Generation and Application of Mid-IR Sources

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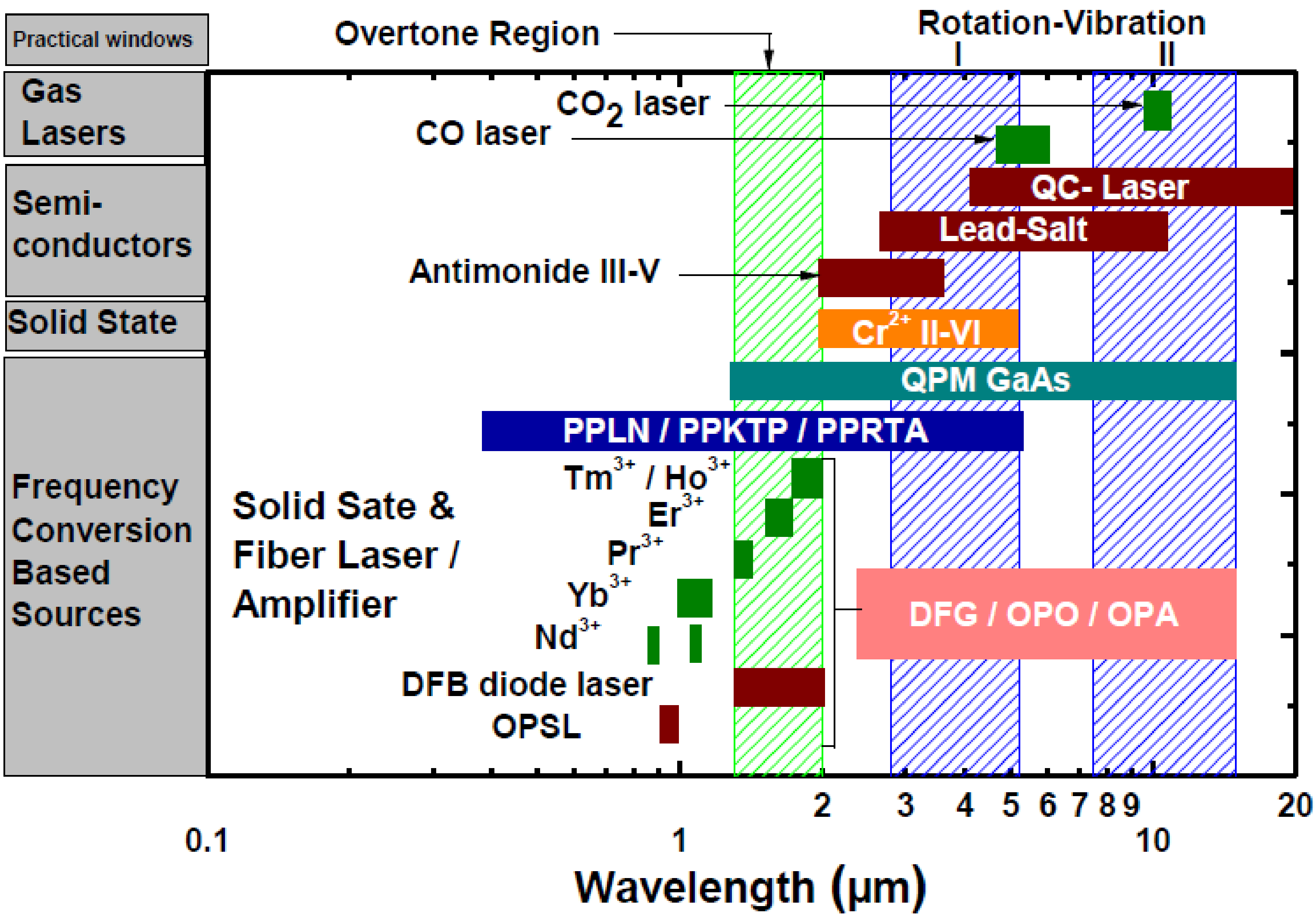
Dec 20, 2010, AMO Seminar

Outline

- Generation of Mid-IR Sources
  - 2 micron laser sources
  - 2 micron laser pumped Mid-IR sources
- Application of Mid-IR Sources
- Outlook

Generation of Mid-IR Sources



Outline

- Generation of Mid-IR Sources
  - 2 micron laser sources
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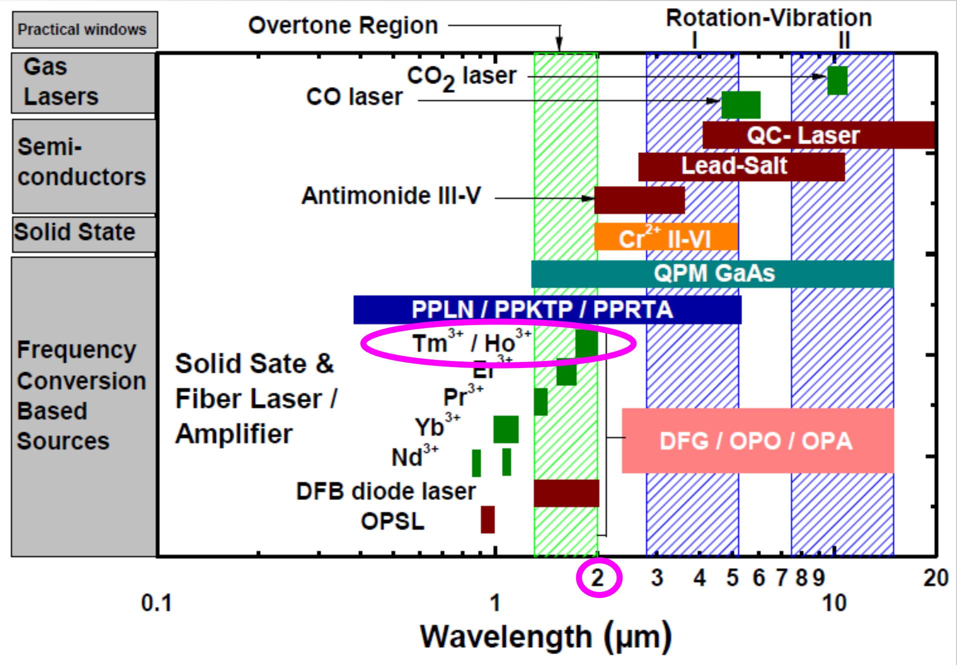
- Outlook

