INNOVATIVE OPTICAL PARAMETRIC SOURCES USING ISOTROPIC SEMICONDUCTORS

E. Rosencher, M. Baudrier, R. Haidar ,A. Godard, M. Lefebvre and Ph. Kupecek*

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*** University PMC**

SUMMARY

- Why bother?
- Semiconductor $\chi^{(2)}$ properties
- Quasi-phase matching
- Total internal reflection phase matching
- Random phase matching
- Self-difference frequency generation
- Conclusions

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- **Why bother?**
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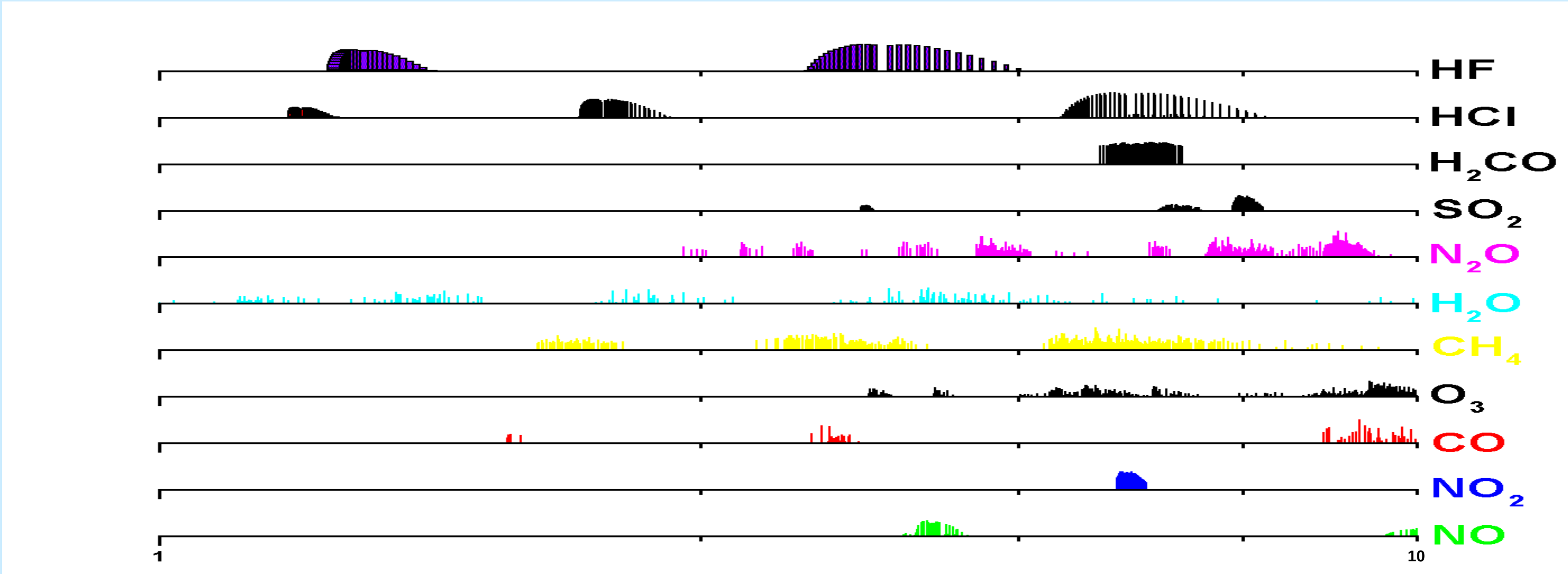
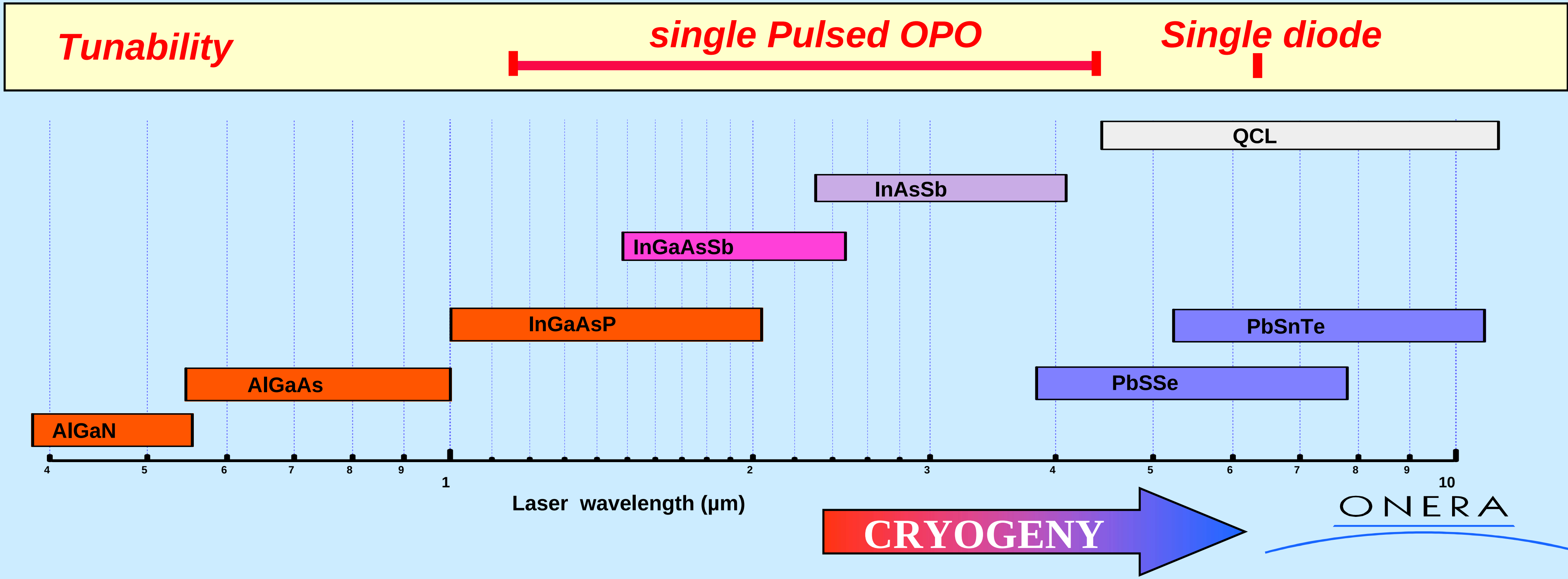
- **Self-difference frequency generation**
- **Conclusions**

