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2 µm lasers and Mid-IR frequency conversion

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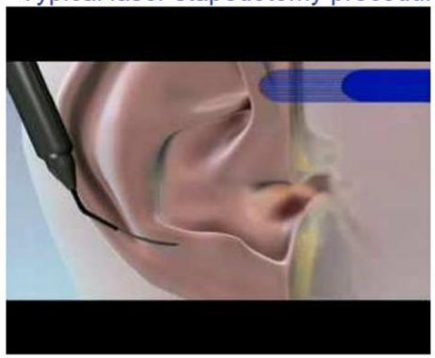
Mid-IR applications

Typical laser stapedotomy procedure



Security

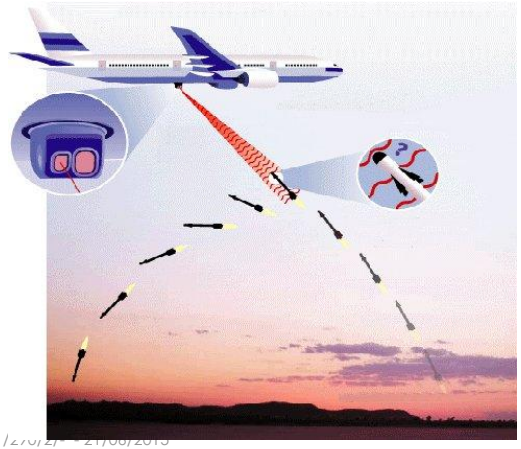
Environment

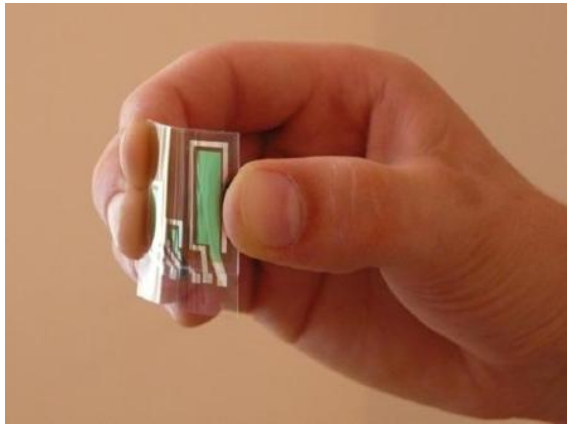
Medical

Mid-IR laser sources

Military

Industrial



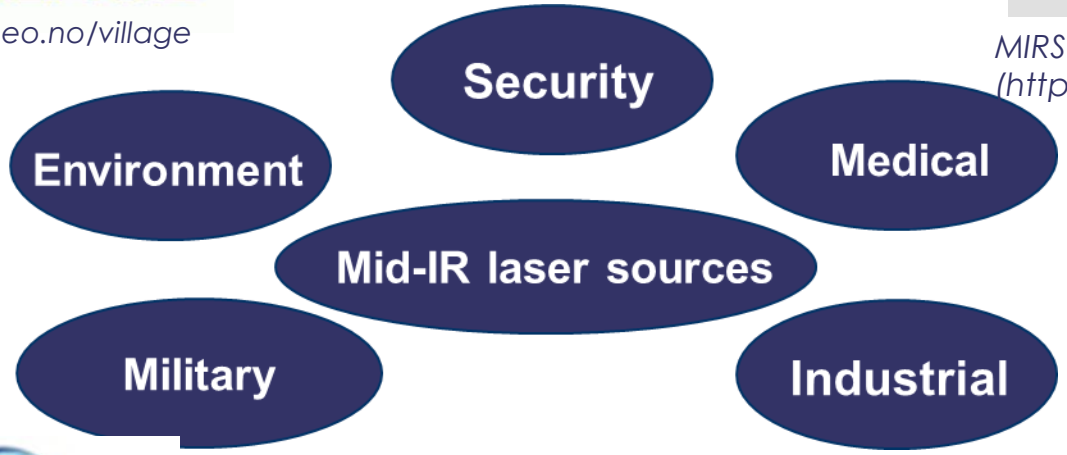


Thales Research and Techonology & MIR EC projects

www.**mirifisens**-project.eu

http://www.neo.no/village

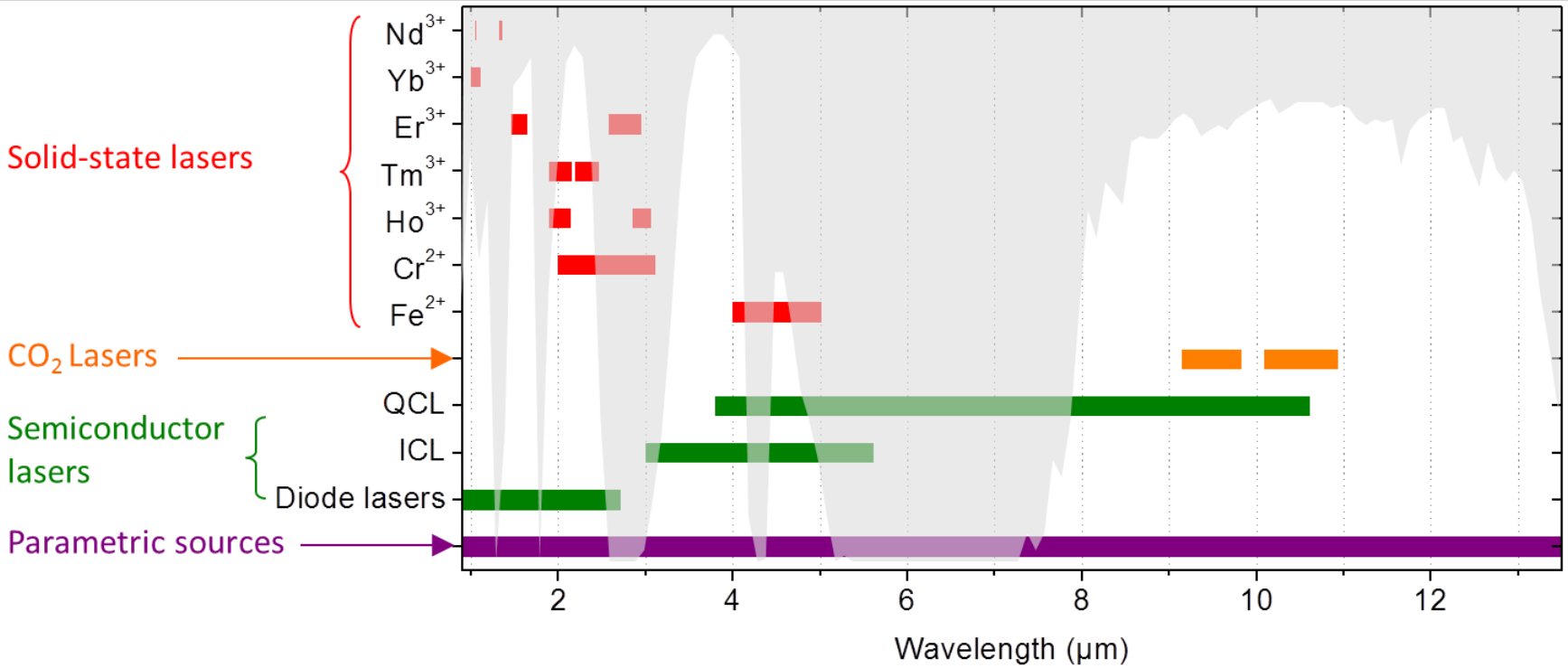
MIRSURG
(http://www.mirsurg.eu)



IMPROV
(http://www.fp7project-improv.eu)

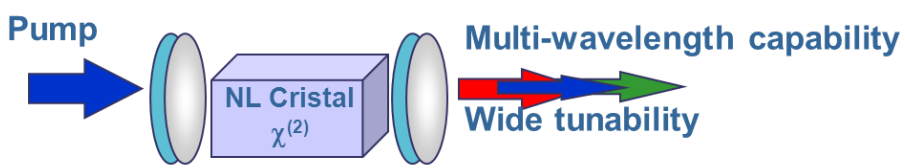
http://ec.europa.eu/research/transport/projects/items/casam_en.htm

MIR laser sources requirements and OPOs



- **Parametric sources are still a promising option assuming 2 µm fiber laser pumping and NCPM efficient nonlinear crystal.**

Optical Parametric Oscillator (OPO)



Suitable MIR nonlinear crystal?