2 micron laser sources

- ✪ Diode pumped solid state (DPSS) Laser
- ✪ Fiber Laser
- ✪ Difference frequency generation (DFG)
- ✪ Optical parametric oscillator (OPO)
- ✪ Semiconductor Laser
- ✪ Free Electron Laser

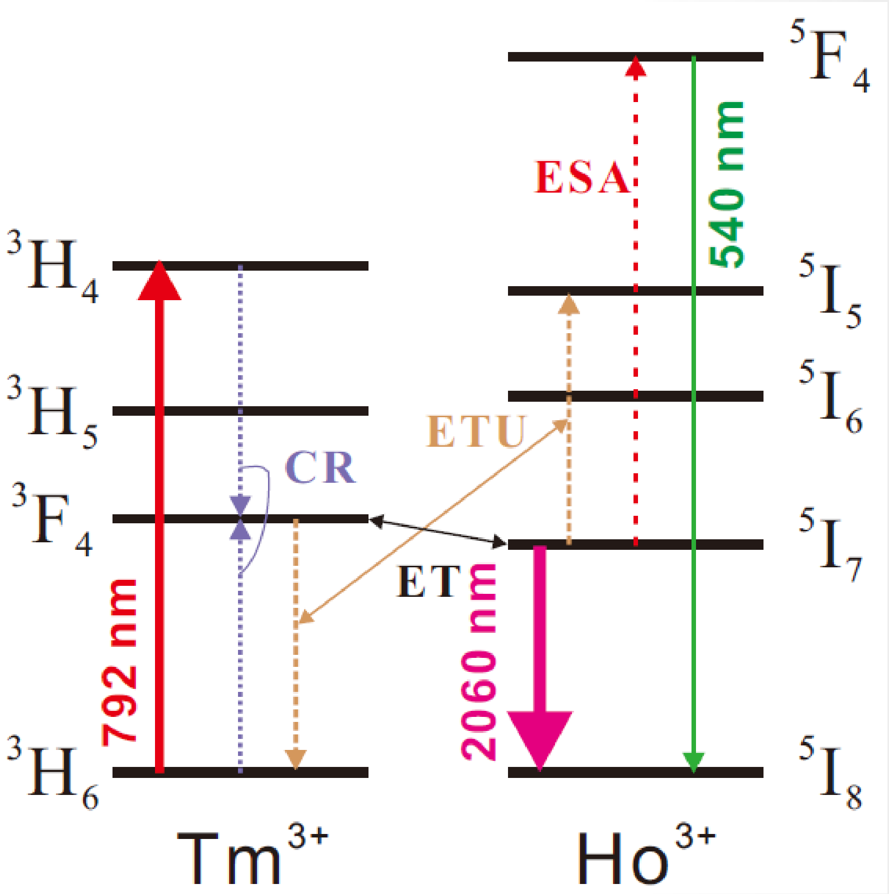


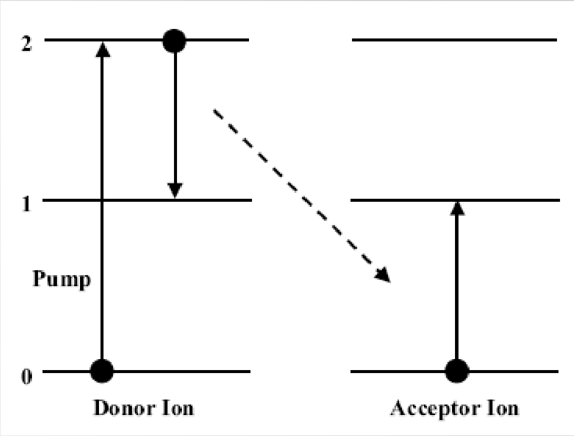
Tm^{3+} / Ho^{3+} doped laser hosts

Table 11 Important data on Ho^{3+}-doped laser hosts (BYF: BaY_2F_8). Some data are taken from [7, 11, 64, 180, 181]

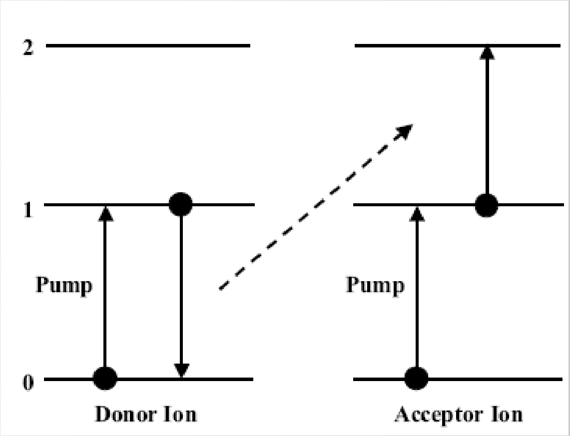
Host crystal	YAG	YALO	YLF	BYF
Symmetry	cubic	orthorhombic	tetragonal	monoclinic
$^5I_7$ levels [cm^{-1}]	5229, 5232, 5243, 5250, 5303, 5312, 5320, 5341, 5352, 5375, 5395, 5404, 5418, 5455, 5485	5186, 5187, 5222, 5253, 5255, 5264, 5266, 5268, 5280, 5288, 5318, 5326, 5337, 5346, 5357	5153, 5157, 5157, 5164, 5164, 5185, 5185, 5207, 5229, 5229, 5233, 5291, 5293, 5293, 5293	5173, 5177, 5189, 5191, 5197, 5220, 5220, 5220, 5220, 5228, 5256, 5269, 5273, 5276, 5358
$f_{u,(i)}$	0.105 (1), 0.096 (3)	0.100 (0)	0.087 (0)	0.084 (1)
τ_f [ms]	7.8	8.1	16.1	17.9
$^5I_8$ levels [cm^{-1}]	0, 4, 41, 51, 141, 144, 150, 162, 398, 418, 448, 457, 498, 506, 520, 531, 535	0, 6, 37, 48, 58, 71, 100, 126, 137, 193, 211, 222, 289, 327, 425, 474, 499	0, 0, 7, 23, 48, 56, 72, 72, 217, 270, 276, 276, 283, 290, 303, 303, 315	0, 20, 37, 39, 54, 58, 89, 120, 200, 200, 239, 276, 310, 324, 352, 382, 399
$f_{g,(i)}$	0.018 (10), 0.012 (16)	0.012 (15)	0.025 (14)	0.025 (13)
λ_s [nm]	2090, 2121	2122	2062	2060
$\sigma_e(\lambda_s)$ [10^{-20} cm^2]	1.2, 0.55	0.82	1.9 ($E\|c$)	1.18 ($E\|c$)
$\frac{\sigma_e(\lambda_s)}{\sigma_a(\lambda_s)}$	5.81, 8.13	8.39	3.44	3.42
I_{sat}^s [kW cm^{-2}]	0.866, 1.94	1.26	0.244	0.353
λ_p [nm]	1907, 2017	1976	1948	1933
$\sigma_{a,p}(\lambda_p)$ [10^{-20} cm^2]	1.2, 0.15	0.9	1.2 ($E\|c$)	0.7 ($E\|c$)
$\frac{\sigma_{e,p}(\lambda_p)}{\sigma_{a,p}(\lambda_p)}$	0.64, 2.53	1.58	0.88	0.74
I_{sat}^p [kW cm^{-2}]	0.949, 0.898 (2090 nm) 2.16, 2.04 (2121 nm)	1.35	0.258	0.376
E_P^{max} [cm^{-1}]	700	550	400	415

