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CW and Graphene Passively Q-switched Er:YAG Ceramic Laser at 1.6 μm

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OUTLINE

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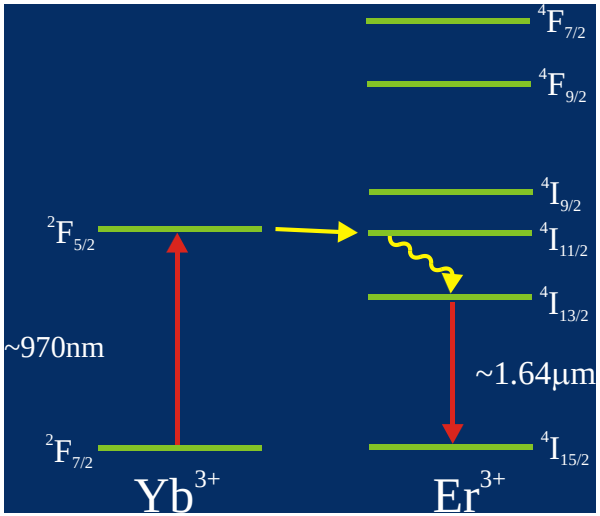
1. Introduction
2. Narrow linewidth Er,Yb:fiber lasers
3. CW Er:YAG ceramic laser
4. Passively Q-switched operation
5. Summary

Introduction

High power solid-state lasers operating in the ~1.5-1.6μm eyesafe spectral region have numerous applications and provide an ideal starting wavelength for nonlinear frequency conversion to the mid-IR.

1. Direct diode pumping of Yb,Er-doped crystals

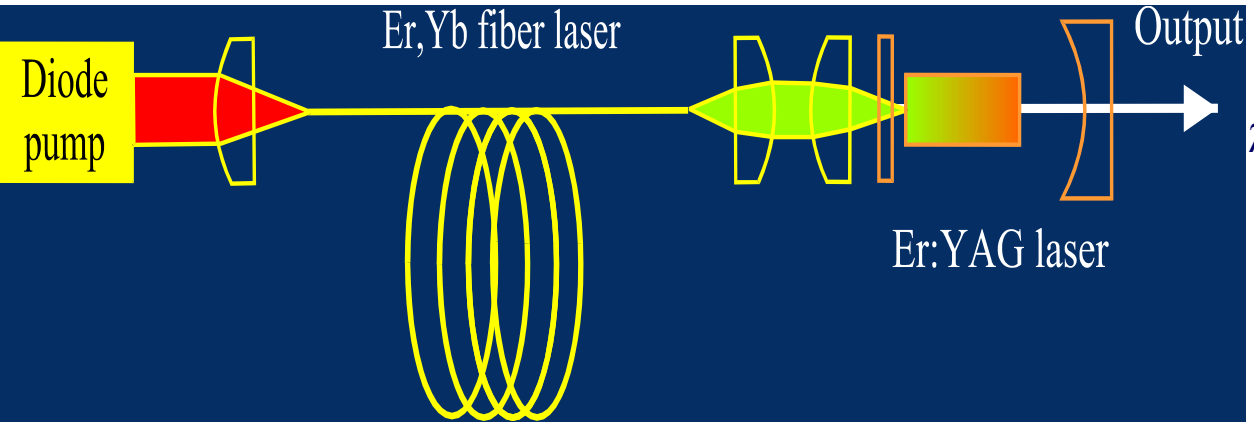
- Require Yb co-doping
- High quantum defect heating (~40%)
- Doping concentration need to be relatively high
  - → thermal loading & Upconversion
  - → reduced energy storage time
  - → Power scaling is difficult