Laser Diodes

vs

OPO





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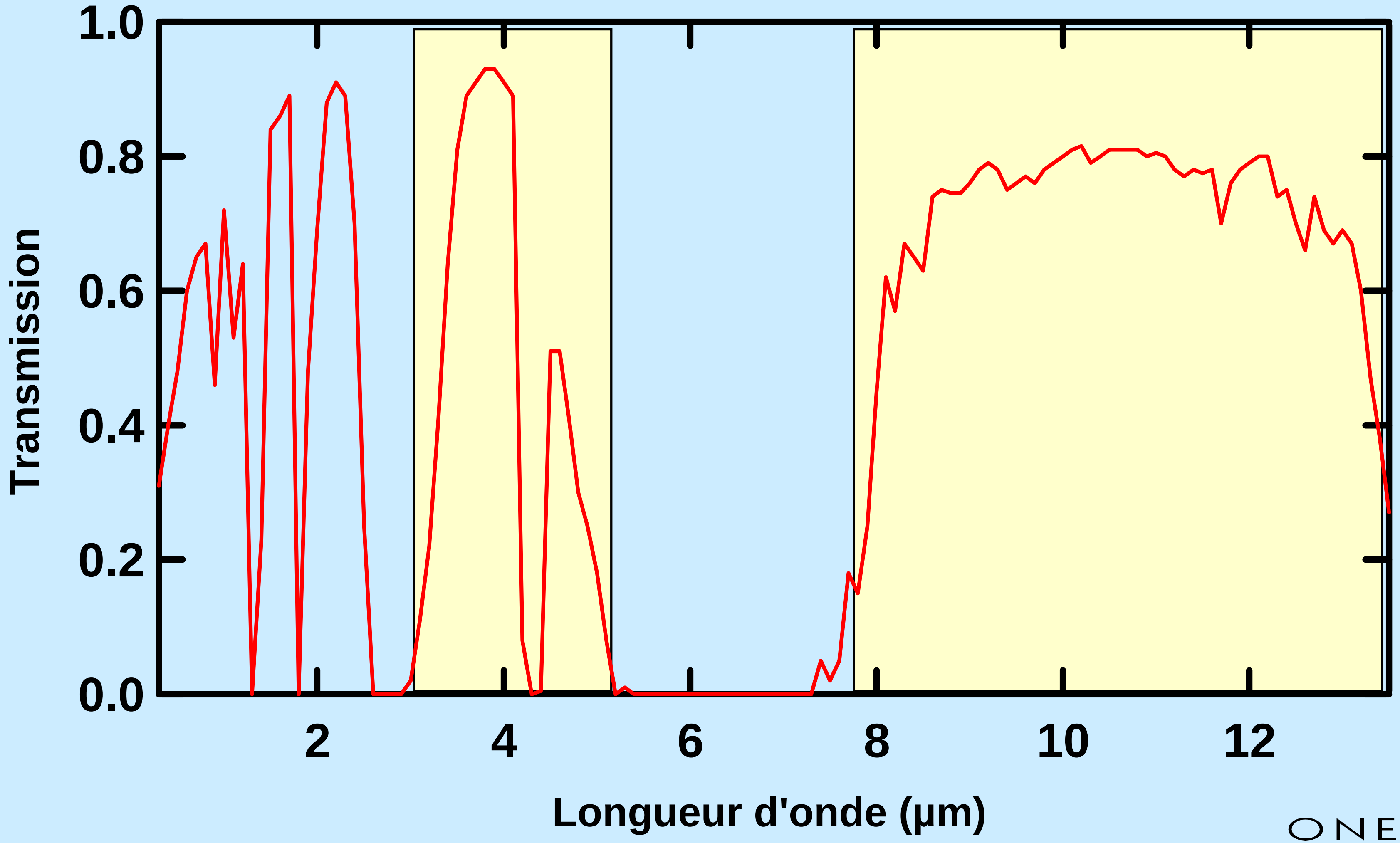
Atmospheric transmission
(dry weather, sea level, 5 km)



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SEMICONDUCTORS

- 0.45 µm < λ_{cutoff} < 20 µm (0.05 eV < E_{gap} < 3 eV)

- High nonlinear performance (quantum theory of solids) :

Second Fermi Golden Rule

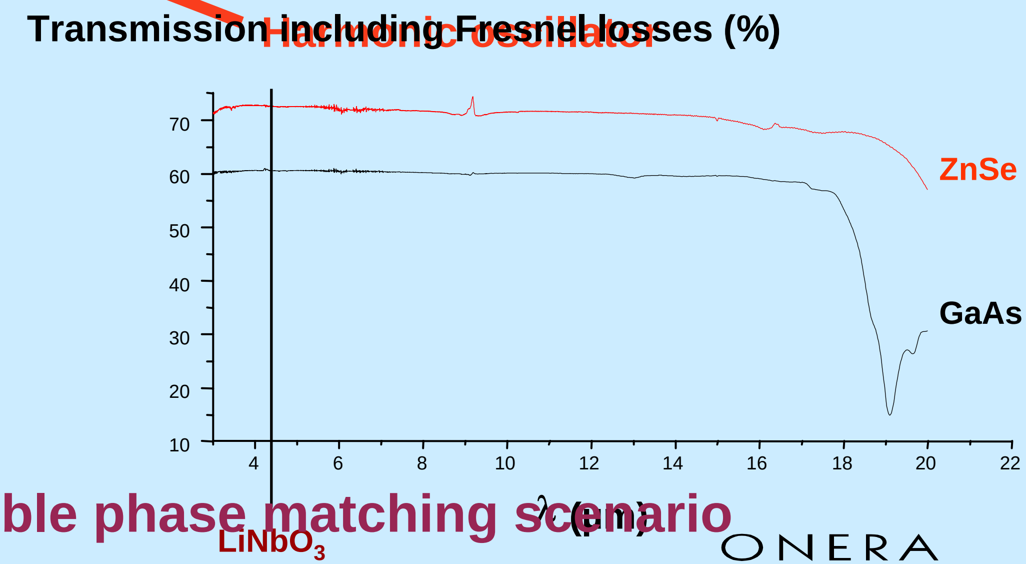
$$P_{NLO} \propto \frac{d^2}{n^3} \propto \frac{E_{gap}^{-4}}{E_{gap}^{-3}} \propto \lambda_{cutoff}$$