Energy levels of Tm,Ho codoped YLF



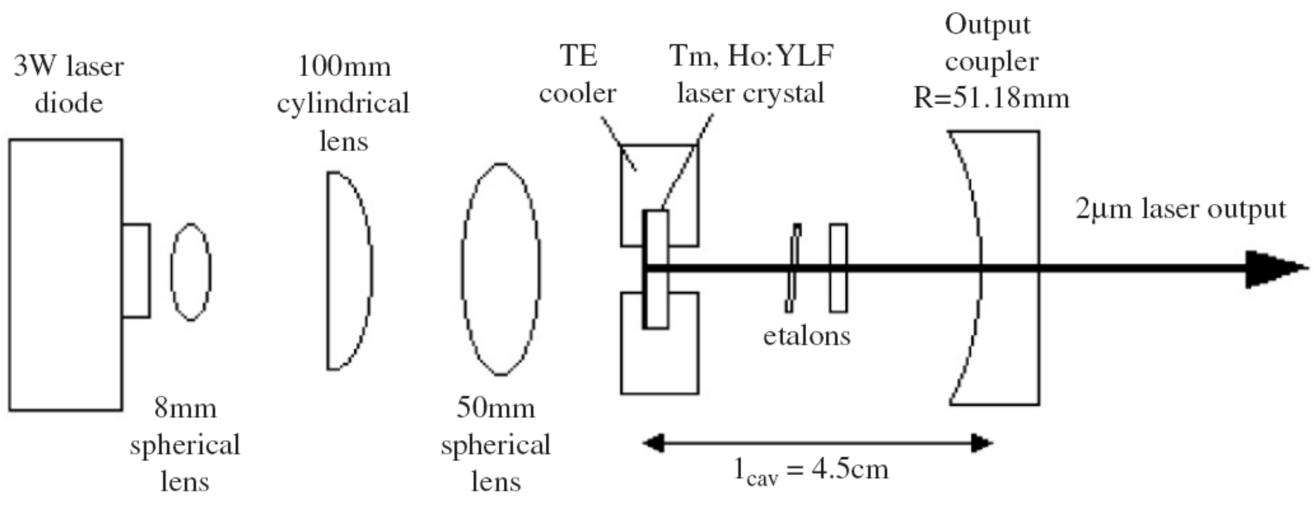


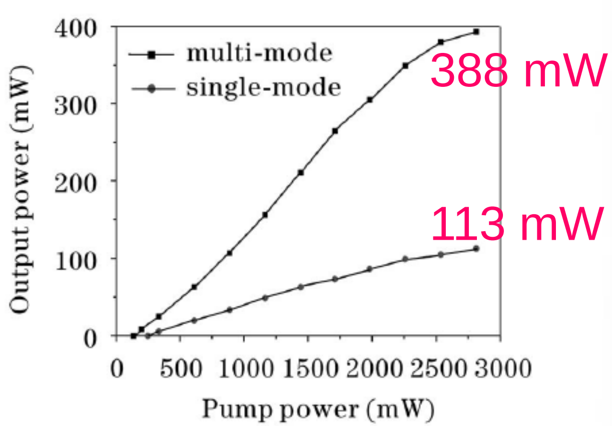
Cross Relaxation (CR)



Energy Transfer Upconversion (ETU)