MWIR nonlinear crystals

Desirable properties for the NL crystal:

- High nonlinear coefficient
- Low absorption loss
- High laser damage threshold
- Low thermal lensing
- Non-critical phase matching

QPM vs BPM:

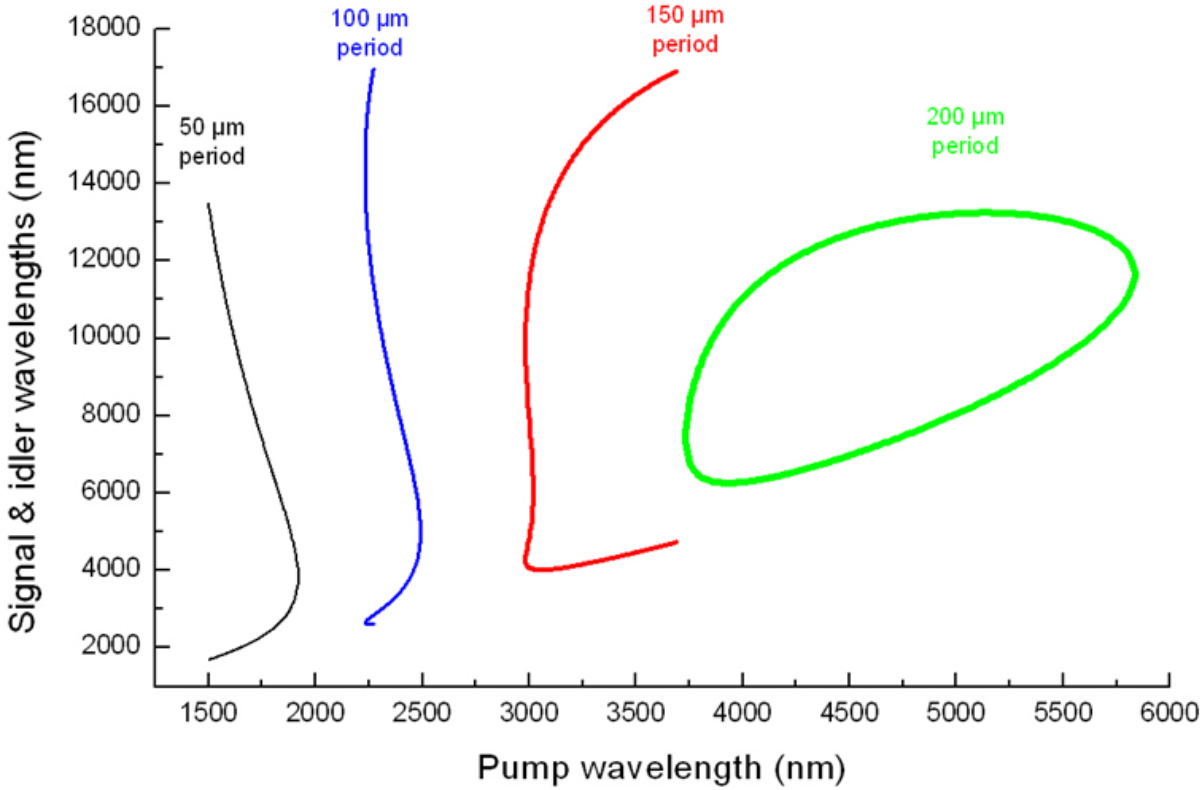
- High nonlinearities
- Non-critical interactions
- Engineering flexibility

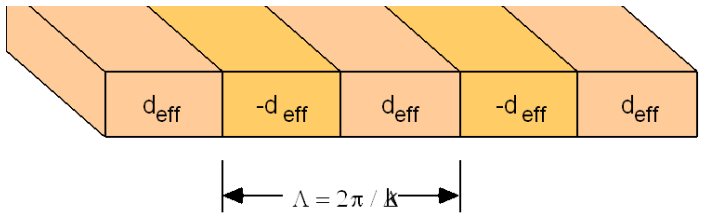
	PPLN	*ZGP*	*GaAs*
Transmission (µm)	0.35-5	1-12	1-16
Nonlinear Coefficient (pm/V)	27	75	96
Thermal Conductivity (W/m.K)	5	35	52
α (cm^{-1}) (> 2 µm)	--	0,025	0,02

OP-GaAs = PPLN of the MIR ?

Quasi-Phasematching (QPM) in GaAs

- Periods under 100 µm for near-infrared pump lasers





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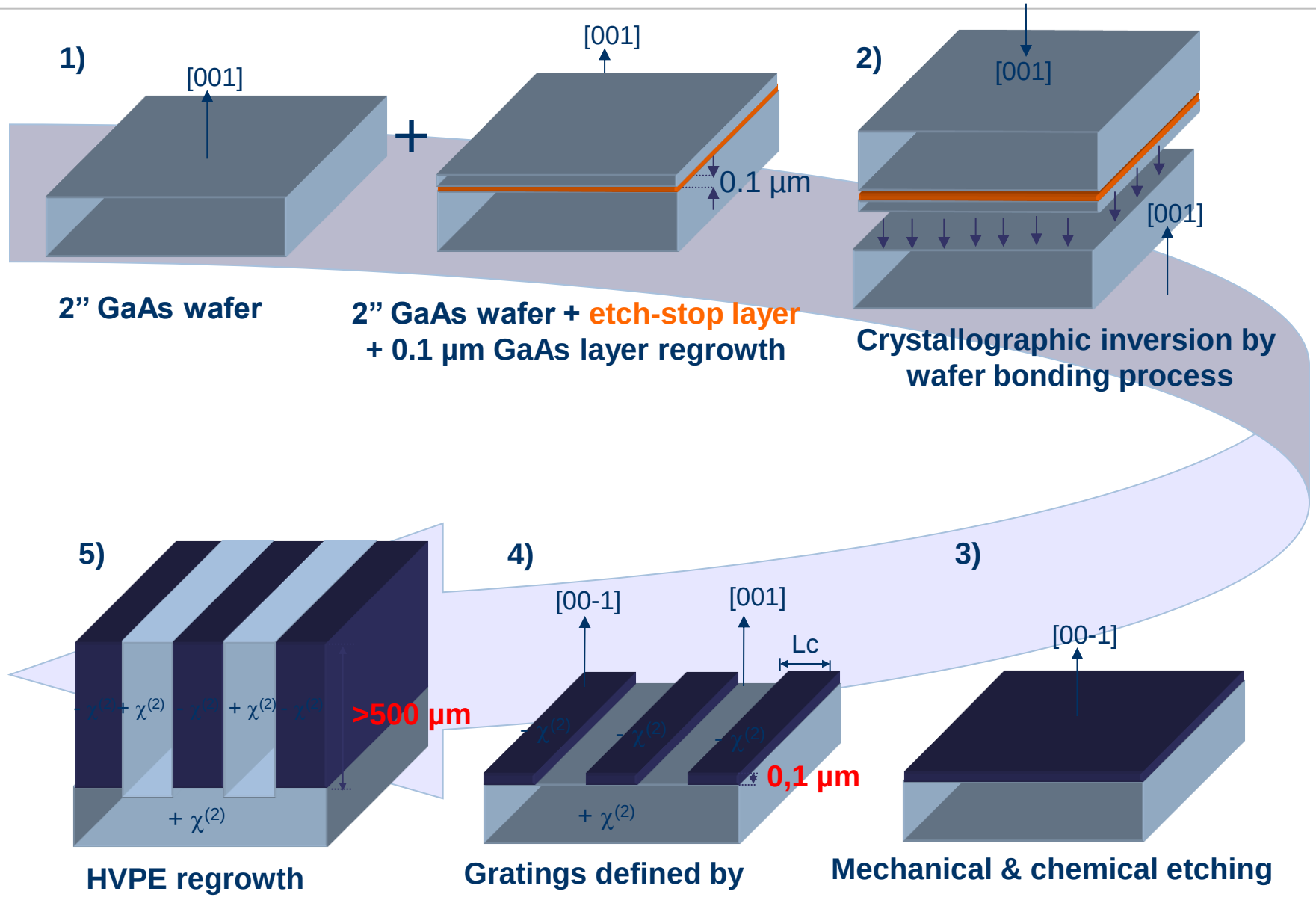
Fabrication of Thick Orientation-Patterned GaAs



