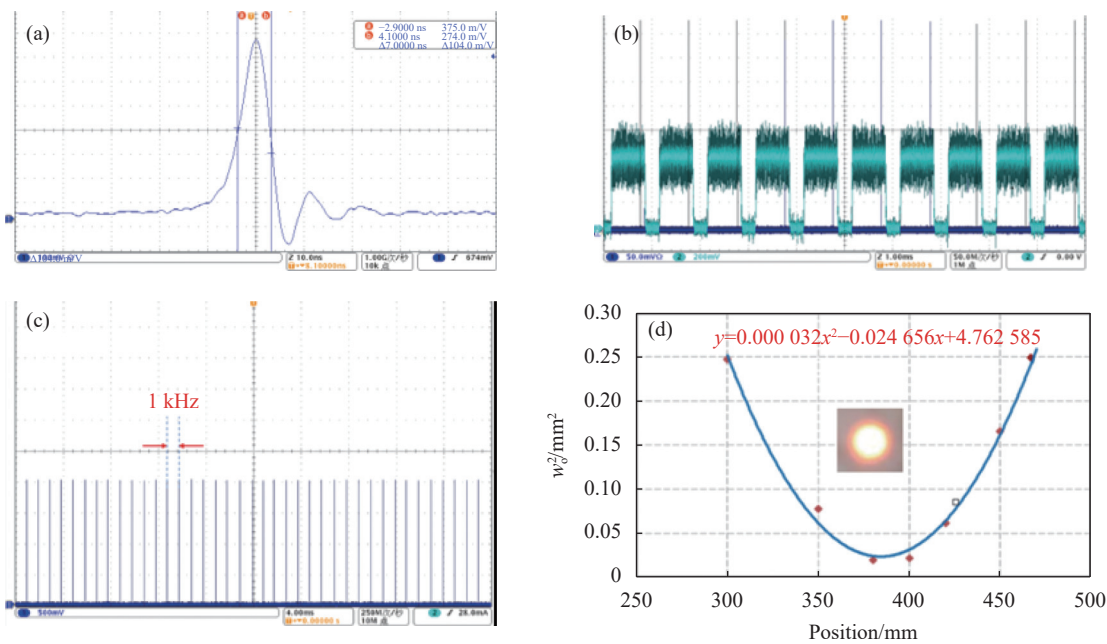


图 4 1 kHz 下的脉冲特性。(a) 脉宽图; (b) 泵浦光和激光脉冲的波形图; (c) 输出激光脉冲序列图; (d) 远场光斑及光束质量测量图

Fig.4 Pulse performance for 1 kHz. (a) Pulse width figure; (b) Pump waveform and output laser pulse train; (c) Output laser pulse train; (d) Far field facula and beam quality measurement diagram

与之前采用 Er^{3+}/Yb^{3+} :glass 的实验结果比较^[11], Er^{3+}/Yb^{3+} :LPS 输出激光的单脉冲能量和光光效率相对低, 但是基于晶体优异的散热性能, 热效应对光束质量退化影响较小, Er^{3+}/Yb^{3+} :LPS 输出激光的光束质量优于 Er^{3+}/Yb^{3+} :glass。

在利用激光进行测距时, 激光的重频越高、单脉冲能量越大, 测量速度越快、精度越高、距离越远。

因此, 对输出重频为 10 kHz 的被动调 Q 激光输出进行了研究。优化过程与重频为 1 kHz 相同, 实验结果如表 4~表 6 所示, 最终在泵浦光斑直径 240 μm , Co^{2+} : $MgAl_2O_4$ 的初始透过率 98.6%, 输出耦合镜 10%, 实现单脉冲能量 10 μJ 、脉宽 10 ns、光束质量因子 $M^2=1.51$ 的 1537 nm 激光输出, 脉冲特性如图 5 所示。