2 micron DPSS laser

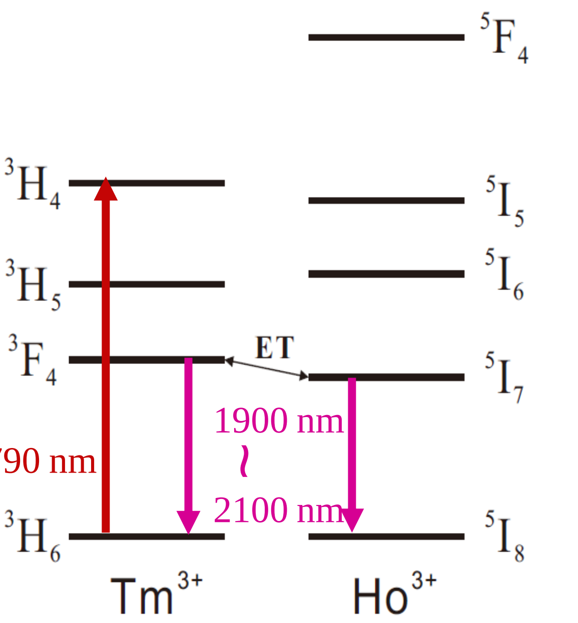




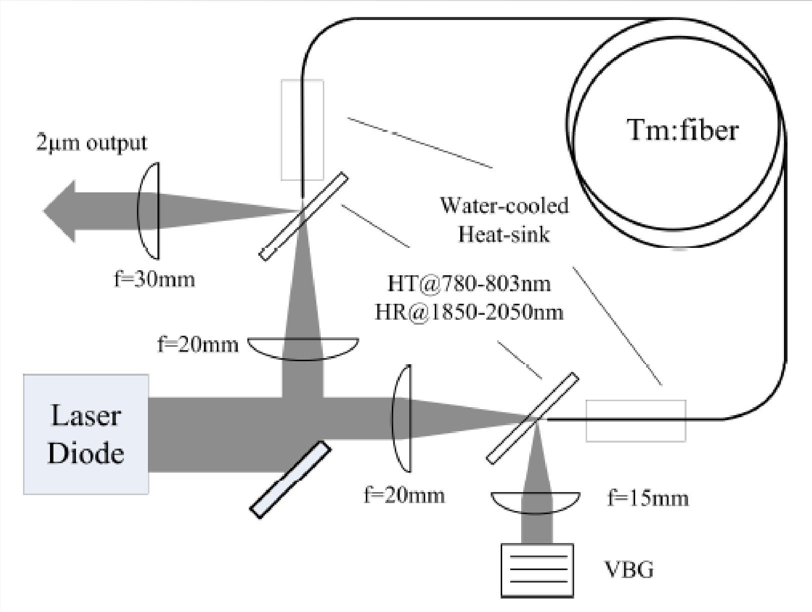
- ☑ The crystal temperature = 293 K
- ☑ Output coupler = 2 %
- ☑ Pth = 250 mW
- ☑ The single frequency P_{max} = 113 mW (P_{in} = 2810 mW)
- ☑ The single frequency could be tuned from 2063 to 2069 nm by changing the angle of the 1 mm thick etalon

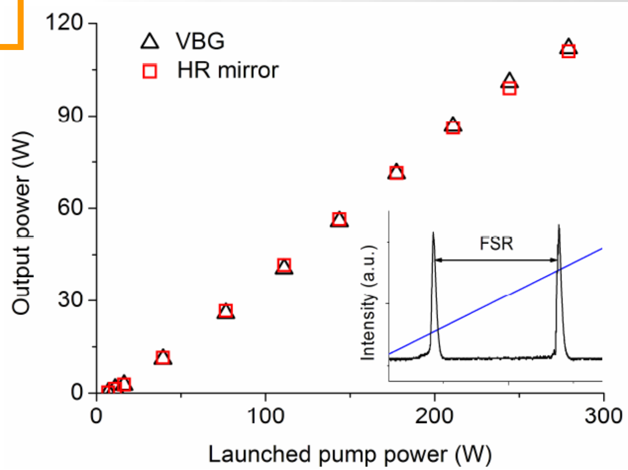
Chinese Optics Letters, **3**, 463-465 (2005)
Optics & Laser Technology, **39**, 782-785 (2007)

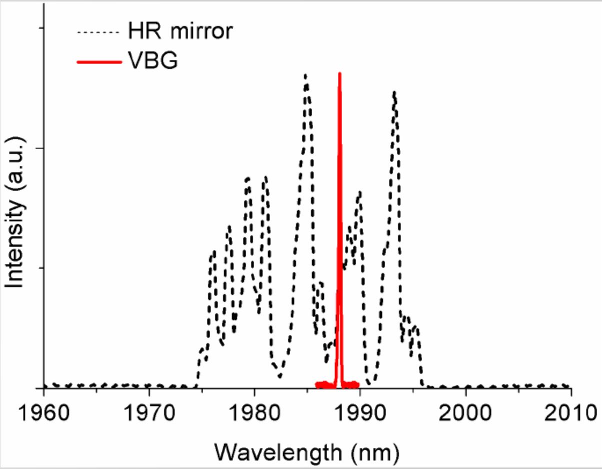
2 micron fiber laser - *Diode pumped fiber laser*



Energy levels of Tm^{3+} / Ho^{3+} in silica



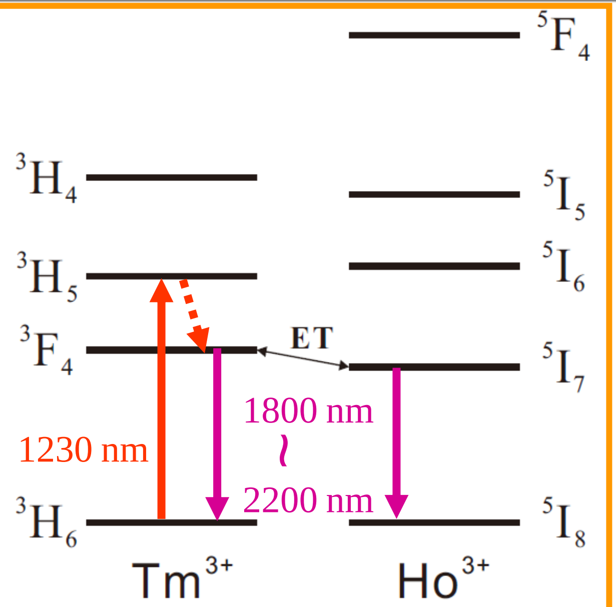




Pump = 279 W @ 792 nm
Output = 112 W @ 1988 nm
Slope efficiency = 43.3 %

OPTICS EXPRESS Vol. **18**, 8937 (2010)