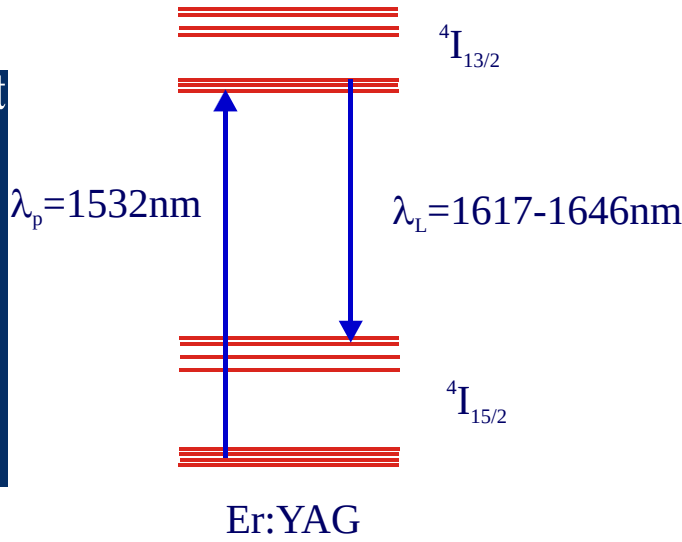


2. Cladding pumping of Er,Yb fiber lasers

- High efficiency, good beam quality and immunity from thermal effects
- High power (cw) and,
- broad range of operating wavelengths (~1.53-1.63μm)
- Pulse energy limited by ASE, parasitic lasing and facet damage
- Nonlinear processes (SBS, SRS) limit performance

Hybrid Fiber-Bulk Erbium Laser

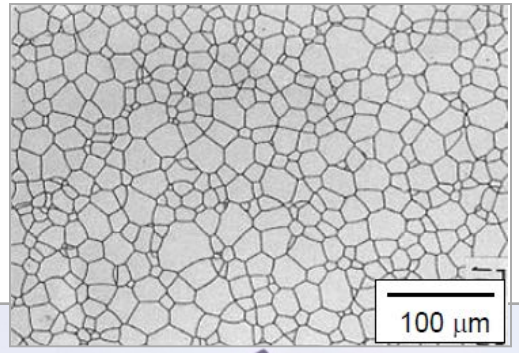




- Combines the advantages of fiber and bulk lasers
- Most of the heat is generated in the fiber
- Very low quantum defect heating in Er:YAG (~7%) - In-band pumping
- Long fluorescence lifetime in Er:YAG ~ 8ms
- Good fibre laser beam quality allows use of low Er^{3+} conc.
  → Low upconversion loss
  → Long energy storage time

Laser ceramics debut

Laser ceramics



Loss <0.001cm^{-1}

Advantages of ceramic

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- **Scaling to large aperture active elements**
  - ***Large and thin (1m x 1m) : effectively no limit***
  - ***Industrial lasers, Fusion drivers, and so on***
  - ***Glass-like fabricated polycrystalline material***
- **Composite materials**
- **New materials, spectral control-Gain uniformity**
- **Wave guide and gain profile control**
- **Multi-layered elements**
- **Low cost, mass production**

Ceramic Laser development

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Low loss laser ceramics and efficiency lasing achieved in 1995