Harmonic oscillator

- Large transparency region

- Low cost

- Mature technology III-V



- Isotropic materials ⬇ NO possible phase matching scenario

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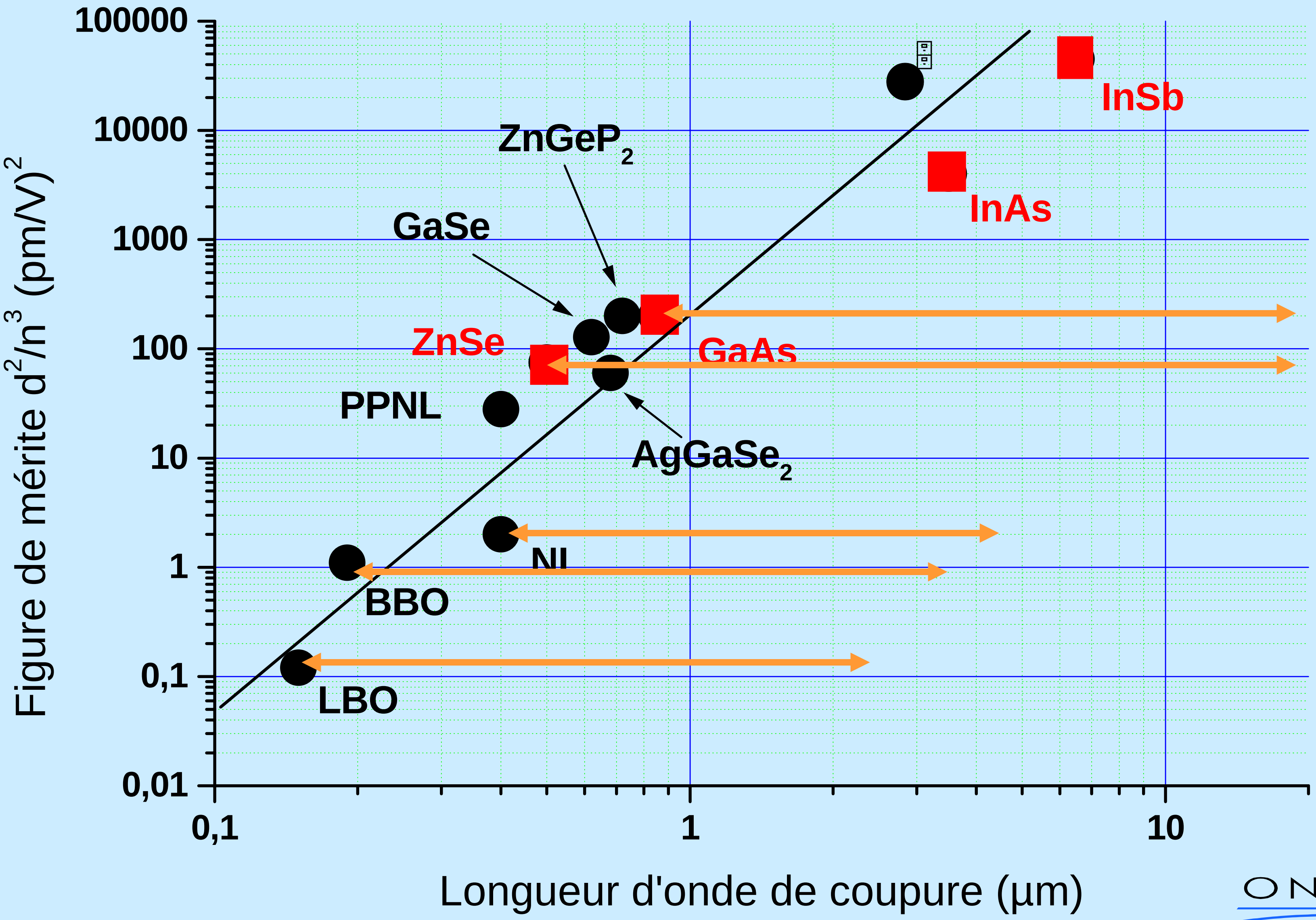
Propriétés optiques non linéaires des matériaux



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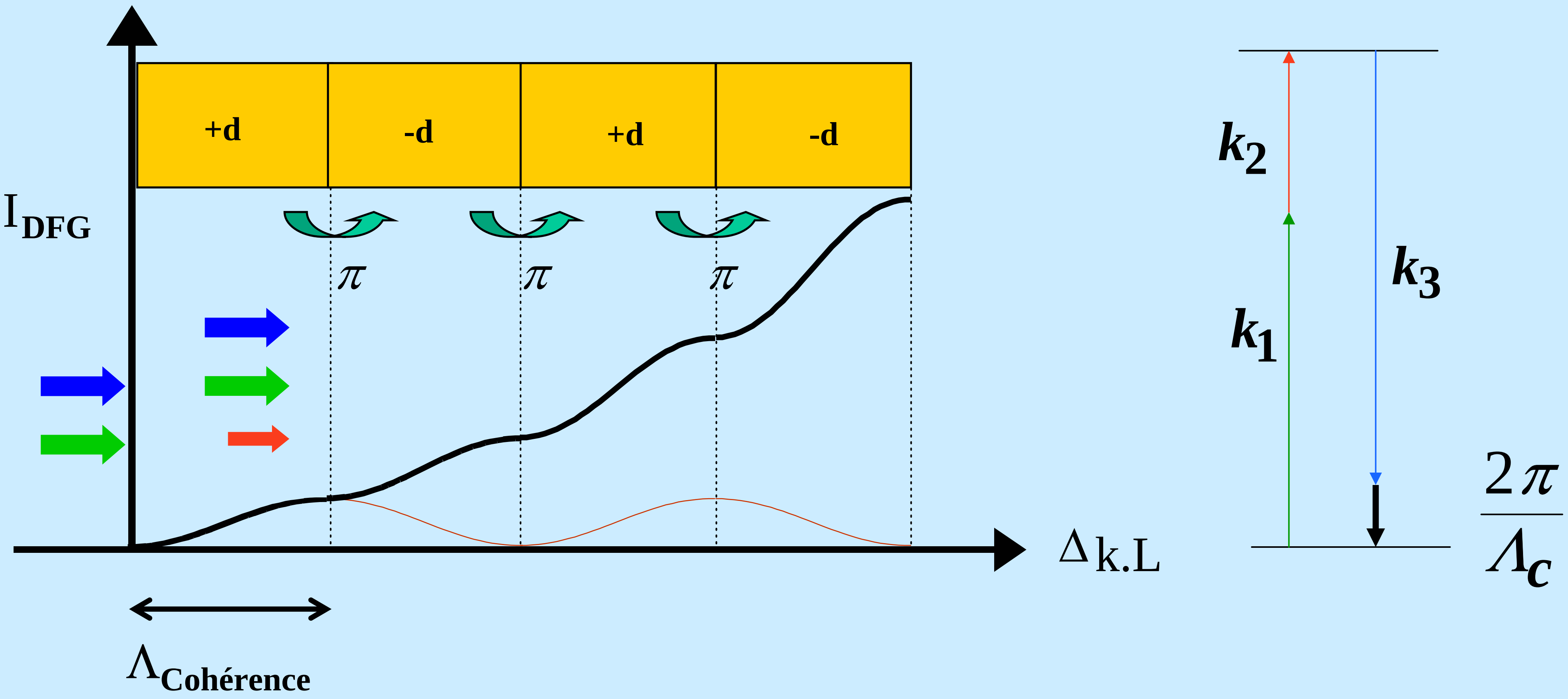
First order quasi-phase matching