2 micron fiber laser - *All-fiber laser*



Energy levels of Tm^{3+} / Ho^{3+} in silica

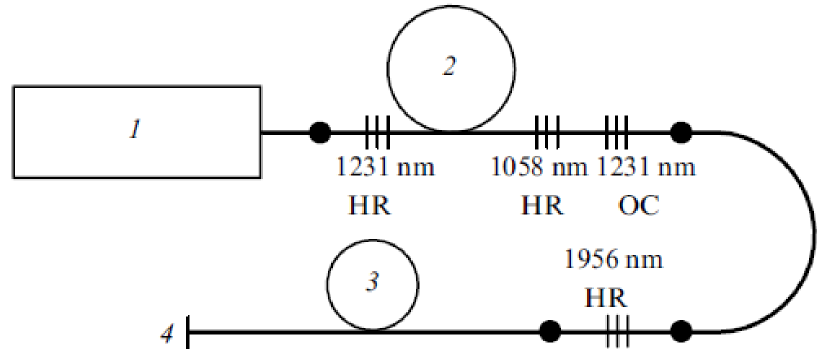
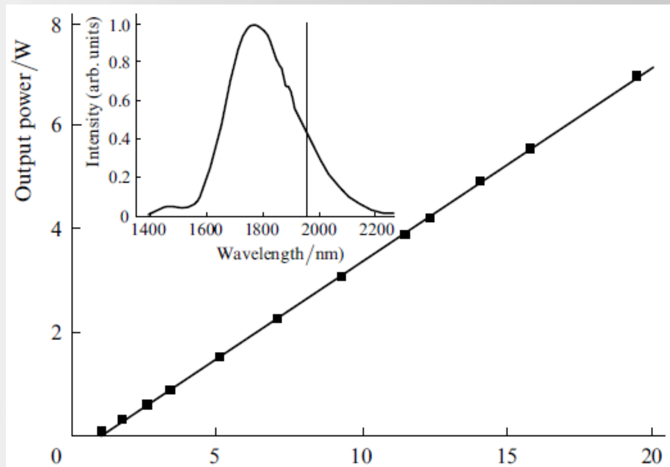


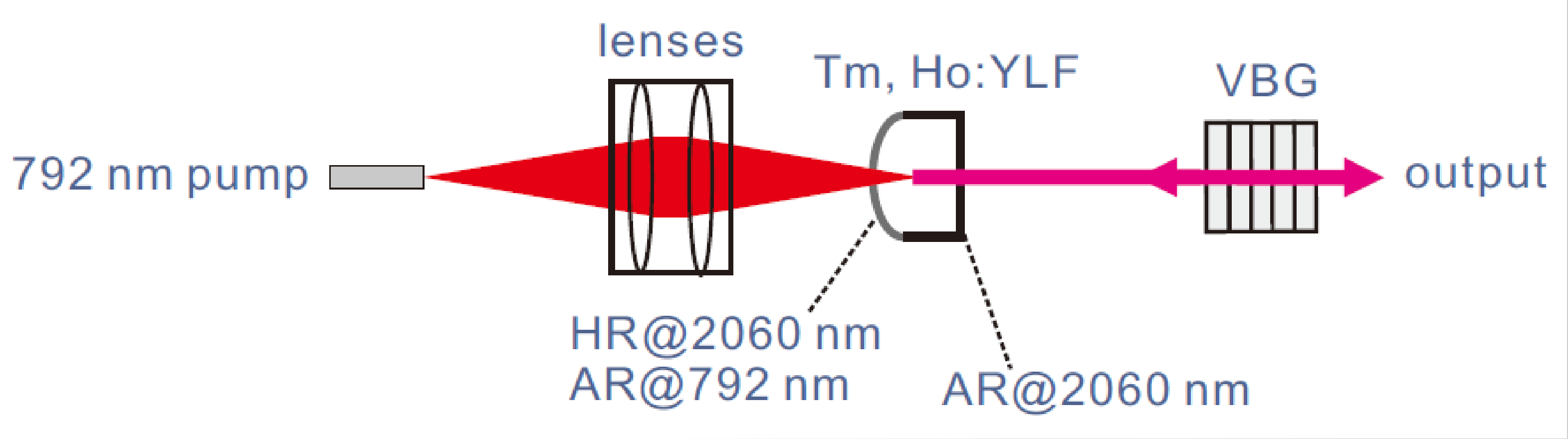
Figure 3. Scheme of a thulium-doped fibre laser: (*1*) 1058-nm single-mode ytterbium-doped fibre laser; (*2*) phosphosilicate fibre; (*3*) thulium-doped fibre; (*4*) output end of the thulium-doped fibre. The scheme shows splices (circles) and FBGs (HR: highly reflecting FBG; OC: output coupler FBG).

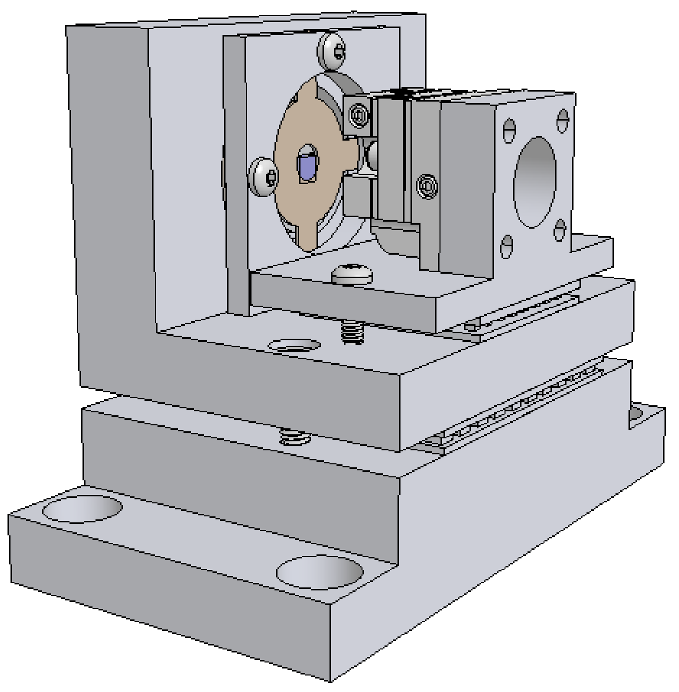
Pump = 20 W RFL @ 1231 nm
Output = 7 W @ 1956 nm
Slope efficiency = 35 %

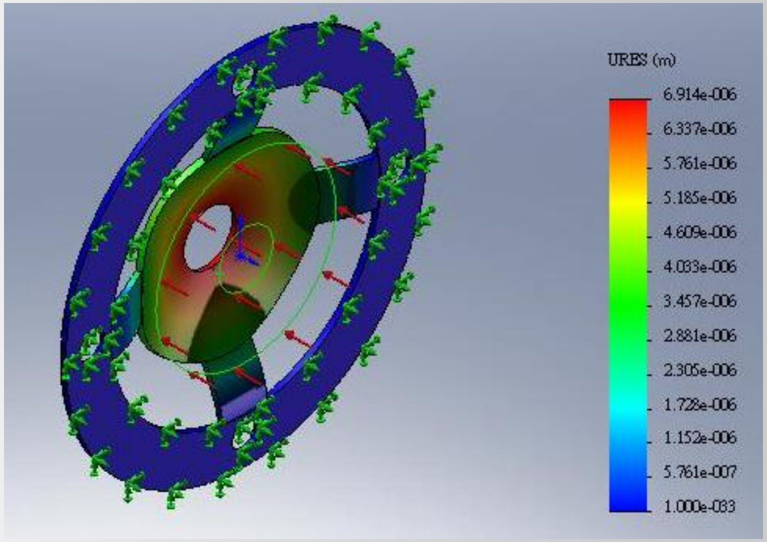


QUANTUM ELECTRONICS Vol. **35**, 586 (2005)

