CW and Pulsed Lasers at 2 µm for Material Processing Applications

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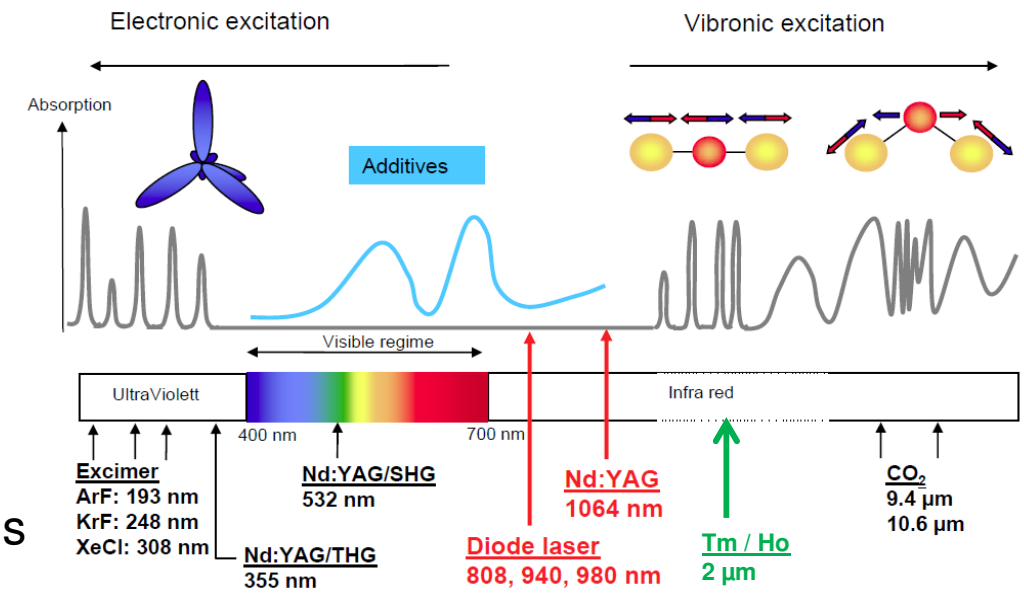
Material Processing at 2 µm: Overview

- Vibronic excitations lead to higher absorption at 2 µm, especially for transparent materials:
  - Scribing of transparent thin films: ITO, ZnO, Photovoltaics
    - Pulsed: 1 – 5 ns, 10 – 50 µJ, 100 – 500 kHz
  - Plastics welding without additives
    - cw: 10 – 500 W
  - Laser surgery
    - cw & pulsed

  → low penetration depth

  → small heat affected zone
- Can be delivered by fiber (in contrast to UV & CO_2)
- Relaxed laser safety regulations



CW Lasers at 2 µm

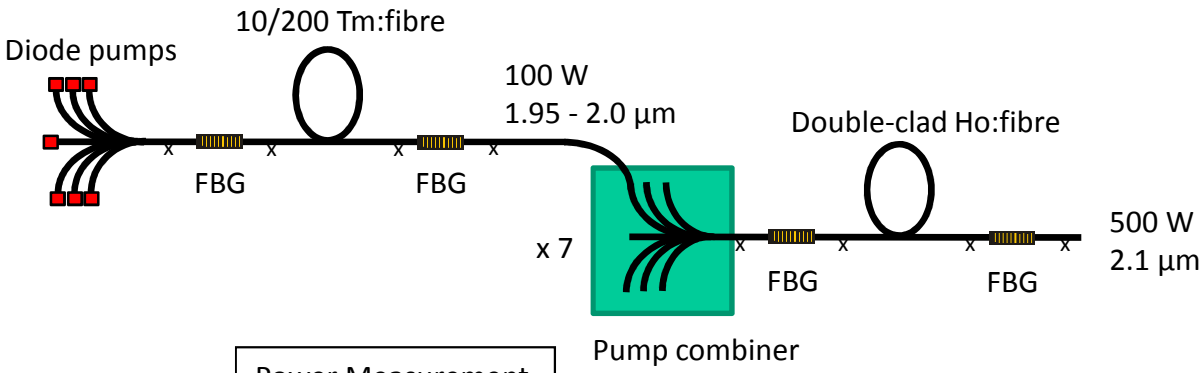
Advantages of Thulium vs. Holmium doped lasers