实验结果表明, 采用 Er^{3+}/Yb^{3+} :LPS 晶体作为增益

介质, 由于晶体的热导率高, 不仅可实现重频 1 kHz 被动调 Q 输出, 还可实现重频 10 kHz 被动调 Q 输出, 且重频越高时, 晶体热导率高的优势越突出。接下来, 将 $\text{Er}^{3+}/\text{Yb}^{3+}:\text{LPS}$ 和 $\text{Co}^{2+}:\text{MgAl}_2\text{O}_4$ 晶体进行光学热键合, 以提高其输出性能, 并且实现重频更高的激光输出。

表 4 10 kHz 泵浦光斑优化

Tab.4 Optimization of pump beam diameter for 10 kHz

$F_{\text{focus}}/\text{mm}$	$\omega_p/\mu\text{m}$	f_p/kHz	T_Q	T_{OC}	$\tau_p/\mu\text{s}$	E_p/mJ	f_o/kHz	$E_o/\mu\text{J}$
3	240						10	7
4	300	10	98.6%	15%	70	0.35	10	5
5	350						<10	-

表 5 10 kHz $\text{Co}^{2+}:\text{MgAl}_2\text{O}_4$ 的初始透过率优化

Tab.5 Optimization of initial transmittance of $\text{Co}^{2+}:\text{MgAl}_2\text{O}_4$ for 10 kHz

f_p/kHz	T_Q	$\omega_p/\mu\text{m}$	T_{OC}	$\tau_p/\mu\text{s}$	E_p/mJ	f_o/kHz	$E_o/\mu\text{J}$
10	98.6% 99%	240	15%	70	0.35	10 >10	7 -

表 6 10 kHz 输出耦合镜透过率优化

Tab.6 Optimization of transmittance of output coupling mirror for 10 kHz

f_p/kHz	T_{OC}	T_Q	$\omega_p/\mu\text{m}$	$\tau_p/\mu\text{s}$	E_p/mJ	$E_o/\mu\text{J}$	τ_o/ns
	8%					8	10
10	10%	98.6%	240	70	0.35	10	10
	15%					7	12

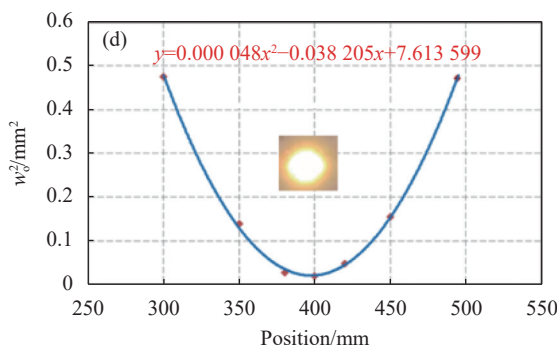
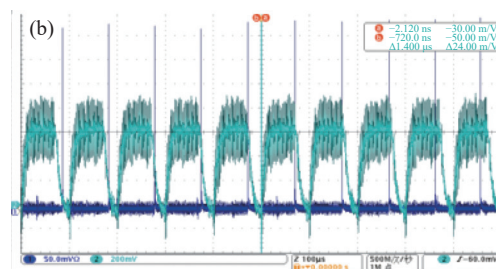
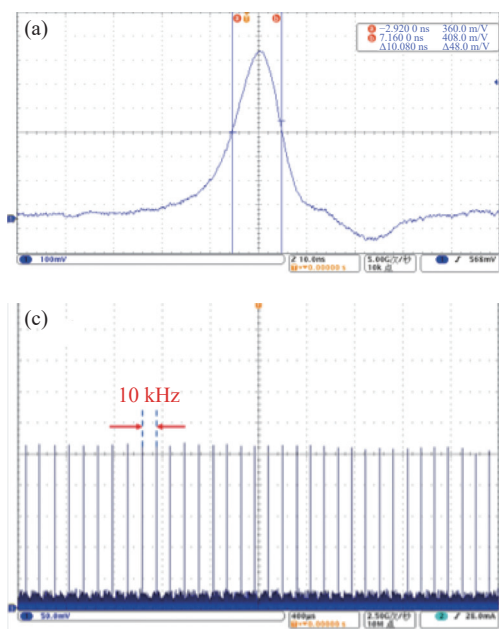