Setup of our 2 micron laser







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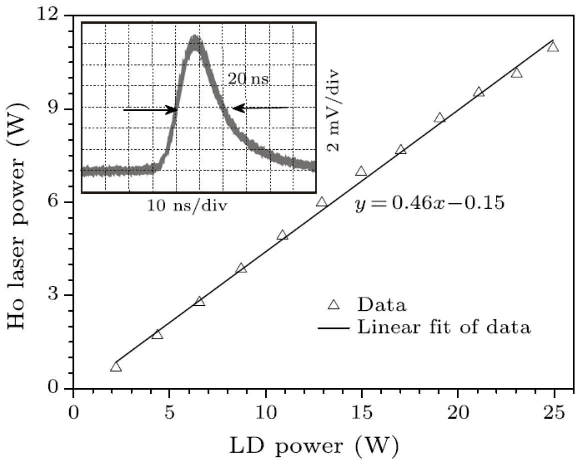
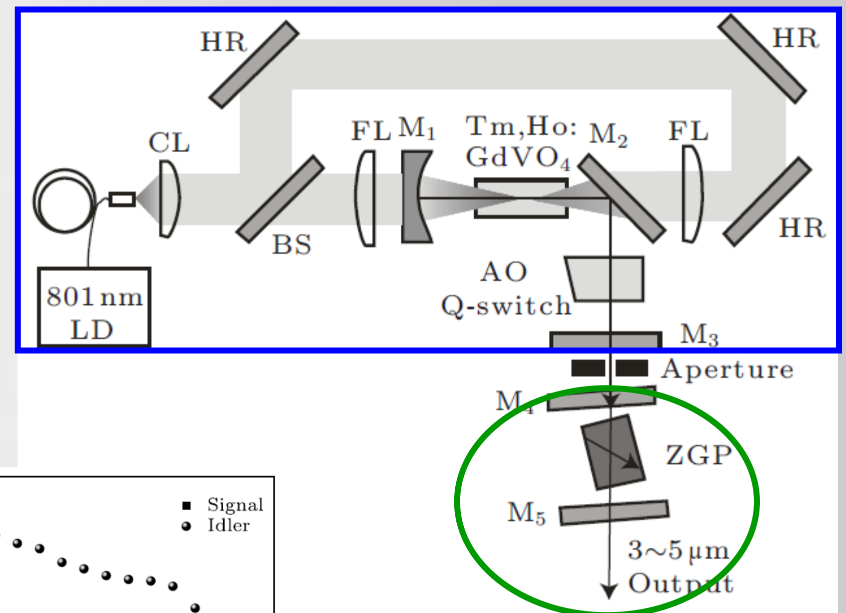
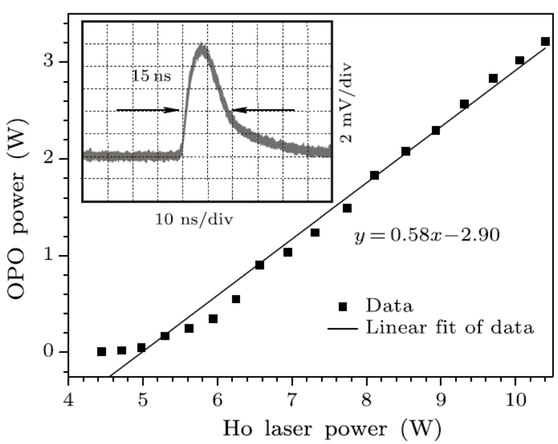
2 micron laser pumped Mid-IR sources

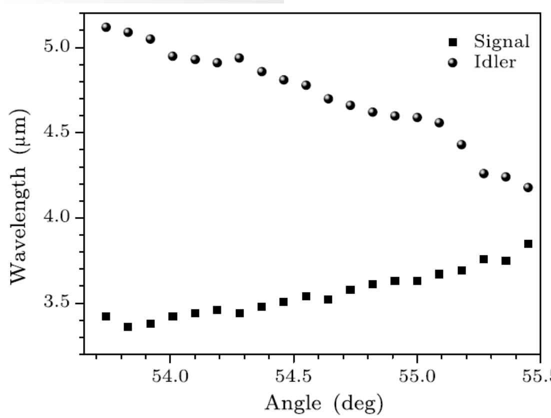
- Optical parametric oscillator (OPO)
- Difference frequency generation (DFG)