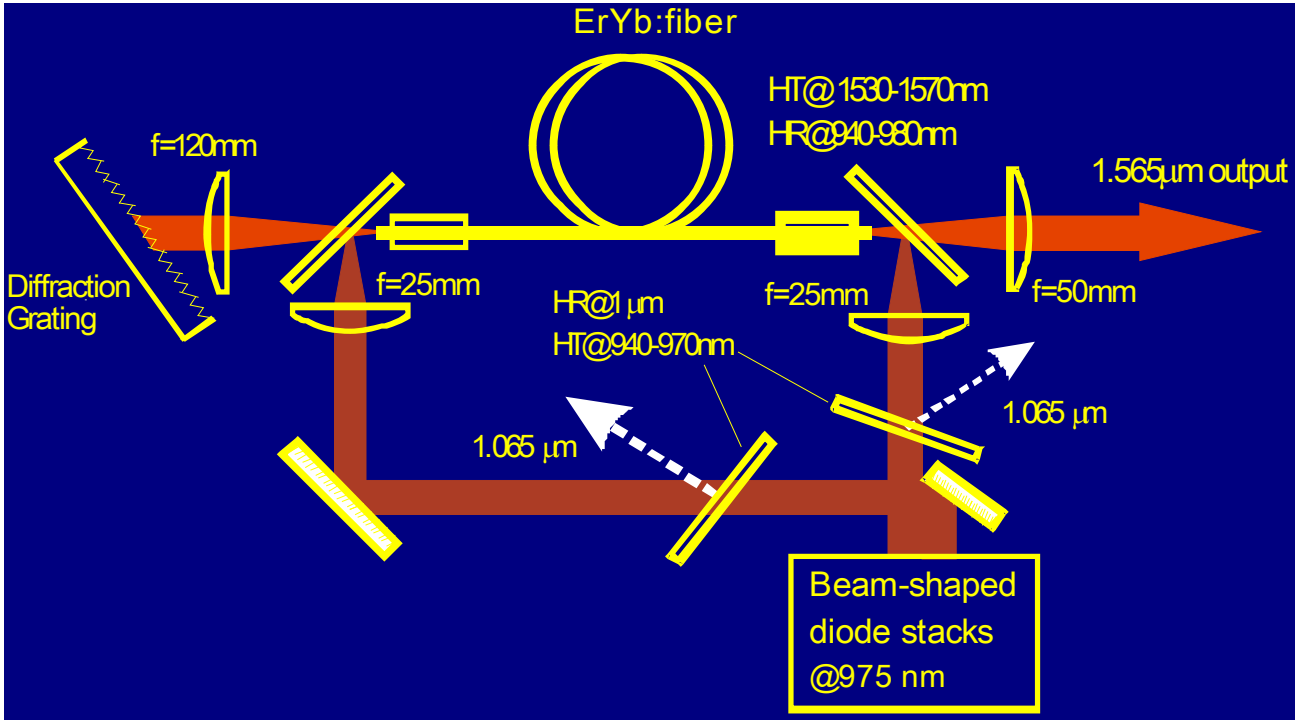
J. Am. Ceram. Soc., 78 [4] 1033–40 (1995): A. Ikesue et al.

- Ceramic laser Nd:YAG, Yb:YAG … (~1 μm)
  Same performance as single crystals

- Er doped ceramic laser ~ 1.6 μm
  Opt. Lett. **35** (7), 922 (2010)
  6.8 W output, slope effi. 56.9%