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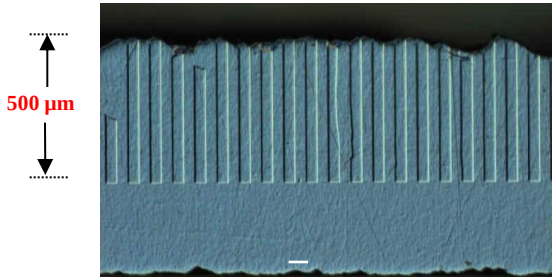
Full wafer growth

2” multigrating 500 µm thick OP-GaAs

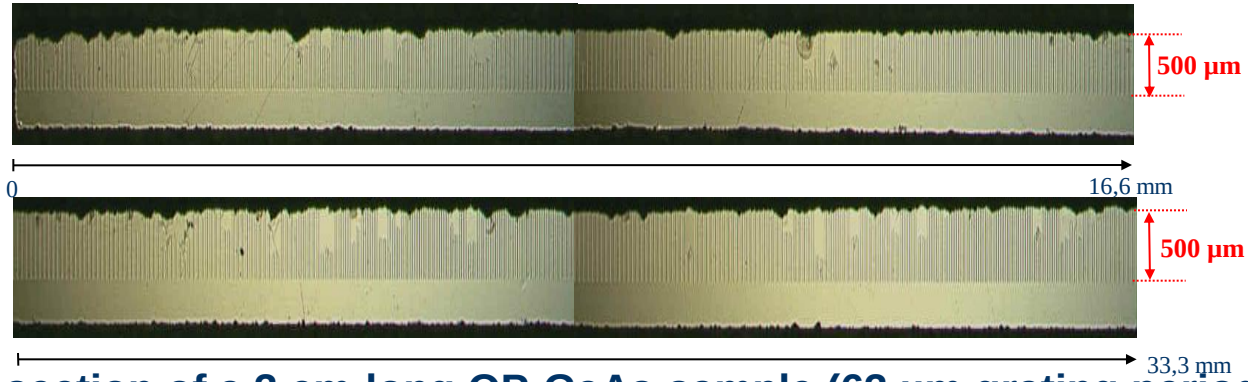


Growth characteristics:

- **Growth rates:**

v(113)= 33 µm/h
v(-112)= 30 µm/h

- **4 growth interruptions**



Cross section of a 3 cm-long OP-GaAs sample (63 µm grating period)

Losses down to 0.016 cm-1 at 2 µm (< 0.03 cm-1 in average)

Difference Frequency Generation

DFG at around 7.8 µm from Er and Tm CW fiber lasers : UoDusseldorf & ORC

(S. Vasilyev et al., Opt. Lett., 33, 13, 2008, pp. 1413-15)

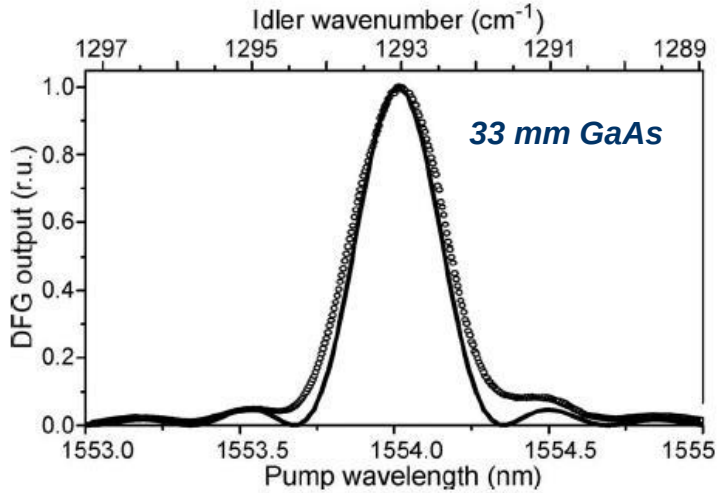
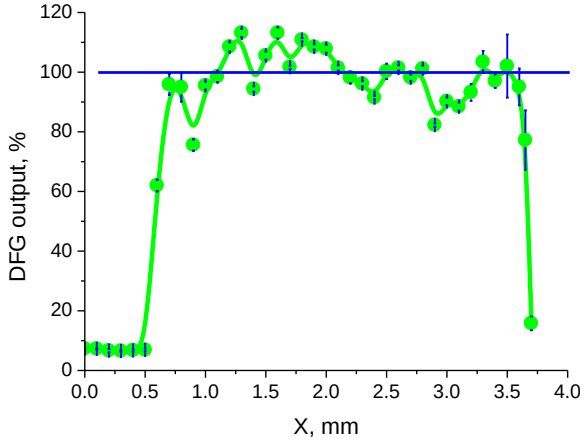
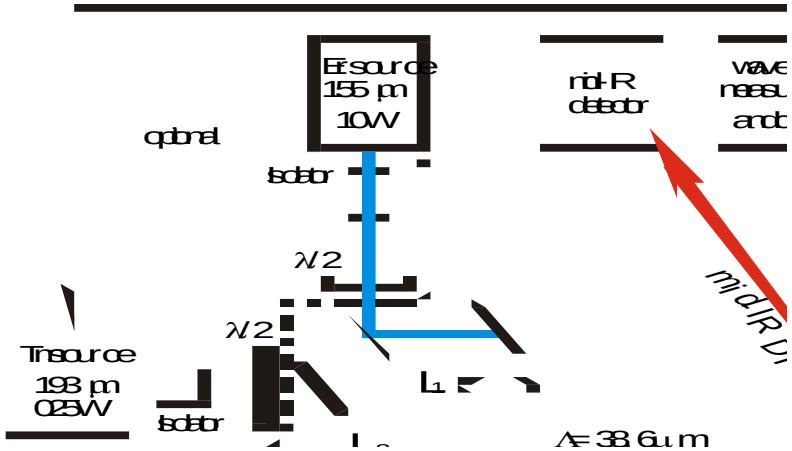


Fig. 2. Measured (°) and calculated (solid curve) DFG output versus signal wavelength.