图 5 10 kHz 下的脉冲特性。(a) 脉宽图; (b) 泵浦光和激光脉冲的波形图; (c) 输出激光脉冲序列图; (d) 远场光斑及光束质量测量图

Fig.5 Pulse performance for 10 kHz. (a) Pulse width figure; (b) Pump waveform and output laser pulse train; (c) Output laser pulse train; (d) Far field facula and beam quality measurement diagram

3 结 论

文中首先通过自由振荡实验, 优化了增益介质的长度及 Yb^{3+} 离子的掺杂浓度, 最终选择长度为 2.85 mm, Er^{3+} 离子掺杂浓度为 0.5 at.%, Yb^{3+} 离子掺杂浓度为 4.0 at.% 的 Z 切 LPS 晶体进行调 Q 实验。在调 Q 实验中, 采用脉冲泵浦方式, 通过优化泵浦光斑及输出镜透过率的大小, 使其与调 Q 晶体初始透过率相匹配, 实现激光输出重频与泵浦重频一致。最终实现了

输出重频为 1 kHz、单脉冲能量 35 μJ 、脉冲宽度 7 ns、峰值功率为 5 kW、光束质量因子 $M^2=1.33$ 以及输出重频为 10 kHz、单脉冲能量 10 μJ 、脉冲宽度 10 ns、峰值功率为 1 kW、光束质量因子 $M^2=1.51$ 的 1 537 nm 激光输出。实验结果表明, $\text{Er}^{3+}/\text{Yb}^{3+}:\text{Lu}_2\text{Si}_2\text{O}_7$ 晶体是实现 1 kHz 和 10 kHz 高重频 1.5 μm 激光输出的优良介质, 并且重频越高, 晶体热导率高的优势越突出。文中研究结果对 LD 脉冲端面泵浦的 kHz 钕共掺晶体被动调 Q 微片激光器具有重要的参考意义。

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$\text{Er}^{3+}/\text{Yb}^{3+}$: $\text{Lu}_2\text{Si}_2\text{O}_7$ crystal microchip laser pumped by LD at kHz

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Abstract:

Objective The 1.5 μm laser which has an excellent transparency in atmosphere and is in the eye safety wavelength region, has been widely used in range finders, LiDAR, optical communication, medicine and other fields. LD end-pumped $\text{Er}^{3+}/\text{Yb}^{3+}$ co-doped glass/crystal laser is an effective way to obtain 1.5 μm wavelength output micro laser because it meets the requirements of small volume, peak power, low cost and high efficiency. When using laser for ranging, the higher the laser repetition frequency is, the greater the single pulse energy is, the narrower the pulse width is, the faster the measurement speed is, the higher the accuracy is, and the farther the distance is. However, due to the low thermal conductivity of $\text{Er}^{3+}/\text{Yb}^{3+}$: glass and the increase of laser output energy and repetition frequency, the gain medium faces the prominent thermal effect problem, which makes it

easier to reach the damage threshold of dielectric coating and glass, affecting the lifetime of the laser. For $\text{Lu}_2\text{Si}_2\text{O}_7$ (LPS) crystal, its upper level fluorescence lifetime can be compared with that of glass, and its thermal conductivity is more than 10 times higher than that of the glass. It is an excellent gain medium for realizing 1.5 μm pulsed laser with large energy and high repetition frequency. At present, LPS crystal is mainly pumped continuously. Continuous pumping will cause heat accumulation inside the crystal and reduce the output energy and beam quality of laser output. In this paper, the pulse pumping mode and $\text{Er}^{3+}/\text{Yb}^{3+}:\text{LPS}$ are used as the gain medium to achieve a 1.5 μm laser output with repetition frequency stabilized at 1 kHz and 10 kHz.