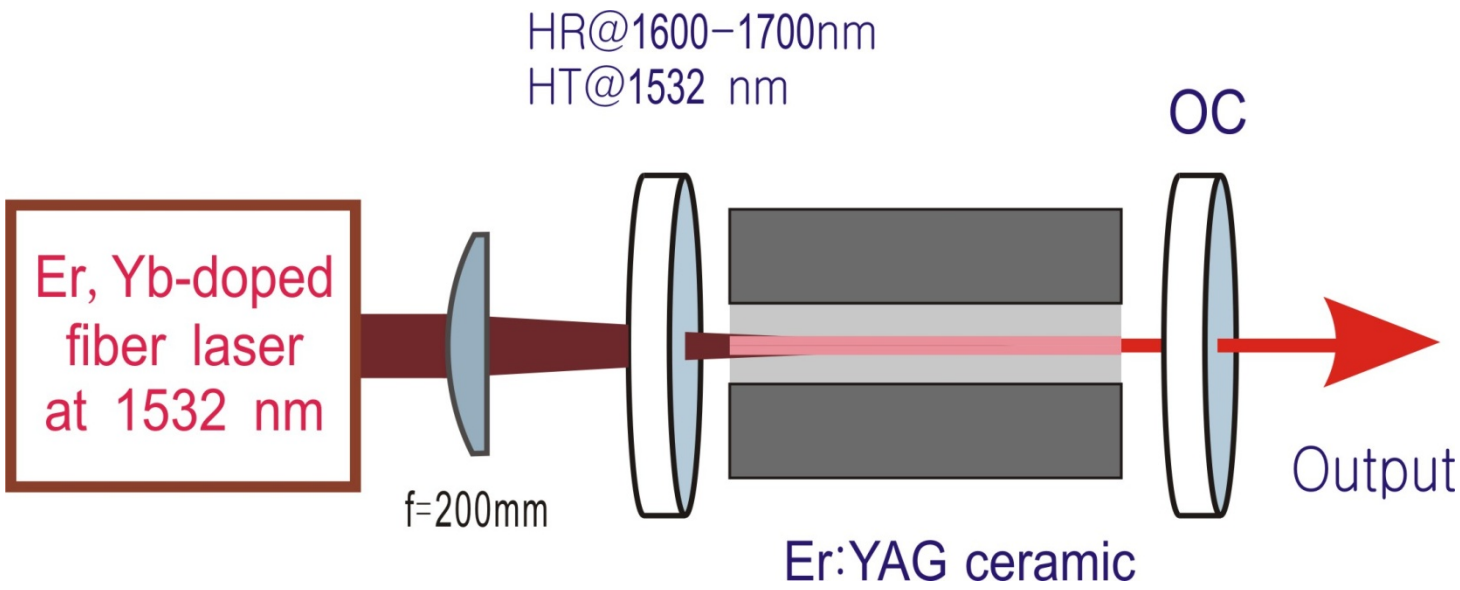
- Tm, Ho doped at ~ 2 μm

Er,Yb fiber laser pump source



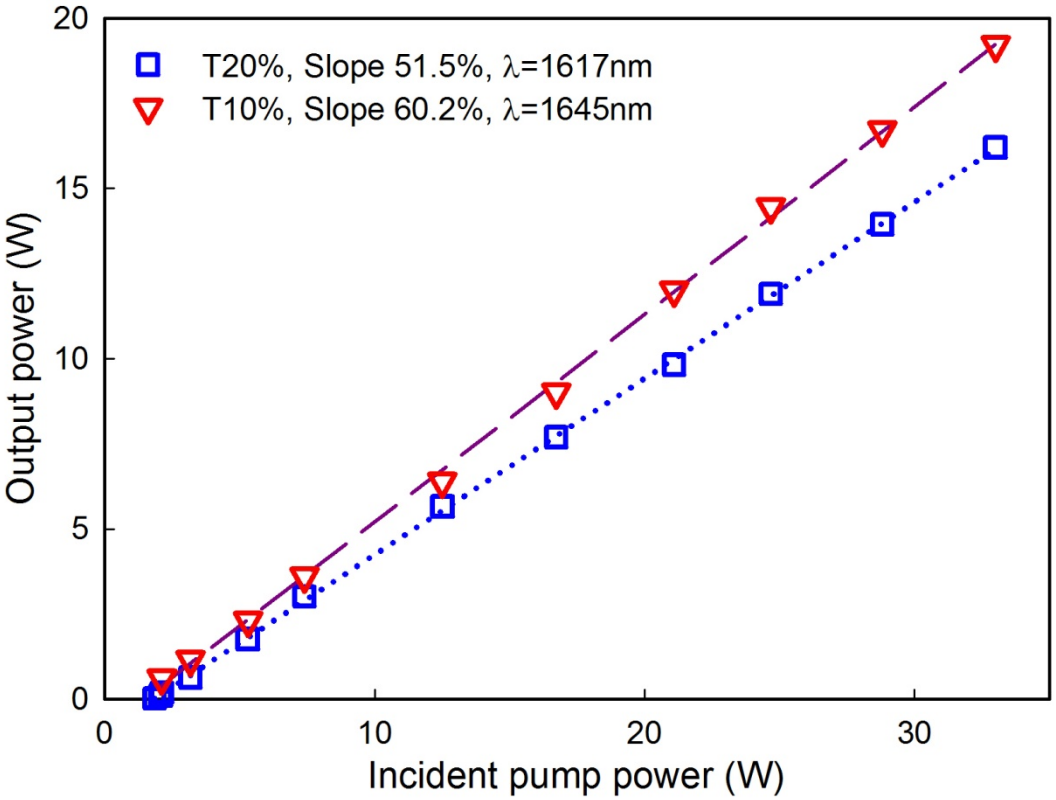
- Over 100W output power from 1532 to 1568nm for 336W launched pump power
- M^2: ~ 1.9
- Short-term stability <0.9% (RMS) checked on 100μs–10ms time scale
- Power fluctuation < 3% over 30 min
- Linewidth (FWHM): ~ 1nm
- Slope efficiency 32% at 1532nm