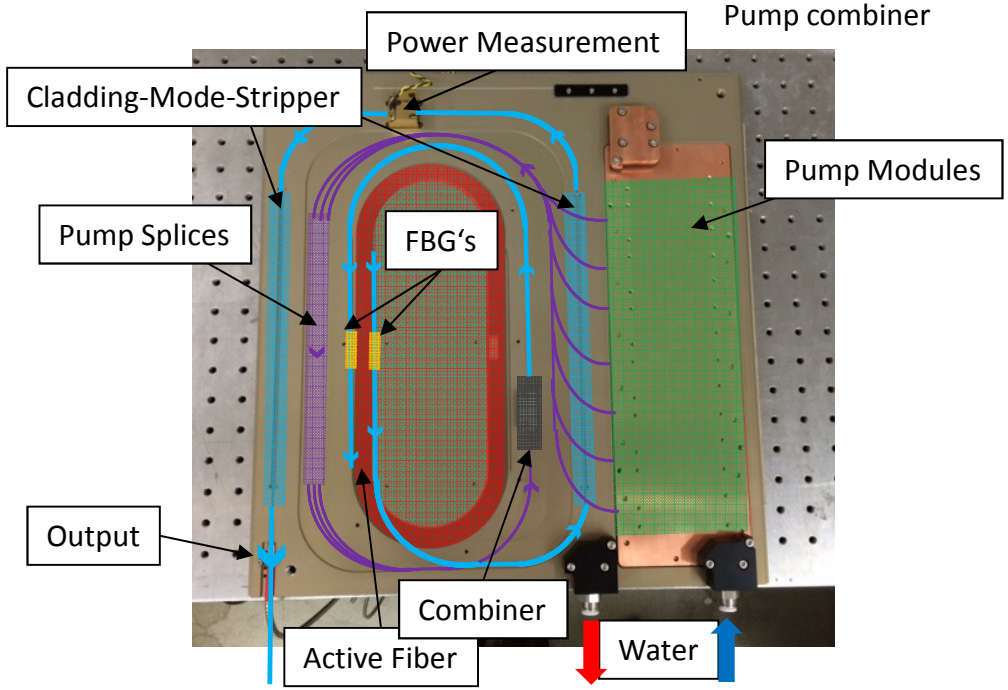
Thulium	**Holmium**
1900 – 2000 nm	2000 – 2100 nm
Pump diodes at ~800 nm avialable	In-band-pumping → reduced thermal load
Broad wavelength tuning range	Higher emission cross section
	Lower thermal population of upper laser level
⇒ Diode pumping	**⇒ Higher efficiency**

State of the art:

- 1000 W, TEM 00, 19xx nm (Tm:fiber) – *SPIE Photonics West 2010, conf. 7580*
- 200 W, TEM 00, 19xx nm (Tm:fiber) – *commercially available*
- 140 W, TEM 00, 21xx nm (Ho:fiber) – *Proc SPIE 82371J*
- 25 W, TEM 00, 21xx nm (Ho:fiber) – *commercially available*