Methods In this study, the factors that affect the output of LD end pumped passively Q -switched laser include crystal doping concentration and length, pump beam diameter, initial transmittance of saturable absorber and output coupling mirror (OC) transmittance. Under the theoretical simulation, the general optimization range of the above parameters was obtained, and the optimal parameters were obtained through the experiment. The optimal doping concentration of Yb^{3+} and length of $\text{Lu}_2\text{Si}_2\text{O}_7$ crystal was obtained by comparing the free oscillating output power at different OC transmittance. In order to achieve the repetition frequency of 1 kHz and 10 kHz Q -switched pulse laser output, we used the control variable method to optimize the pump beam diameter, initial transmittance of saturable absorber and OC transmittance, and obtained the best experimental parameters by comparing the output frequency and single pulse energy.

Results and Discussions The results of free oscillating were shown (Fig.2(a)), the output power of 0.5at.% $\text{Er}^{3+}/4.0\text{at.}\% \text{Yb}^{3+}:\text{LPS}$ was always higher than 0.5at.% $\text{Er}^{3+}/5.0\text{at.}\% \text{Yb}^{3+}:\text{LPS}$ with the transmittance of the OCs changing from 4% to 30%. And when the length of medium increased, the output power of free oscillation also decreased. According to the experimental result, 2.85-mm-thick 0.5at.% $\text{Er}^{3+}/4.0\text{at.}\% \text{Yb}^{3+}:\text{LPS}$ was selected for passive Q -switched experiment. The slope efficiency of 2.85-mm-thick 0.5at.% $\text{Er}^{3+}/4.0\text{at.}\% \text{Yb}^{3+}:\text{LPS}$ was further studied. The optimal slope efficiency of 5.8% was obtained by optimizing the pump beam diameter and the transmittance of OCs (Fig.2(b)-(d)). In order to achieve the repetition frequency of 1 kHz and 10 kHz Q -switched pulse laser output, we compared the repetition frequency, energy, pulse width of three sets of control variable experiments, the results were shown (Tab.1-6). Finally, the laser output with repetition frequency of 1 kHz, single pulse energy of 35 μJ , pulse width of 7 ns, peak power of 5 kW and $M^2=1.33$ was obtained when the pump beam diameter is 300 μm , the initial transmittance of $\text{Co}^{2+}:\text{MgAl}_2\text{O}_4$ is 94.5% and transmittance of OC is 15%. And the laser output with repetition frequency of 10 kHz, single pulse energy of pulse energy of 10 μJ , pulse width of 10 ns, peak power of 1 kW and $M^2=1.51$ was obtained when the pump beam diameter is 240 μm , initial transmittance of $\text{Co}^{2+}:\text{MgAl}_2\text{O}_4$ is 98.6% and transmittance of OC is 10%.

Conclusions LD pulse end-pumped passively Q -switched 1537 nm laser with $\text{Er}^{3+}/\text{Yb}^{3+}:\text{Lu}_2\text{Si}_2\text{O}_7$ crystal at 1 kHz and 10 kHz was reported. In this experiment, the doping concentration of LPS crystal was optimized by the free oscillation experiment and the 2.85-mm-thick 0.5at.% $\text{Er}^{3+}/4.0\text{at.}\% \text{Yb}^{3+}:\text{LPS}$ was selected for passive Q -switching experiment. Secondly, the Q -switching experiment was conducted to optimize the pump beam diameter, the initial transmittance of $\text{Co}^{2+}:\text{MgAl}_2\text{O}_4$ and the transmittance of the output coupling mirror. Finally, the laser output with repetition frequency of 1 kHz, single pulse energy of 35 μJ , pulse width of 7 ns, peak power of 5 kW and $M^2=1.33$ and repetition frequency of 10 kHz, single pulse energy of 10 μJ , pulse width of 10 ns, peak power of 1 kW and $M^2=1.51$ were realized. The results show that $\text{Er}^{3+}/\text{Yb}^{3+}:\text{Lu}_2\text{Si}_2\text{O}_7$ crystal is an excellent medium for 1.5 μm laser output with high repetition frequency.

Key words: microchip laser; passively Q -switched; high repetition rate; $\text{Er}^{3+}/\text{Yb}^{3+}:\text{Lu}_2\text{Si}_2\text{O}_7$ crystal; pulse pumped

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