Q-switched 2 μm laser





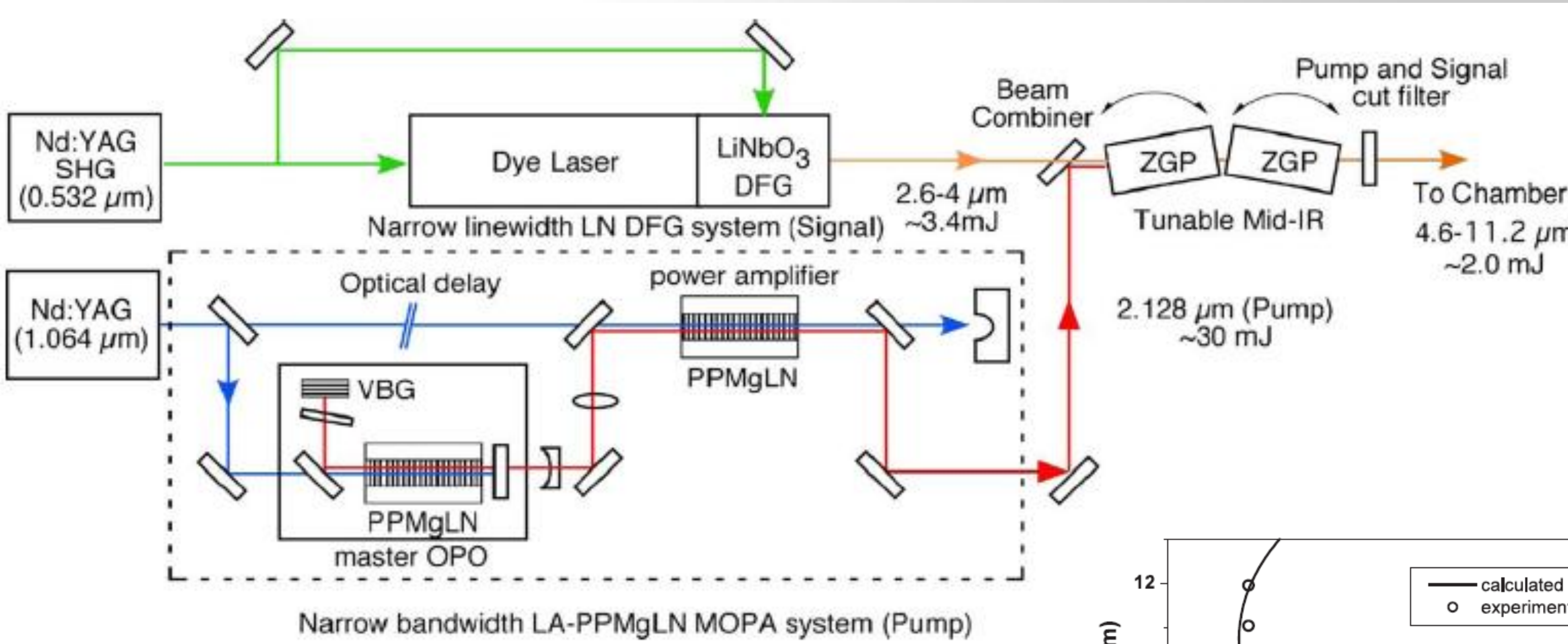


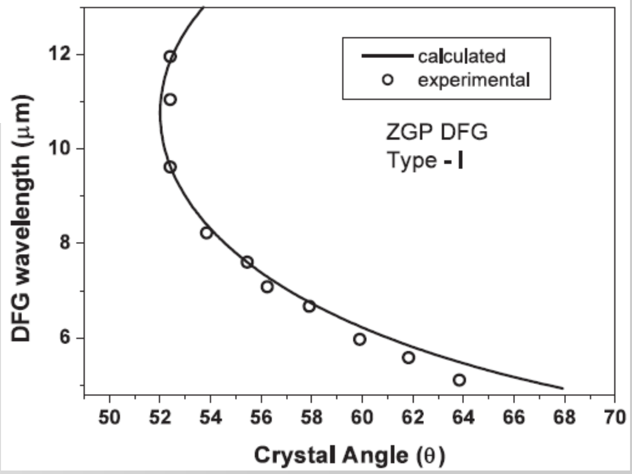
Mid-IR OPO
15 ns pulse
10 kHz repetition rate

CHIN. PHYS. LETT. Vol. **26**, 024209 (2009)

2 micron laser pumped Mid-IR sources

- Optical parametric oscillator (OPO)
- Difference frequency generation (DFG)





OPTICS LETTERS, Vol. 33, 1699 (2008)

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Application of Mid-IR Sources

Atomic & Molecular Physics

Mid-IR Sources (2~12 micron)

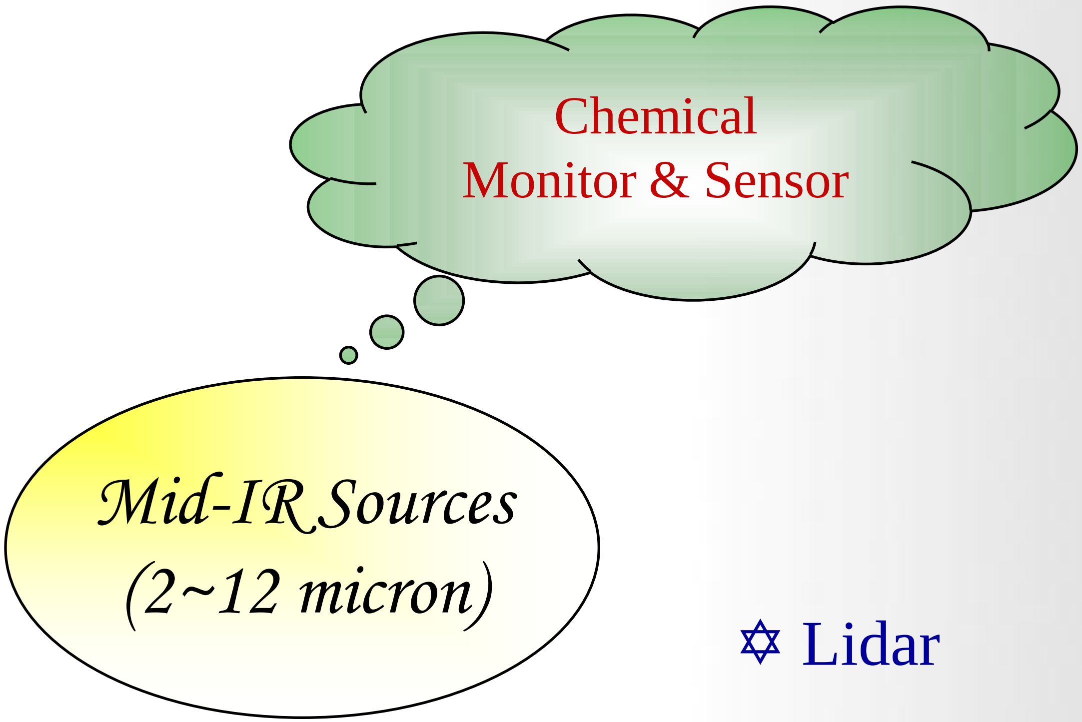
The strongest vibrational transitions in molecules are located in the mid-infrared spectral region, between 2 and 12 μm.