A CW Laser at 2 µm: ISLA Demo Laser 1

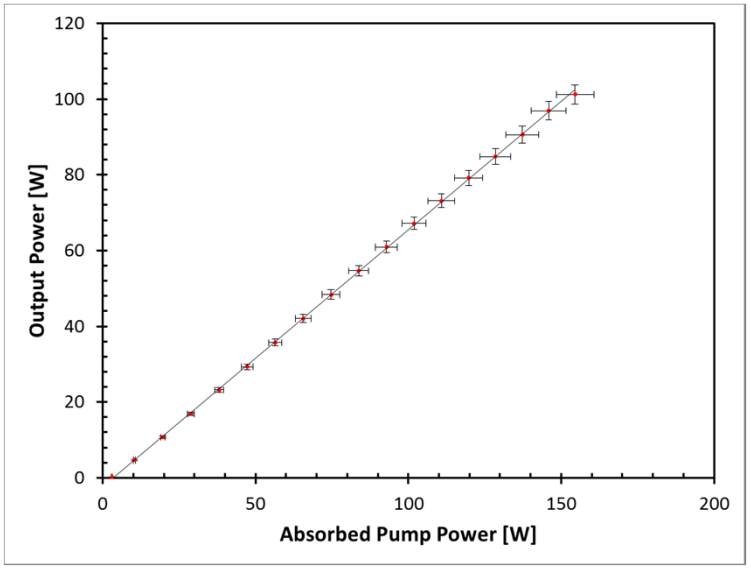


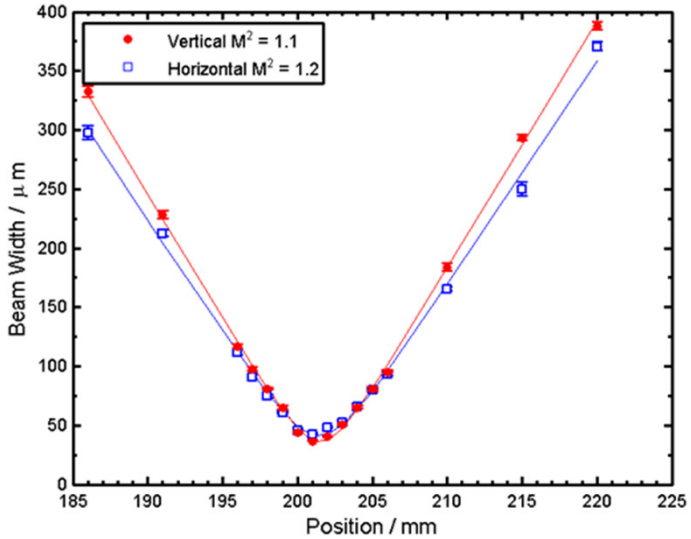


- Goal: 500 W cw Hm:fiber laser
- 7 x 100 W Tm:fiber lasers as pump
- Uses ISLA components: diodes, combiners, active fiber, FBG

A CW Laser at 2 µm: ISLA Demo Laser 1

Preliminary results of Tm stage:





- Reached 100 W at excellent beam quality
- So far: free space pumped

Next steps:

- Implement all-in-fiber design of Tm stage
- Combine Tm beams for Hm pumping

Material Processing at 2 µm: CW Applications

Medical: Prostatectomy

(BJUI 104, p. 361)

- ~ 70 W cw
- Higher precision, reduced bleeding

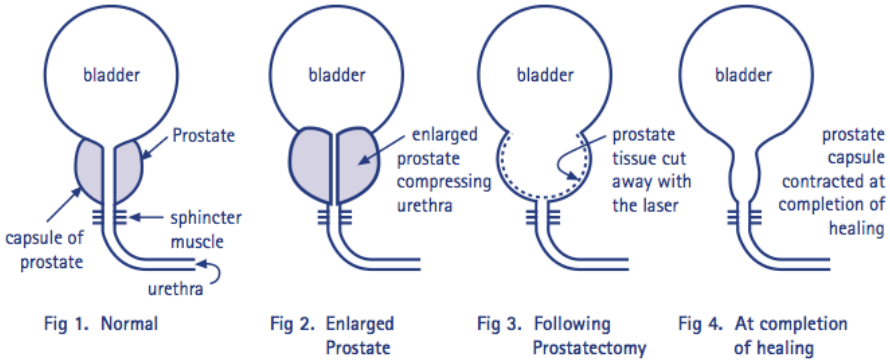
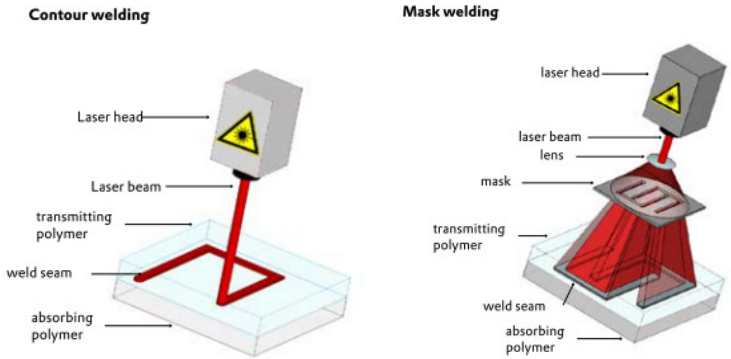