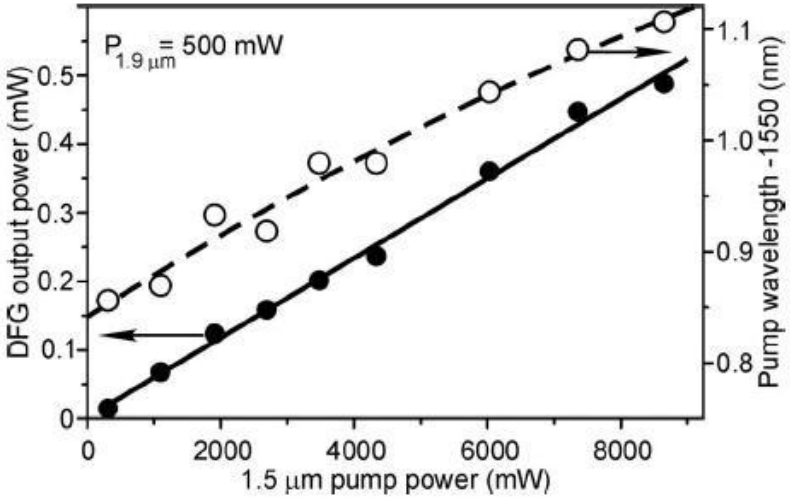
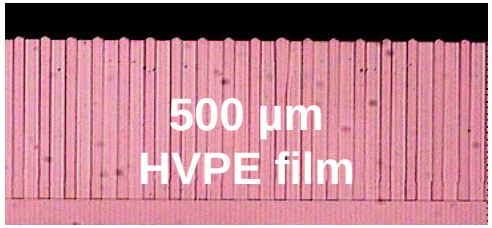


Fig. 3. DFG output power (•) and optimal pump (°) wavelength versus pump power.

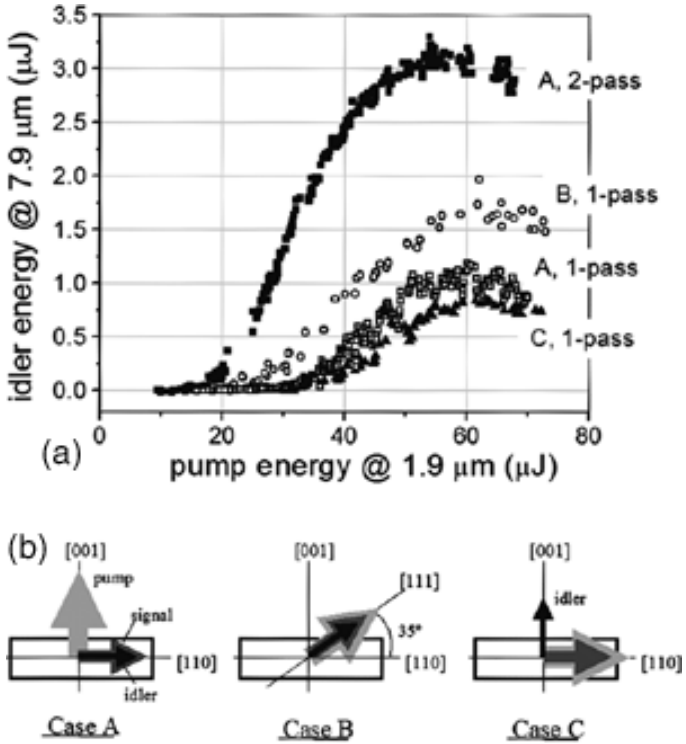
Optical Parametric Oscillation

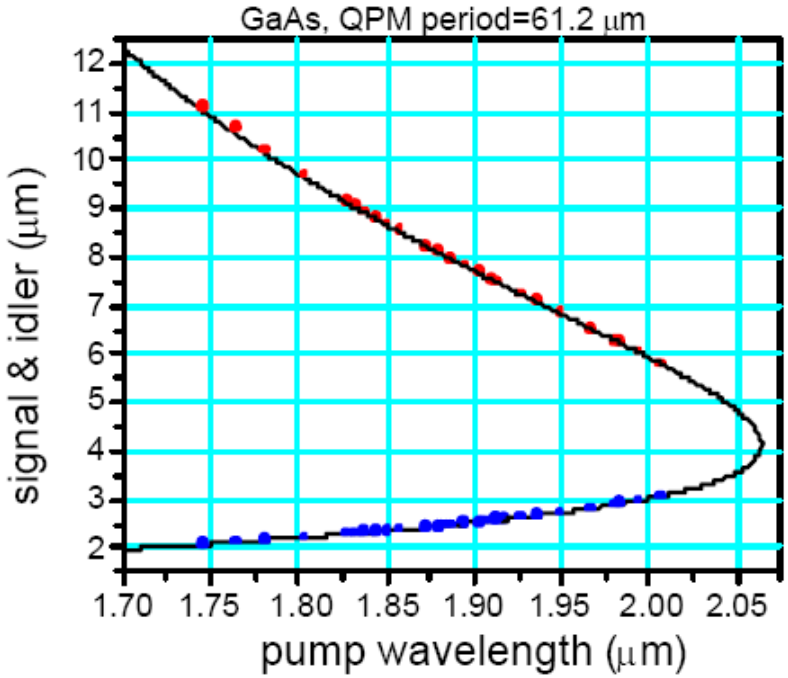
✓ **First demonstration of GaAs OPO (2004): Stanford University & Thales**

(K.L Vodopyanov et al., Optics Letters, Vol 29, 16 (2004))



- **OP-GaAs sample length: 13 mm**
- **HVPE layer thickness: 500 µm**
- **PPLN OPO pump**



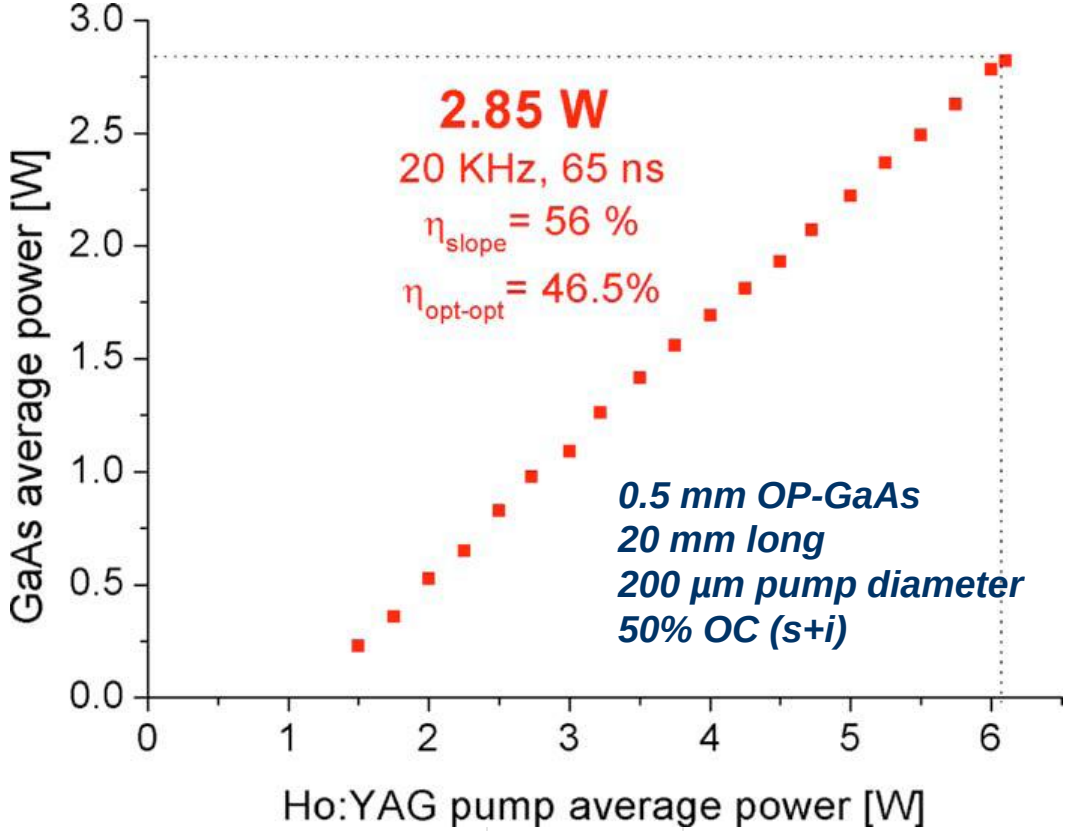


High power OPO

✓ **High power GaAs OPO (2008): Institut St. Louis (ISL)**

(C. Kieleck et al., Optics Letters, Vol 34, 3 (2009))