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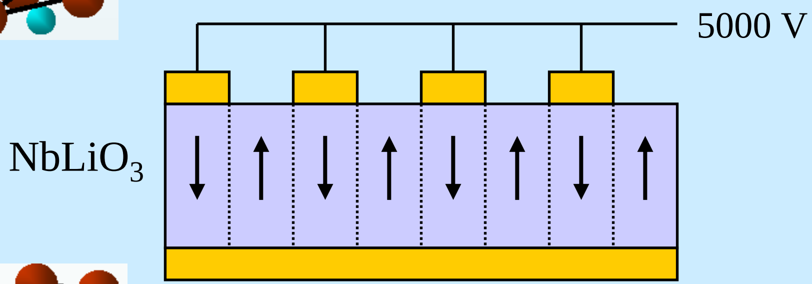
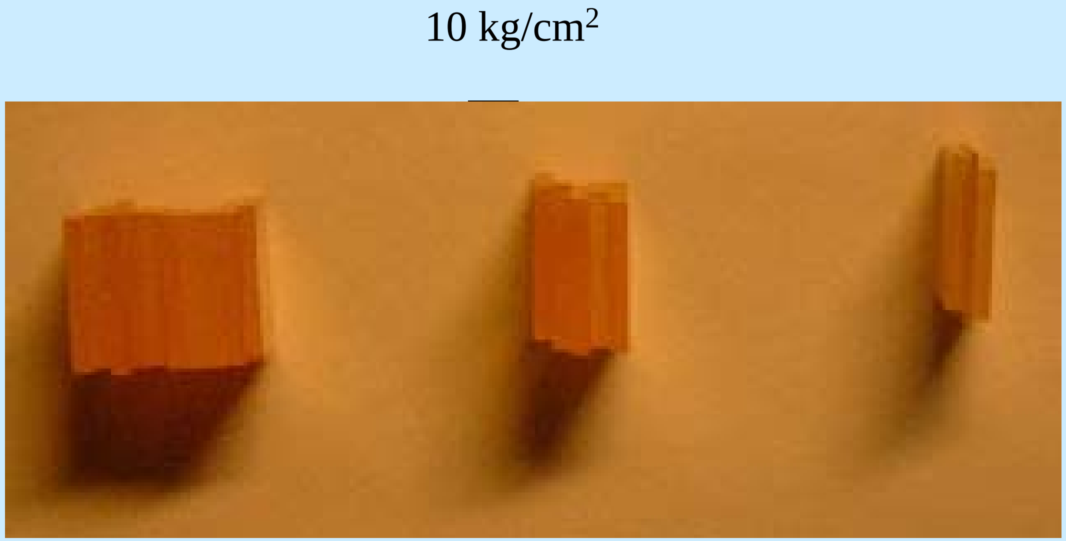
Quasi-phase matching techniques



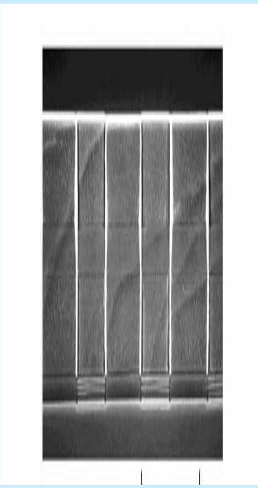
Ferroelectric polling

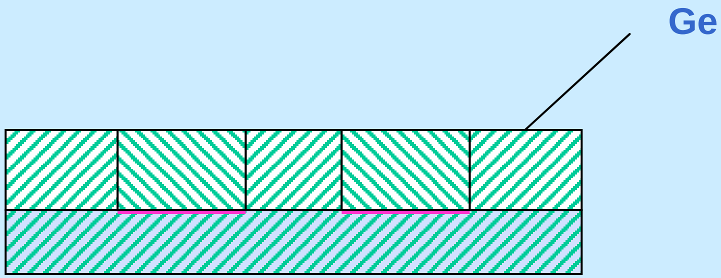
M. Fejer et al (Standord)



Molecular bonding (GaAs, ZnSe)