Table 2 Room-temperature absorption line strength in 10^{-21} cm^2/(molecule cm) for simple and common molecules in different spectral regions from visible to mid-infrared[a]

	Visible/near-infrared	Shortwave mid-infrared	Long-wave mid-infrared
Wavelength	0.7–2.0 μm	2.5–5.0 μm	5.5–12 μm
Wave numbers	5,000–14,500 cm^{-1}	2,000–4,000 cm^{-1}	800–1,800 cm^{-1}
CO_2	0.3	3000	0.03
CO	0.02	300	0
CH_4	1	100	50
C_2H_2	10	200	100
H_2O	20	200	200
NH_3	5	10	200
NO	0.04	0.3	20

Annual Review of Analytical Chemistry, Vol. 3, 175-205 (2010)

Application of Mid-IR Sources



- ✡ Lidar
- ✡ Gas monitor
- ✡ Semiconductor Processing Monitor

Application of Mid-IR Sources

Breath Analysis

Sensors, Vol. **9**, 8230 (2009)

Breath Analysis Using Laser Spectroscopic Techniques: Breath Biomarkers, Spectral Fingerprints, and Detection Limits

Chuji Wang * and Peeyush Sahay

Mid-IR Sources
(2~12 micron)

Acetaldehyde (CH_3CHO) - alcoholism and lung cancer
Ammonia (NH_3) - renal failure and asthma
Carbon dioxide (CO_2) and ^{13}C-isotope - Helicobacter and liver malfunction
Carbon monoxide (CO) - hypertension and smoking cessation monitor
Methane (CH_4) - colonic fermentation and intestinal problems
Nitric oxide (NO) - asthma, hypertension, and rhinitis
…

Application of Mid-IR Sources

Biomedical & Medical Applications

J. Opt. Technol. Vol. **77 (1),** 6, (2010)

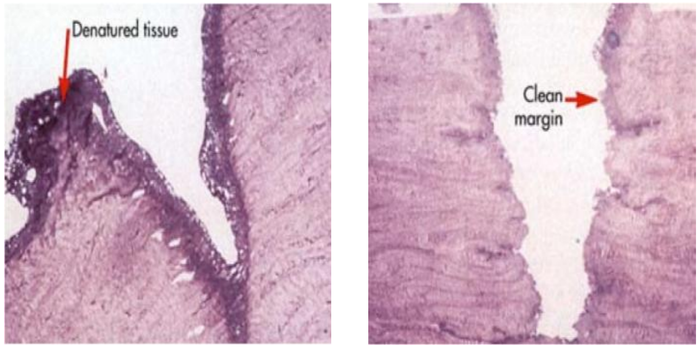
Mid-IR Sources (2~12 micron)

The objective of laser ablation is to remove a definite part of tissue, leaving the surrounding tissues alive.

✪ Vessel-carrying tissues cutting : brain surgery requires surface coagulation “thermal damage” in order to reach hemostasis stopping of blood flow.

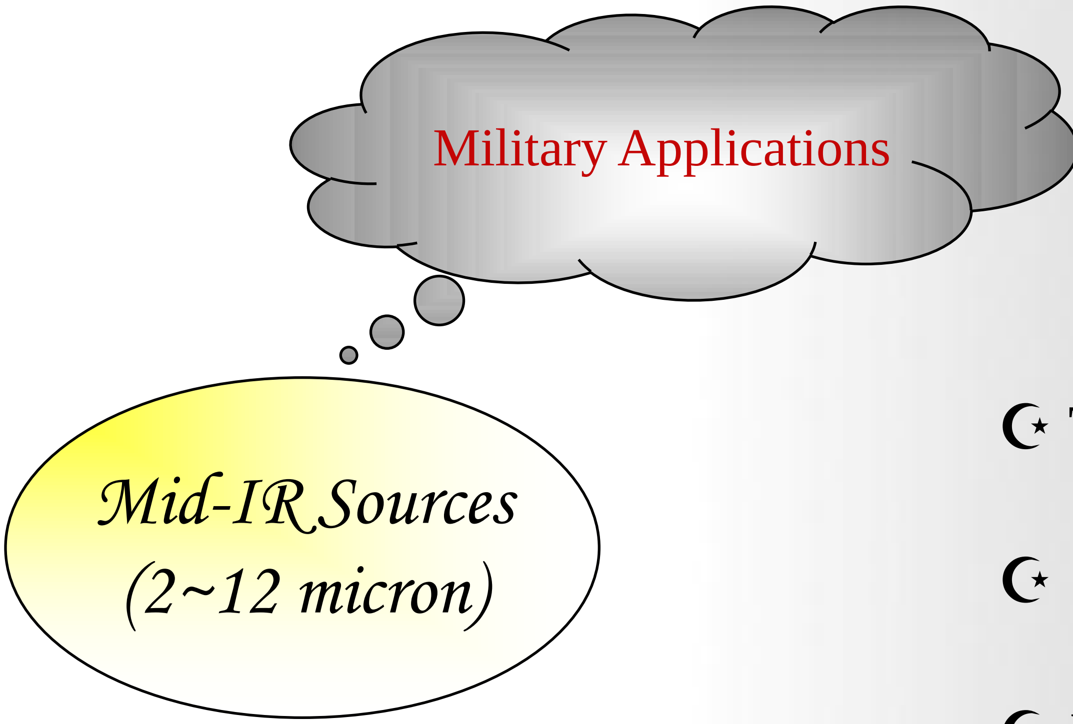
✪ Vessel-free tissues cutting : cosmetology wounds heal better when there is no thermal damage.

✪ Soft-tissue cutting: $\lambda = 6.1\ \mu m$: the deepest crater and the lowest collateral thermal damage



[Sanghera and Aggarwal, NRL]

Application of Mid-IR Sources



- Target acquisition
- Surveillance
- Night vision
- Tracking

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Outlook

CURRENT NEWS

Strategies Unlimited says "mid-infrared lasers could be boosted with advancements in several new laser technologies."

Mid-Infrared Lasers 2010
(Market Review and Forecast)

Advancements in several new laser technologies are opening new opportunities in the part of the spectrum between telecom lasers and the nascent terahertz range, called the mid-infrared. This range is currently dominated by applications in materials processing and medical procedures, but new military and sensing applications will add sizeable and exciting opportunities in the next few years. The new segments will grow 30% per year, compounded annually through 2014.

http://compoundsemiconductor.net/csc/news-details.php?cat=news&id=19732386

Thanks For Your Attention!