- **>2.09 µm high rep.rate Ho:YAG pump , 3-5 µm emission.**
- **>Up to 60% slope efficiency and 2.85 W output**
- **>Efficiency comparable to $ZnGeP_2$**



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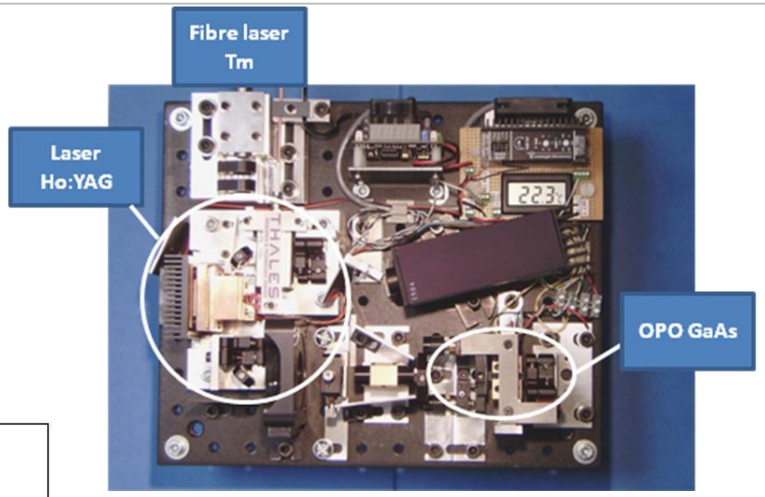
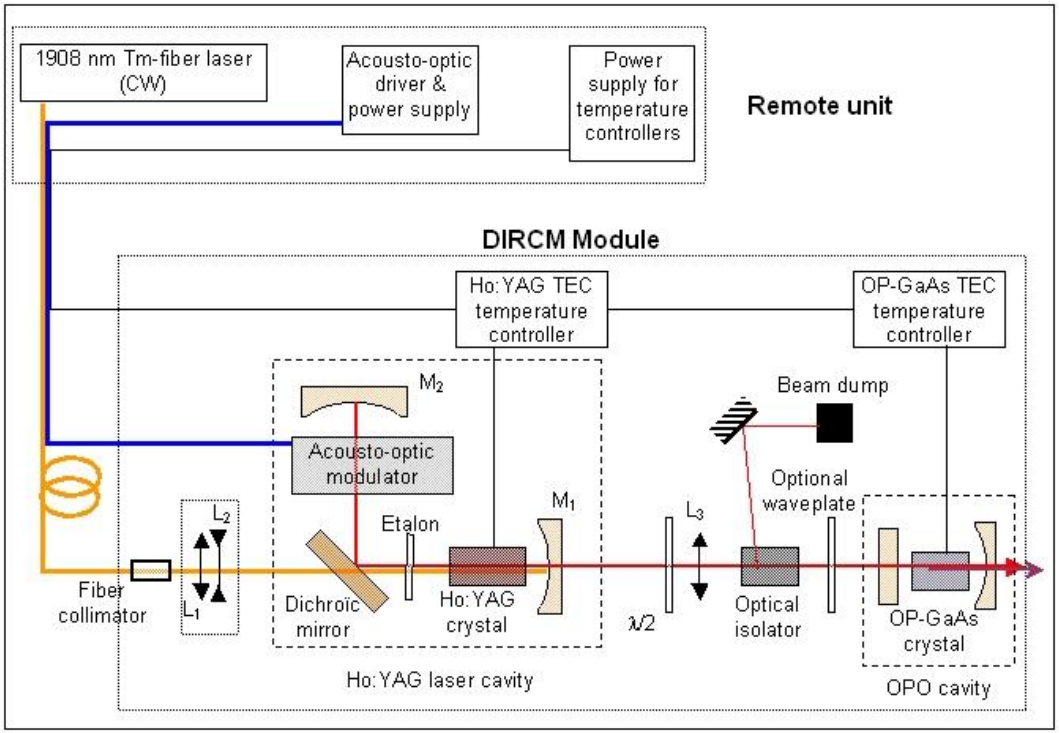
Portable DIRCM module

- 20 W Tm fiber laser
- 10 W Q-switched Ho:YAG
- 3.0 W MWIR at 40 kHz
- $M^2 = 1.4$

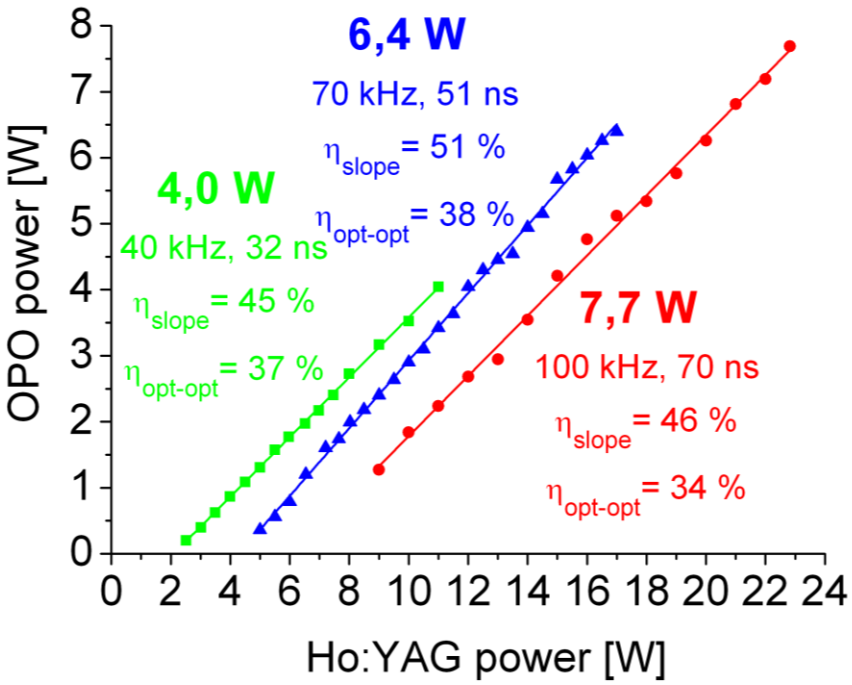




A. Grisard et al., Proc SPIE 7836-06 (2010)

Higher power experiments

- 25 W Q-switch Ho:YAG laser
- 20 mm long crystal, 0.45 mm thick
- 7.7 W at 100 kHz in 3-5 µm range (pump limited)
- M^2 < 1.4 (signal) & 1.8 (idler)