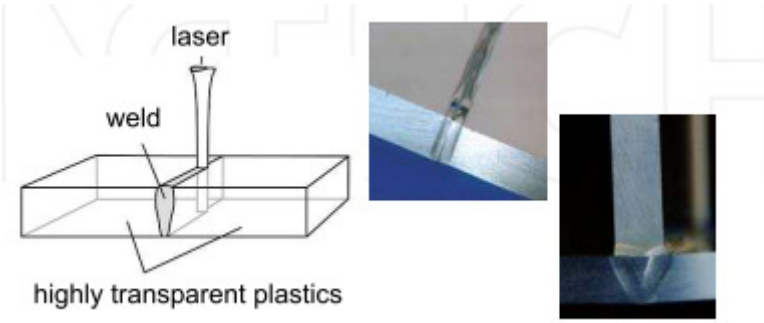
Fig 1. Normal | Fig 2. Enlarged Prostate | Fig 3. Following Prostatectomy | Fig 4. At completion of healing

Industrial: Plastics welding

(Opt. Las. Technol. 44, p. 2095)

- 200 W / cm² → 10 W cw for single spot
- No additives required (cheaper, medical certification)





ns Pulsed Lasers at 2 µm

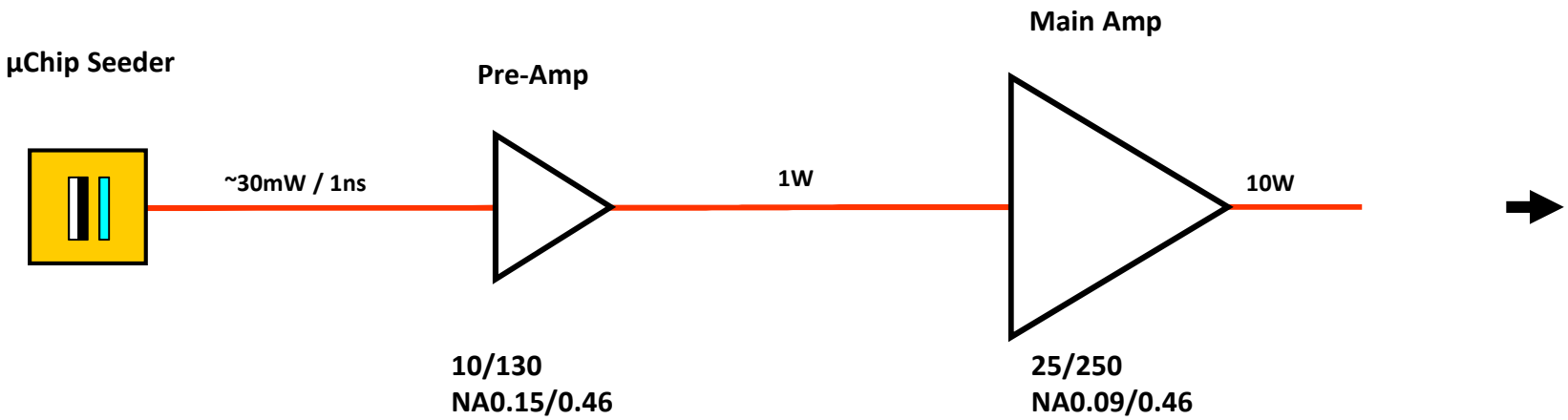
Methods of pulse generation

Active Q-Switching	Passive Q-Switching	Mode Locking	Gain-switching
Pulse on demand	Variable rep. rate	Fixed rep. rate	Pulse on demand
Rep. rate: 0 – 100 kHz	Rep. rate: 50 – 500 kHz	Rep.rate: > 1 MHz	Rep rate: 0 – 100 MHz
Pulse width: > 10 ns	Pulse width: 0.5 – 5 ns	Pulse width: < 100 ps	Pulse width: ~ 100 ps / > 1 ns
Pulse on demand	**Compact, low part count**	**Shortest pulses**	**Pulse on demand Variable pulse width**