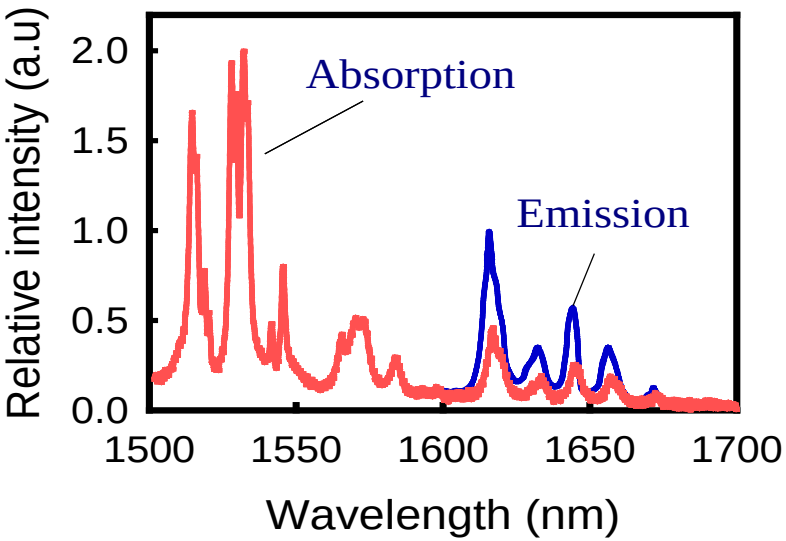
Er:YAG ceramic lasers



- Er:YAG ceramic: ~0.5% Er^{3+} doping
- Er:YAG length ~30mm
- Thresholds: 1.04W/1.62W for T_{oc}=10%/20%
- Loss < 3/1000 cm^{-1} (measured)