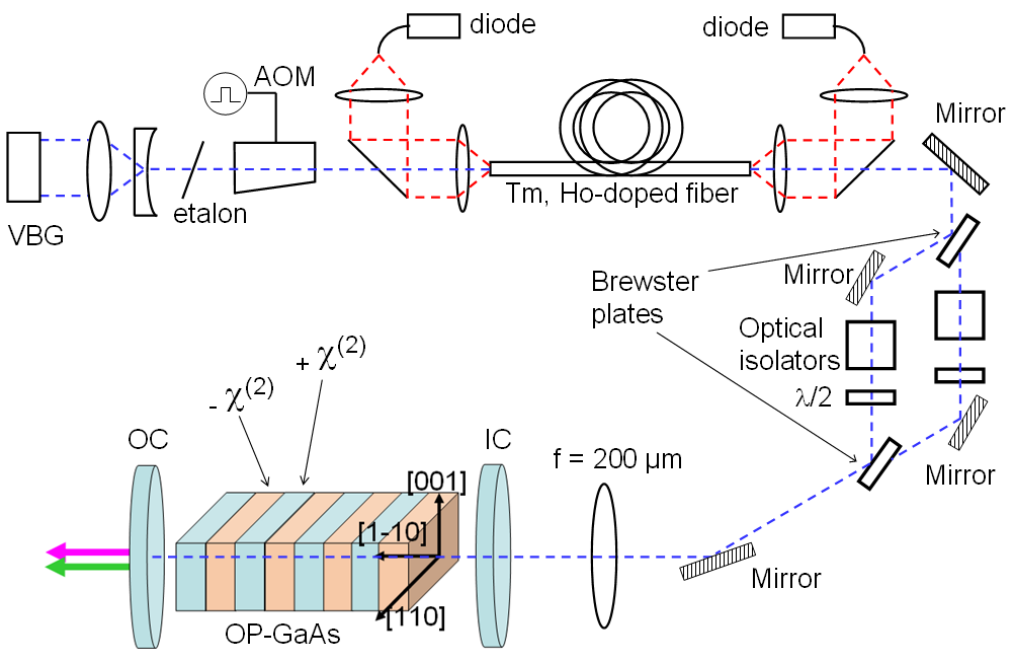


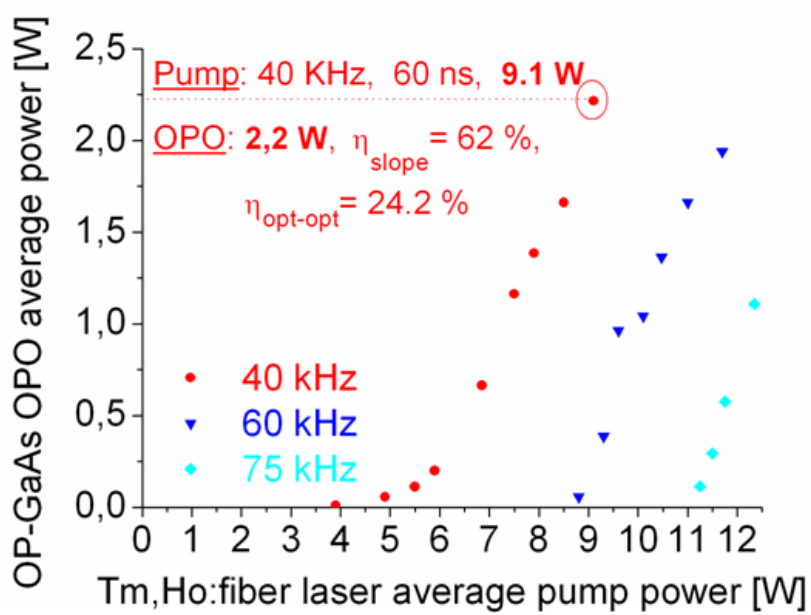
Box dimensions :
391 x 516 mm

A. Hildenbrand et al., Proc. SPIE 8187-15 (2011)

Fiber laser pumping

- Q-switched Tm:Ho fiber laser
- 2.2 W output power at 40 kHz
- Pump peak power limitation

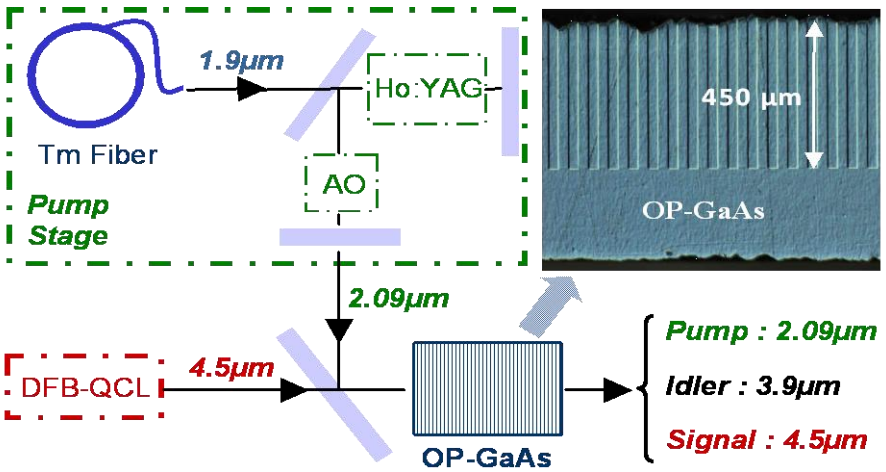


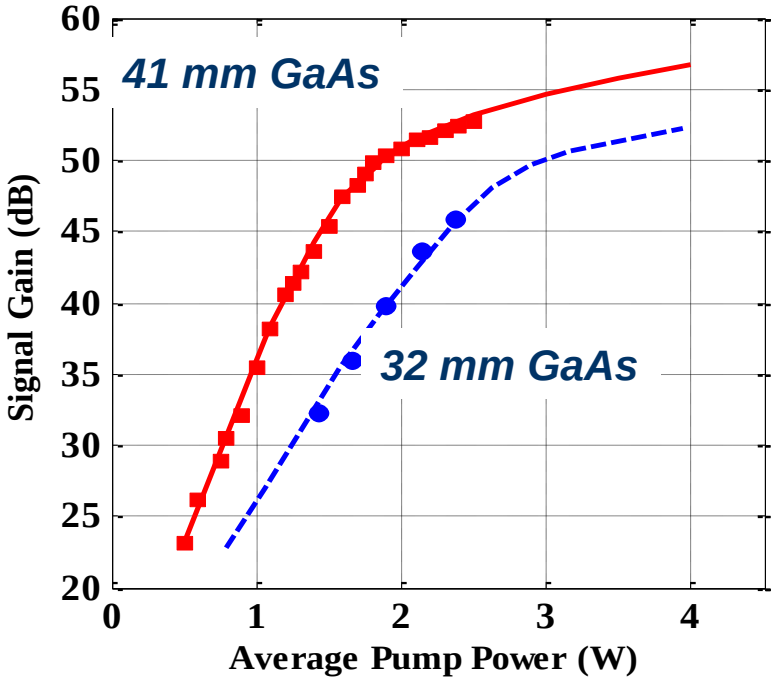


C. Kieleck, et al., Proc. SPIE 7582 (2010)

Parametric amplification of a 4.5 µm DFB QCL

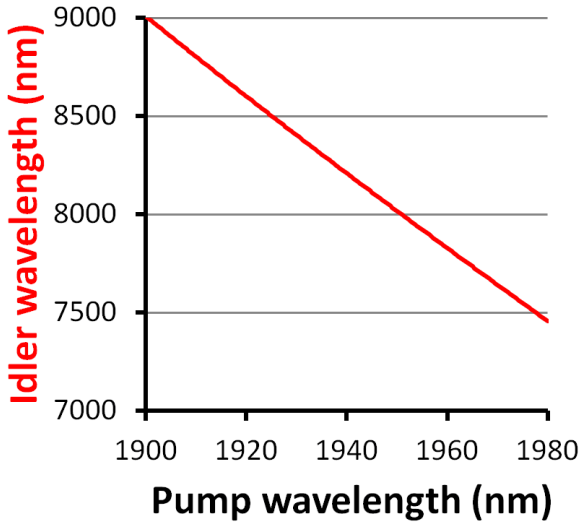
- 3 mW 4.5 µm CW DFB QCL
- 2.09 µm Ho:YAG 30 ns pulsed pump at 20 kHz
- 53 dB gain with 41 mm long GaAs crystal
- 600 W peak power
- $M^2 = 1.3$, $\Delta\lambda < 0.5$ nm (instr. limited)