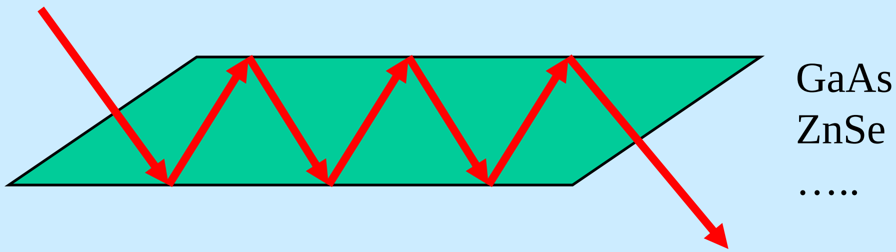
TRT, ONERA, Stanford





Localized growth

E. Lallier et al; M. Fejer et al



Fresnel birefrigence

R. Haidar et al (ONERA)

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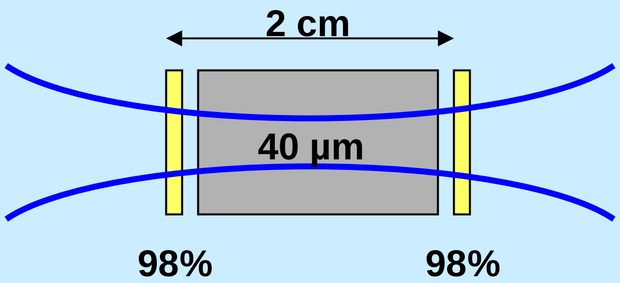
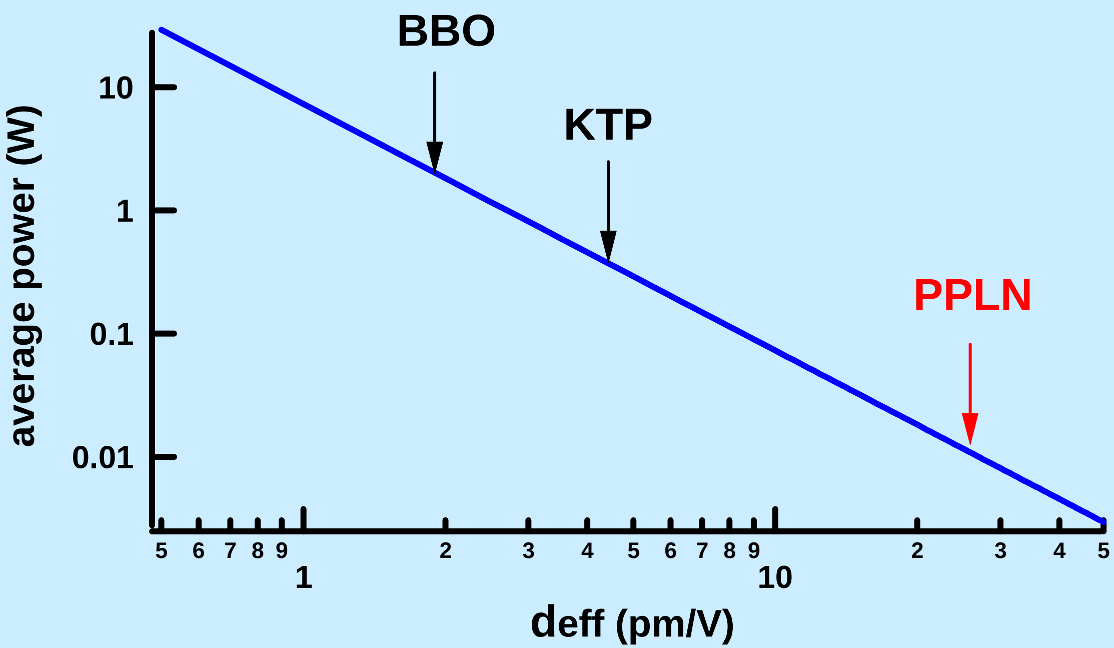
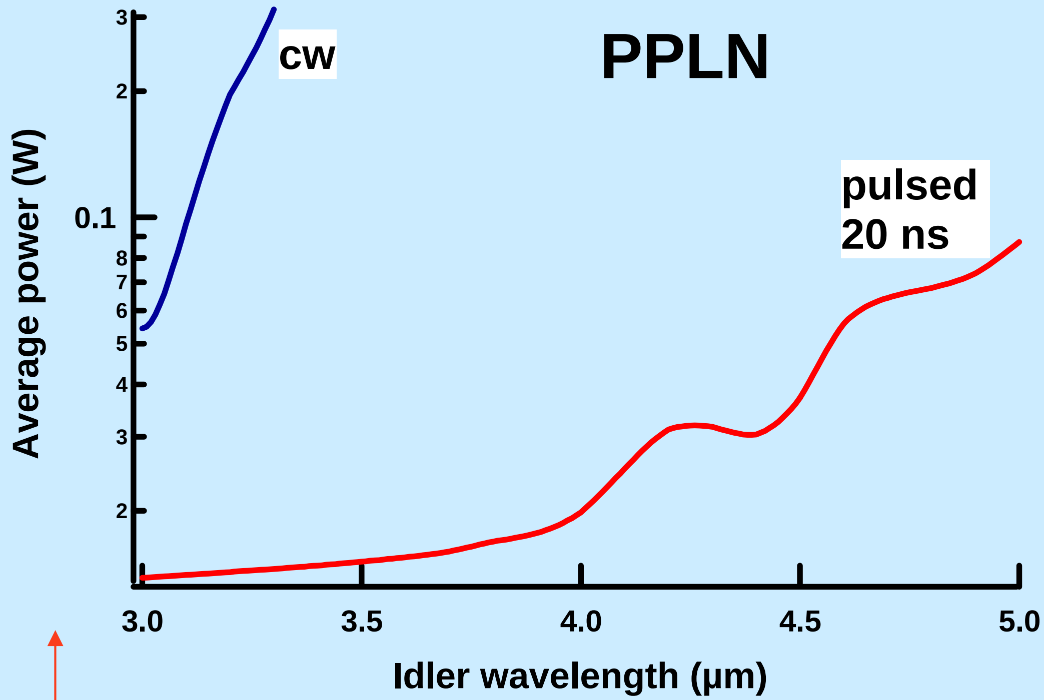
Periodical materials breakthrough