CW operation





1645nm Output

- Pump power: 19.2W
- Slope effi.: 60.2%
- Toc=10%

1617nm Output

- Pump power: 16.2W
- Slope effi.: 51.5%
- Toc=20%

Graphene Q-switched Er:YAG Laser

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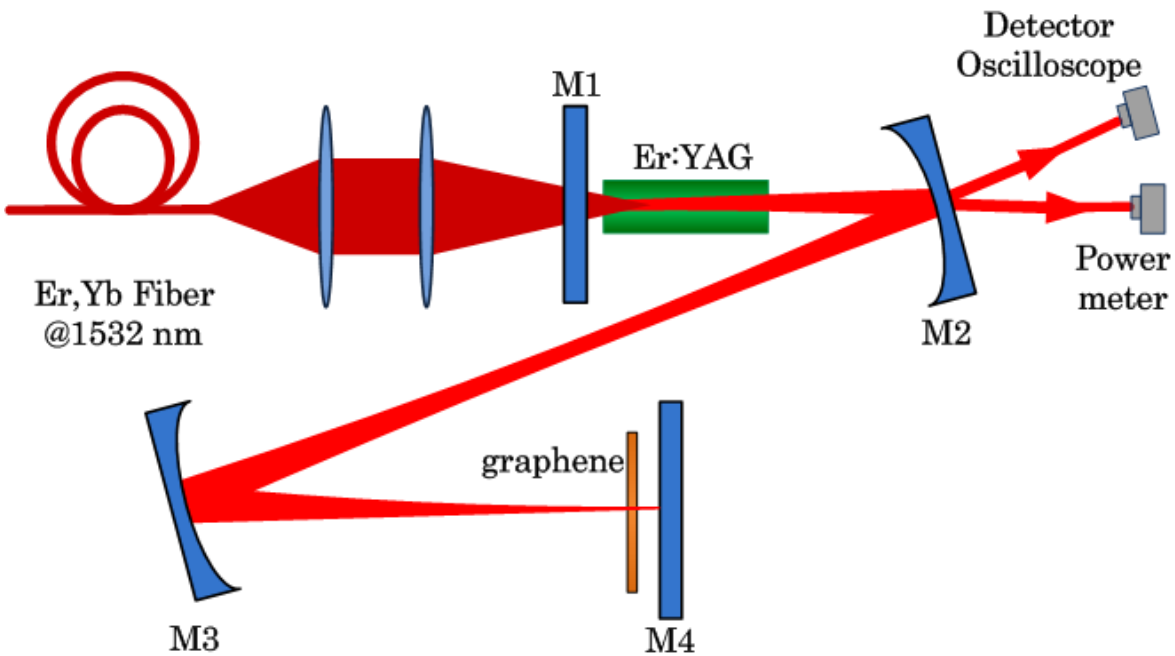
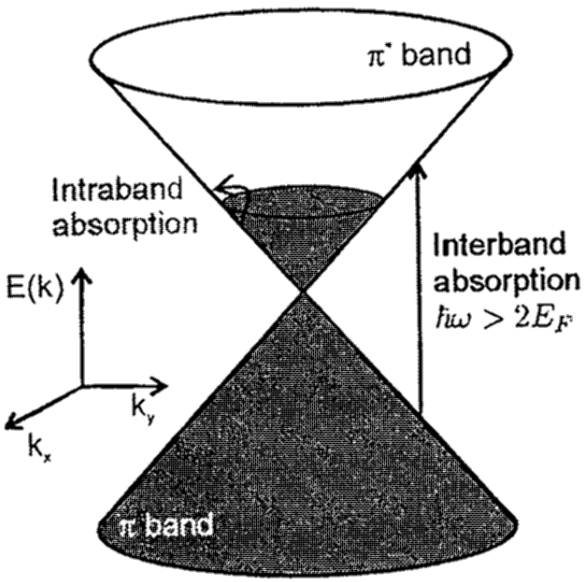
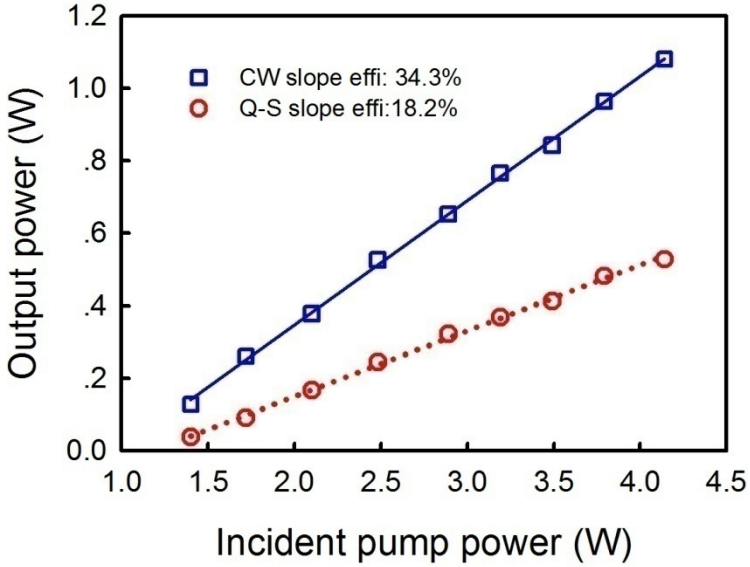