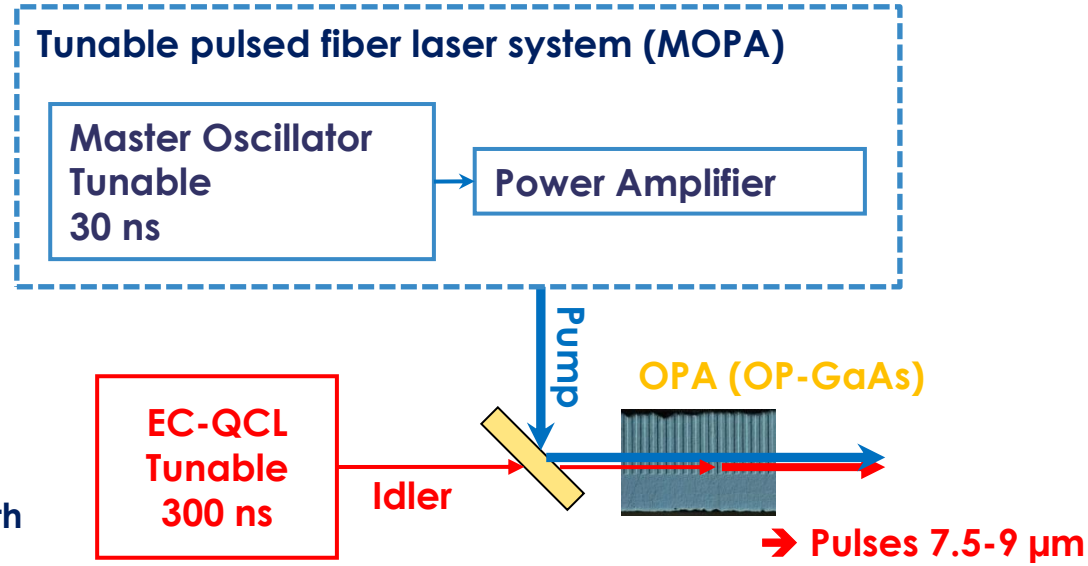


G. Bloom et al., Optics Letters, Vol.35, N 4, (2010).

7-9µm tunable parametric amplification



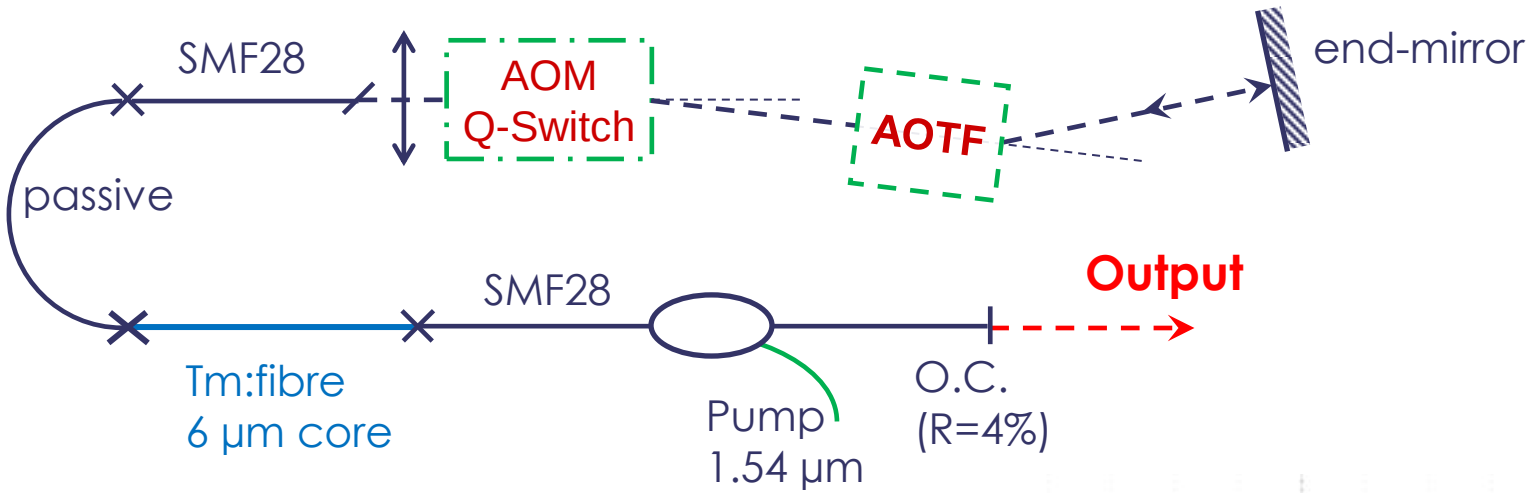
Amplified wavelength vs pump wavelength for a fixed QPM period of 65.8 µm at room temperature