f = 10 kHz
20 ns

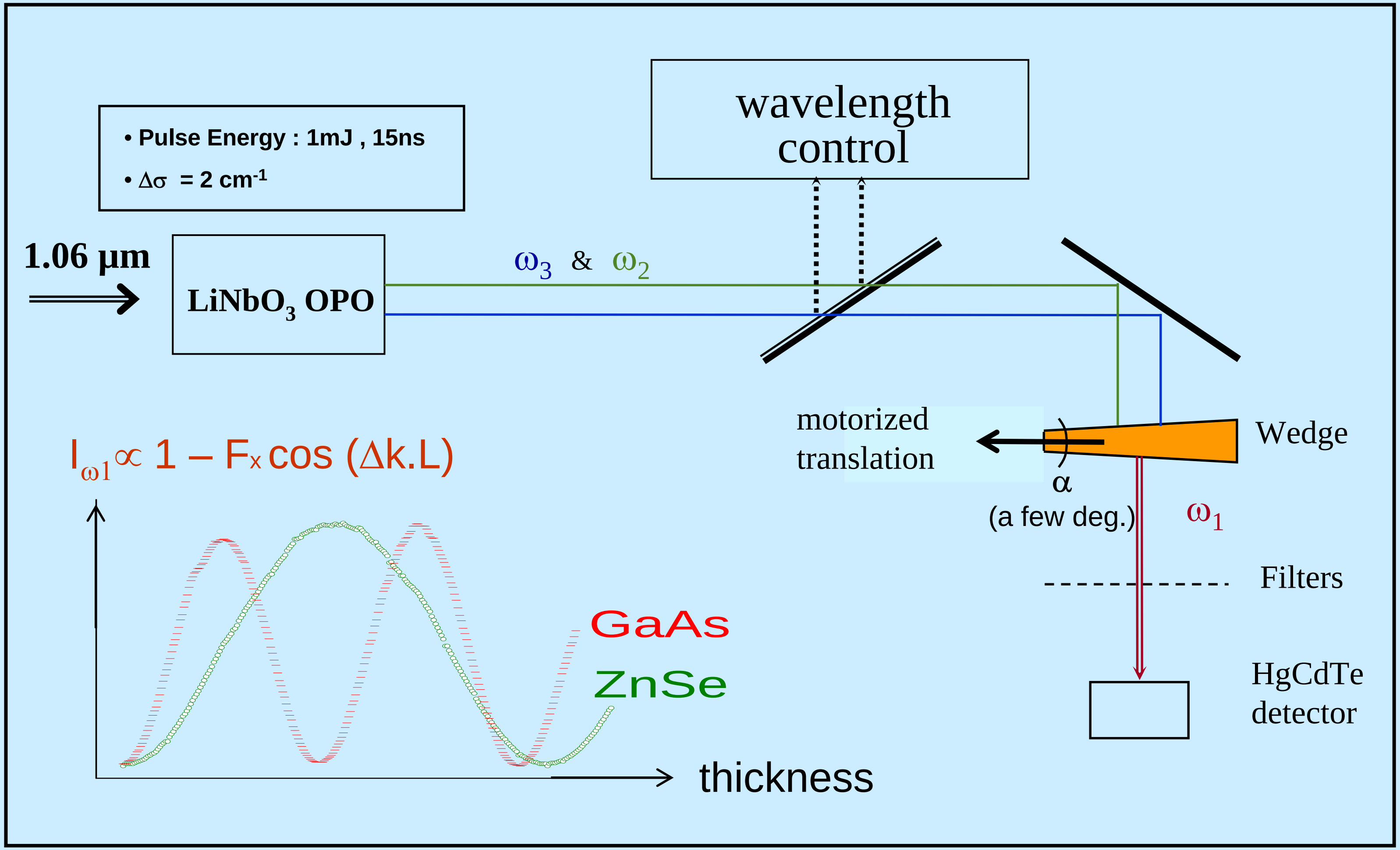






POGaAs

Precise coherence length (Λ_C) determination
experimental set-up



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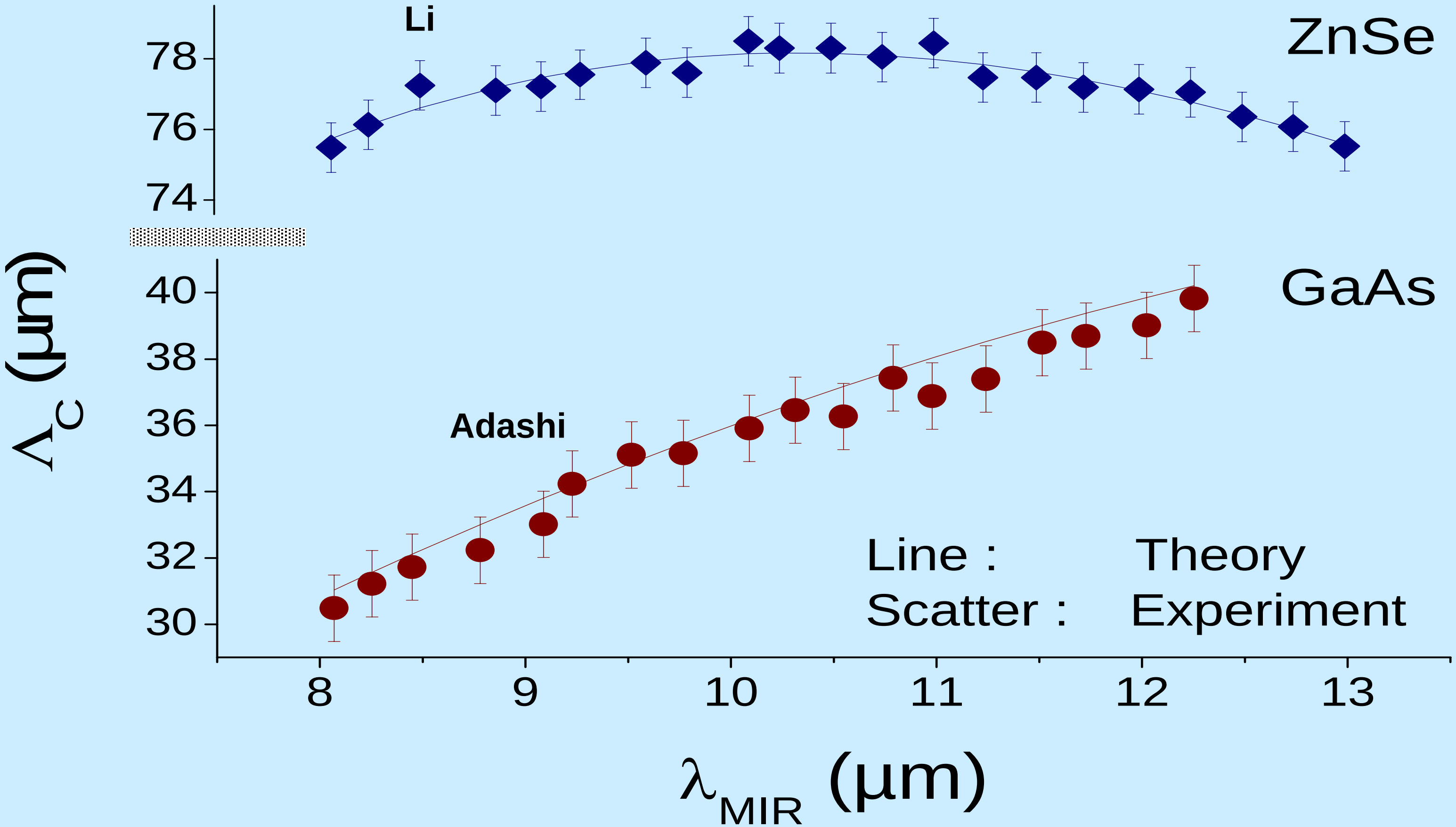
Advantage of large gap semiconductors in the IR: Large coherence length