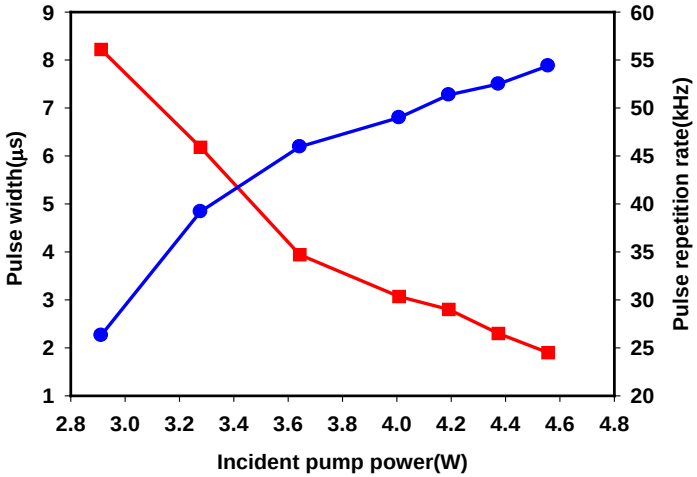


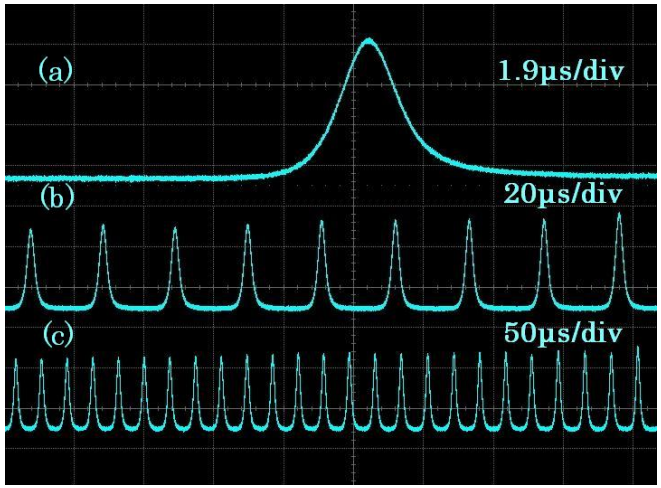
Cavity length: 7.9+25+6 cm
Mode diameter: ~280μm/~100μm
Toc=20%

- Direct bandgap material
- Wavelength independent absorption
- Strong linear absorption

Graphene Q-switched Er:YAG Laser







Repetition rate: 25-55 kHz

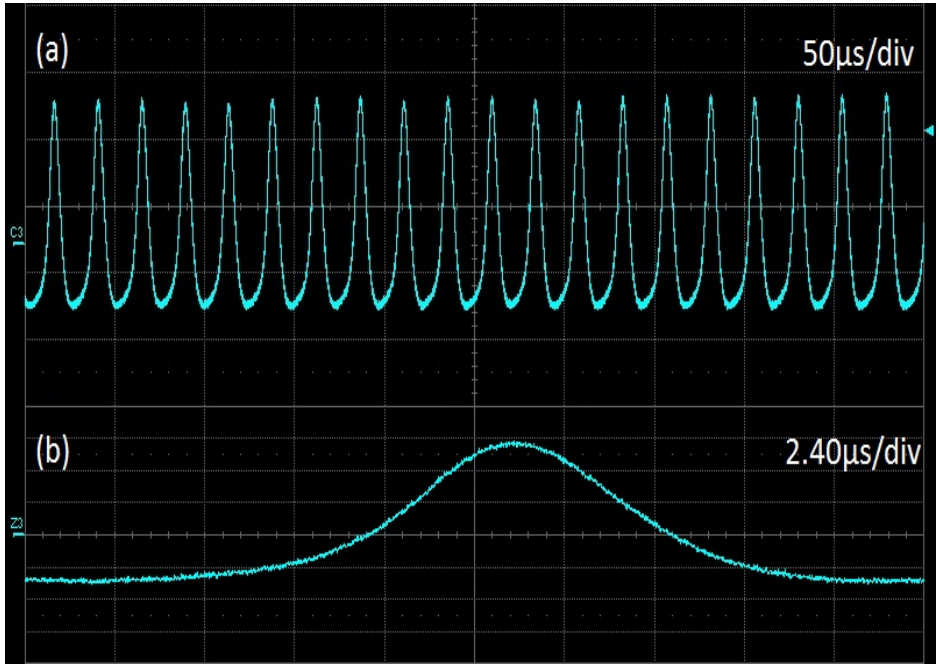
Pulse width:1~10 μs

Pave: 528 mW

Topological insulator as SA

Topological insulator (TI), Bi_2Te_3 is first tried as a broad bandgap saturable absorber

Stable Q-switched operation was demonstrated



- Direct bandgap material
- Wavelength independent?
- High modulation depth

- A few μs
- Tens of kHz
- 200mW average
- Wavelength~Toc

Summary

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Achieved high power and high efficient operation of Er:YAG ceramic laser in-band pumped with narrow Er,Yb-doped fiber

- Pout=19.2 W at 1645 nm; 16.2 W at 1617 nm
- Slope efficiency: 60.2%
- Wavelength ~ Toc

Stable Q-switched operation with Graphene SA

- Pout: =528 mW
- Repetition rate: 25-55kHz
- Pulse duration: 1-10 μs

TI used as broad bandgap SA

- Similar laser output achieved as with Graphene

Thank you