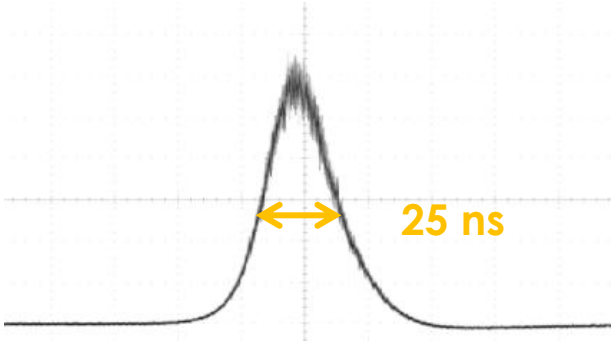
IAF Fraunhöfer

Master oscillator

- AO tunable & Q-switched laser with Tm-doped fiber

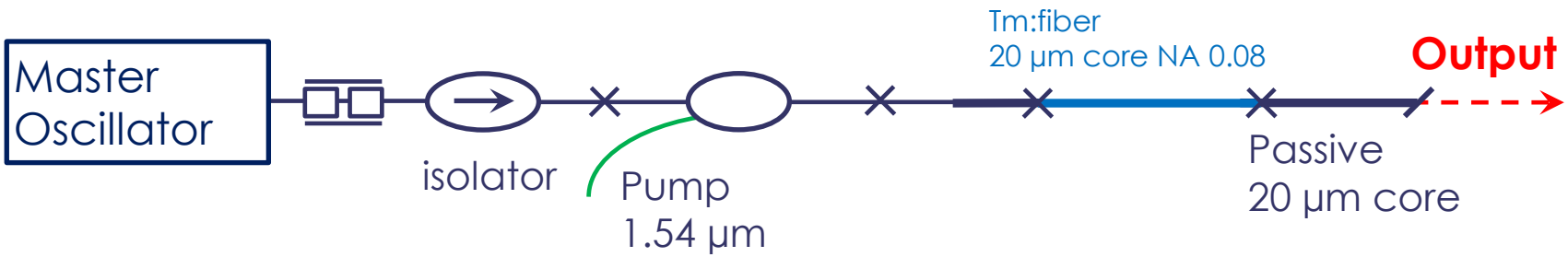


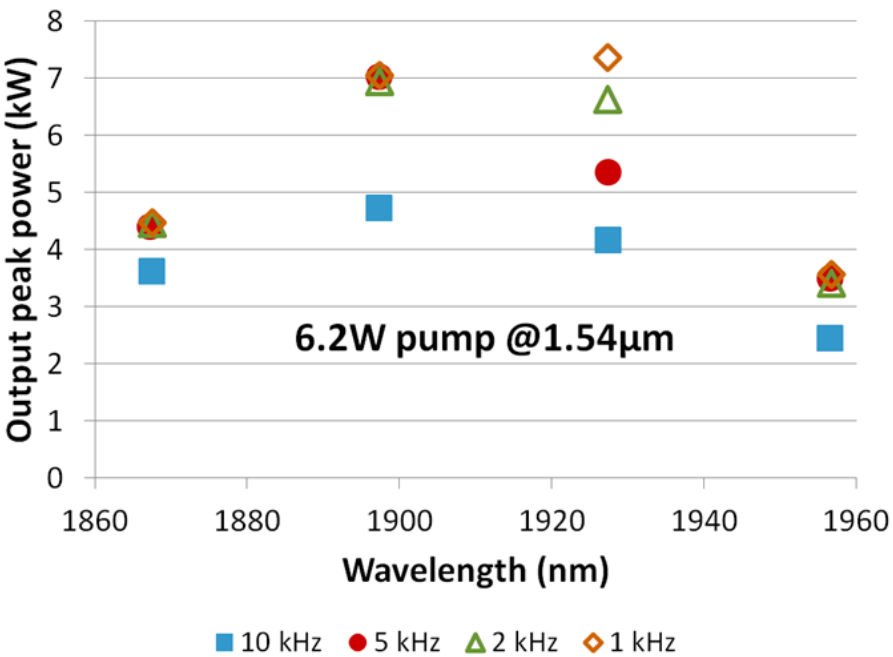
➔ **Q-switch pulses / repetition rate 1-20 kHz**
➔ **Pulse width < 35 ns**
➔ **Tunability > 90 nm**
➔ **Output peak power > 300 W**

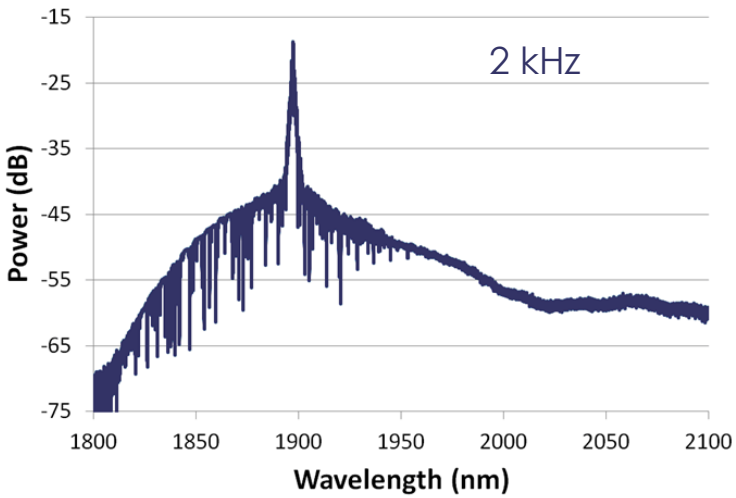


Fiber amplifier

- 20 µm core diameter amplification stage



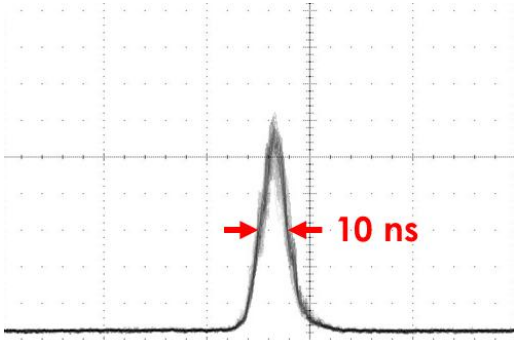




- **50-75% of power within 2 nm**
- **$M^2 < 1.1$**

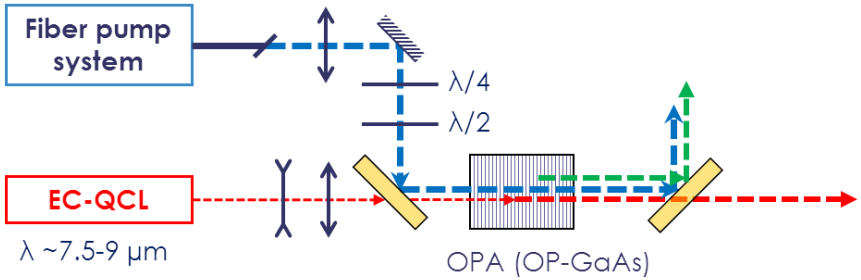
Tunable OPA

- OP-GaAs crystal of period 63.8 µm, length 32 mm, non-optimized AR coatings
- Equal waists for the QCL and the pump
- Experiment at 2 kHz for QCL and pump
- 330 ns QCL pulses synchronized with 25-35 ns pump pulses

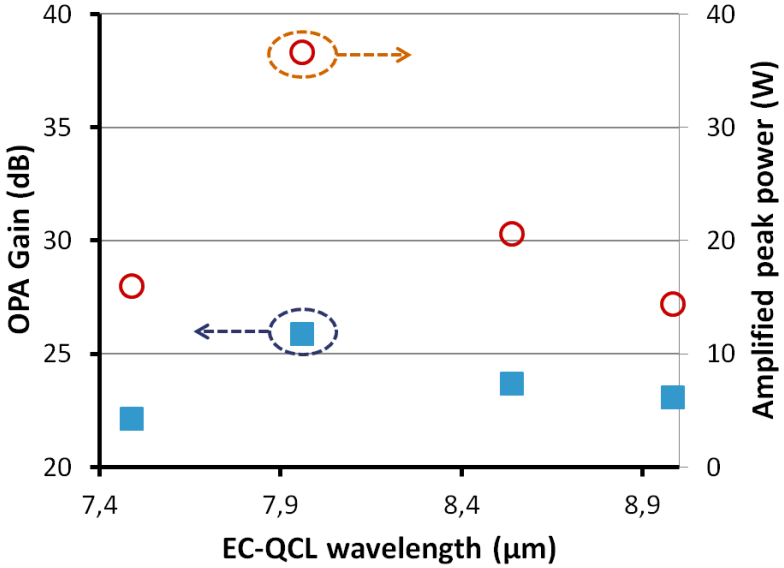


➔ Amplified pulses

- Gain 22-26 dB.
- 15 to 37 W output peak power
- $M^2 < 1.4$



QCL peak power input = 100 mW



Conclusions

- **OPGaAs is a promising material for frequency conversion of 2 µm laser in the Mid-IR spectral range**
- **2 µm fiber lasers and amplifiers are the preferred pump source**
- **However care should be taken to provide:**
  - All-fiber systems
  - Single-spatial mode operation
  - Linewidth control
- **Thales research & Technology is open for future collaborations in the field**
  - eric.lallier@thalesgroup.com

Aknowledgment

Thales R&T

- A. Grisard
- F. Gutty
- D. Papillon

III-V Lab

- B. Gerard

ISL

- C. Kieleck
- M. Eichhorn

Fraunhofer IAF

U of Dusseldorf

ORC Southampton