R. Haïdar, A. Mustelier, Ph. Kupecek, E. Rosencher,
R. Triboulet, Ph. Lemasson and G. Mennerat, JAP 2002

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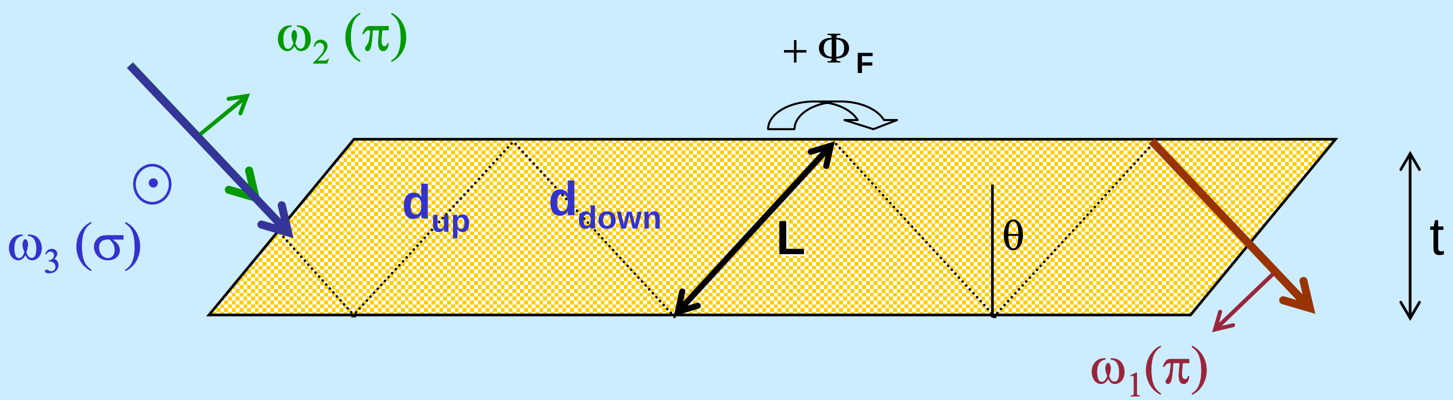
Quasi Phase Matching by Total Internal Reflexion *
(Fresnel Birefringence)



$$\delta\phi_{tot} = \Delta k.L + \Phi_F + \begin{cases} 0 & \text{if } d_{up} \, . \, d_{down} > 0 \\ \pi & \text{if } d_{up} \, . \, d_{down} < 0 \end{cases}$$

$$\Phi_F = \phi_{3,\sigma} - \phi_{2,\pi} - \phi_{1,\pi}$$

*Armstrong et al., Phys. Rev. **127**, 1918-1939 (1962)

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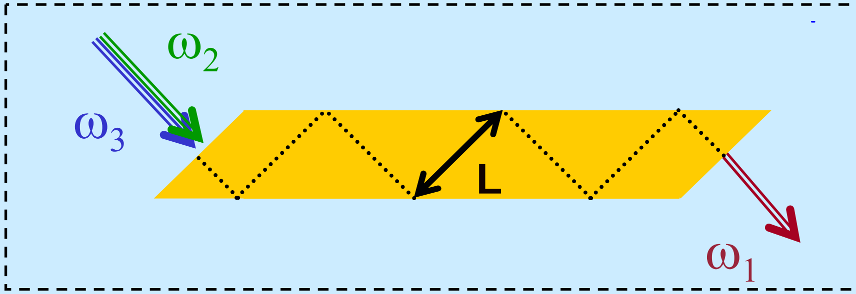
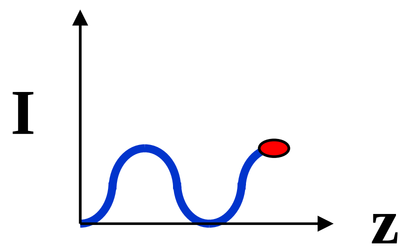
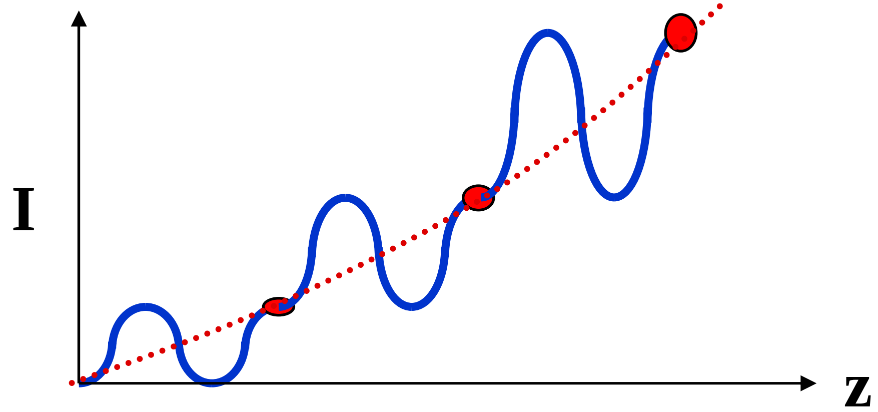
Fresnel QPM



$$I_{dfg} \propto (N\,L)^2 \left(\frac{\sin \Delta k\, L/2}{\Delta k\, L/2}\right)^2 \left(\frac{\sin N\,\delta\phi_{tot}/2}{N \sin \delta\phi_{tot}/2}\right)^2$$



$L = (2n+1)\,\Lambda_c$
Dispersion phase matching



$\delta\phi_{tot} = 0\ [2\pi]$ **Fresnel phase matching**

Optimum thickness

Angle tuning

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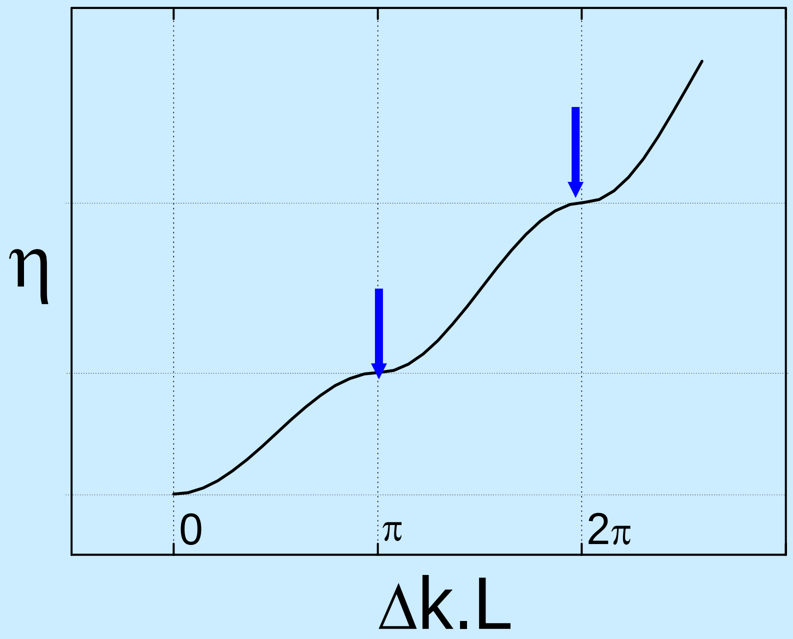
Fresnel QPM