State of the art:

- 1 ns, 1 mJ, 20 - 50 kHz, 20 W (Gain-switched diode + Tm:fiber) – *commercially available*
- 6 ns, 40 µJ, 4 MHz, 160 W (Gain-switched diode + Tm:fiber) – *Proc SPIE 934410*
- Commercial pulsed Holmium lasers: ~100 µs, 100 Hz

A ns Laser at 2 µm: ISLA Demo Laser 2 – Design



Seeder

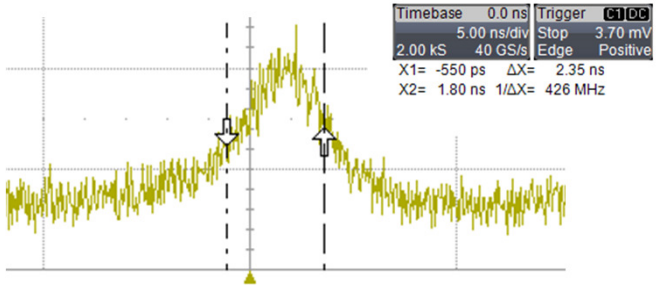
- Solid-state microchip laser
- Target specs: 30 mW, 1 ns, 200 kHz
- Passive Q-switching with SESAM

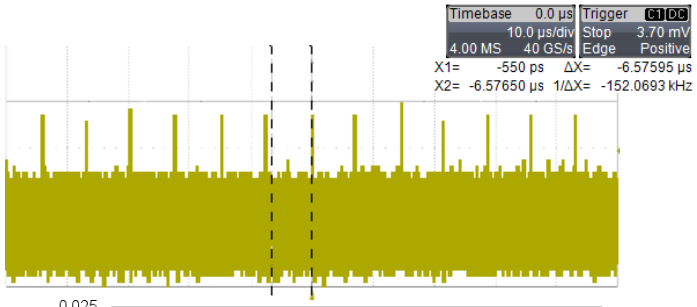
Amplifer

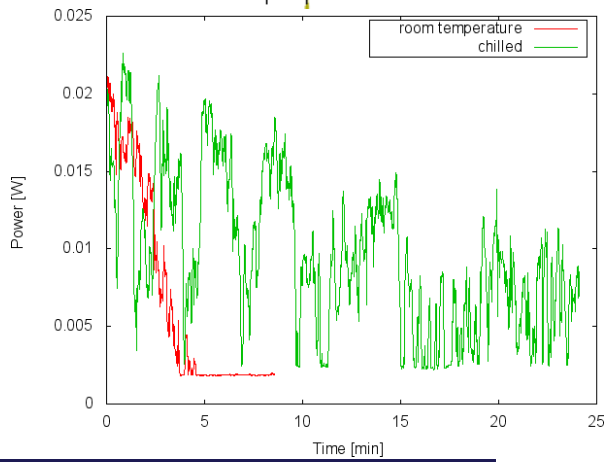
- Fiber-based → uses ISLA components
- Pre Amp: 10/130 µm fiber, amplification to 1 W
- Main Amp: 25/250 µm fiber, amplification to 10 W

A ns Laser at 2 µm: ISLA Demo Laser 2 – Results

- Tested ~ 10 different SESAMs
- **Obtained pulses with**
  - **2.4 ns pulse width**
  - **150 kHz rep. rate**
  - **20 mW power**
- BUT: Degradation within minutes
- Cooling helps: at ~ 10°C degradation is slower
- Irregular power fluctuations probably due to unstable setup
- **Next steps:**
  - improve setup for better cooling and stability
  - Implement fiber amplifier





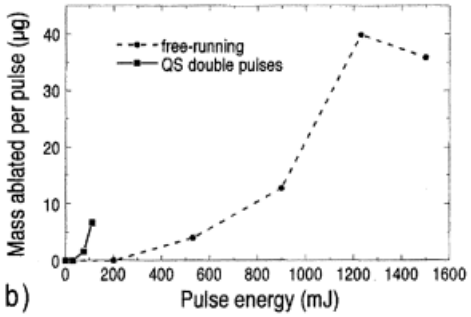


Material Processing at 2 µm: ns Pulsed Applications

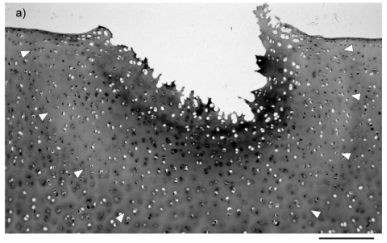
Medical: Tissue ablation

(Med. Laser Appl. 17 p. 15)

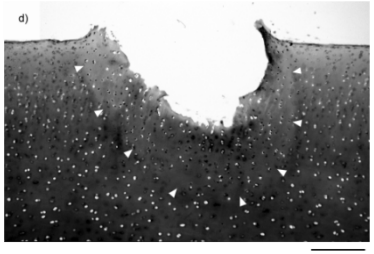
- ns pulses / bursts show higher tissue ablation rates than µs pulses



- Smaller damaged zone and smooth lesion edges



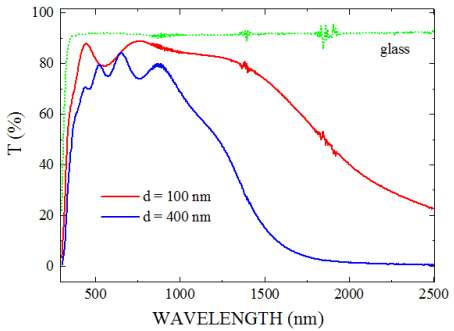
µs Ho pulse



ns Tm burst

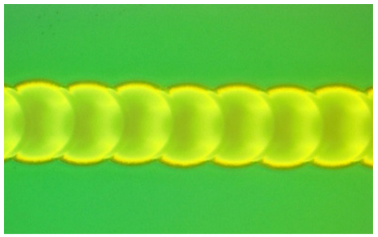
Industrial: TCO scribing

Transparent electrodes for displays & photovoltaic cells
→ transparent at 1 µm, absorbs 2 µm



ITO transparency spectrum

- Si, Ge transparent at 2 µm
  → backside marking through substrate



ITO ablation on glass using a 2 µm Q-Switched laser

Conclusion and Outlook

Advantages of 2 µm lasers:

- High absorption in many materials
  - Low penetration depth → High precision e.g. for surgery
  - New material combinations, e.g. ITO through Si
  - Efficient material processing with moderate power, e.g. plastics welding
- Can be fiber-guided to workpiece
- Relaxed laser safety regulations

Outlook:

- Increasing use of 2 µm lasers in material processing
- Fiber technology catches up to 1 µm state of the art
- Use of cw Tm:fiber lasers as pump for Hm lasers
  → power scaling with good thermal management
- Power scaling through advanced fiber designs and beam combining

Overview: ISLA highlights

- Fibres
  - Thulium fibres with 70% slope efficiency at >100 W output
  - Strategy for further increasing efficiency towards quantum limit
  - Holmium fibres with 75% slope efficiency

- Portfolio of active and passive components
  - Amplitude modulators and tunable filters
  - Fibre-coupled isolators, pump combiners and low loss taps
  - Wavelength-flattened couplers
  - Fibre-coupled silicon pulse pickers
  - Graphene-based mode lockers

- Diodes
  - >38 W in 105 µm fibre with 0.15 NA demonstrated
  - Wavelength stabilised devices with 60% power conversion efficiency

Thank you for your attention!