$$\Delta k.\mathrm{L} + \Phi_F = 2\pi$$

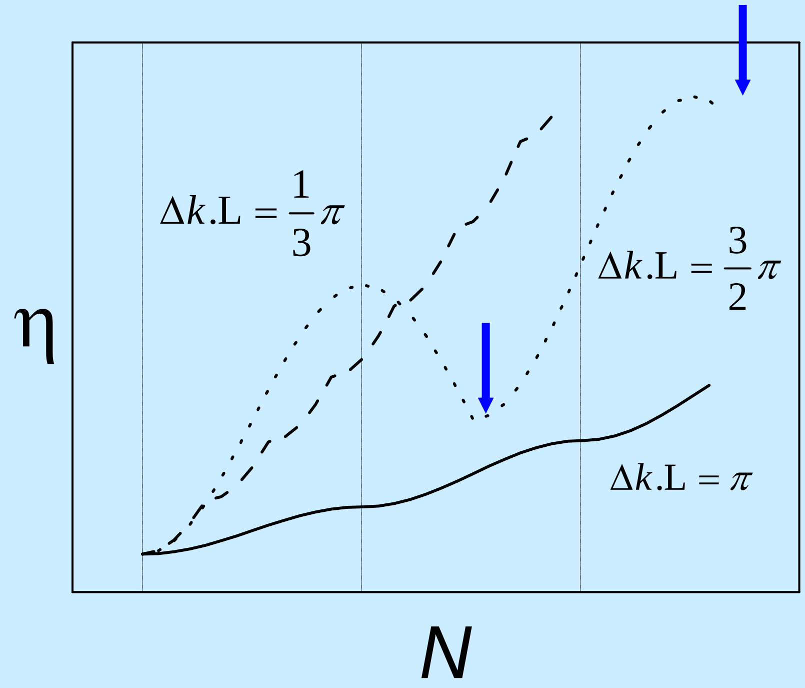
resonant QPM

$$\Delta k.\mathrm{L} = \pi$$



non resonant QPM

$$\Delta k.\mathrm{L} \neq \pi$$



Haïdar et al., APL

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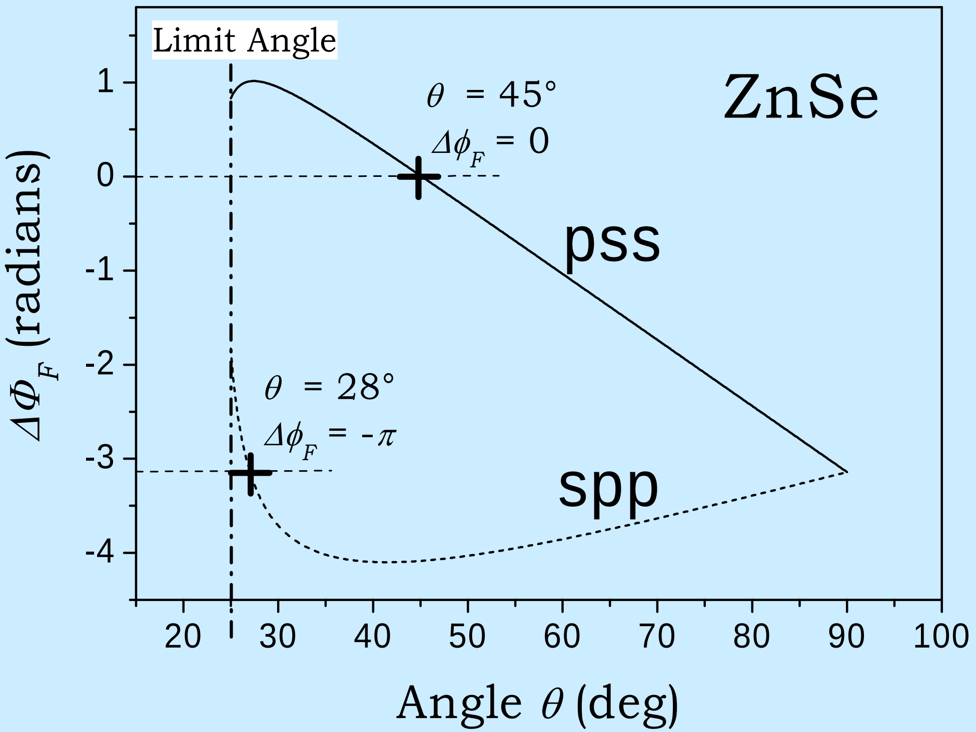
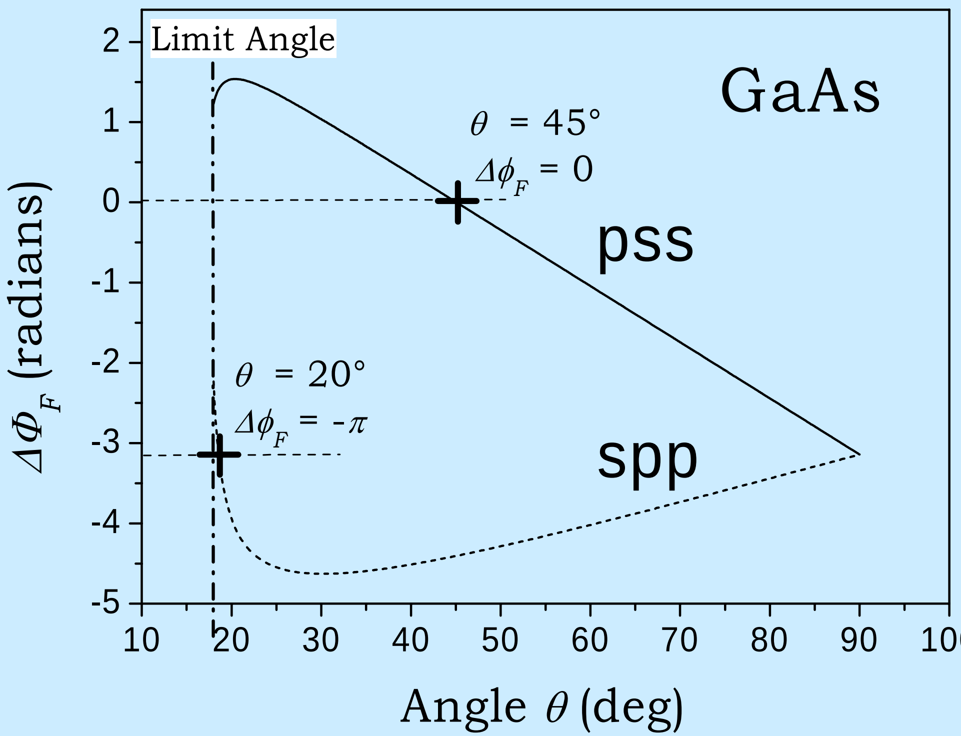
Optimum angle for Fresnel birefringence phase matching

Resonant Fresnel angle allowing (1.9 µm, 2.3 µm)
→ 8 µm





Haïdar et al., JOSA B

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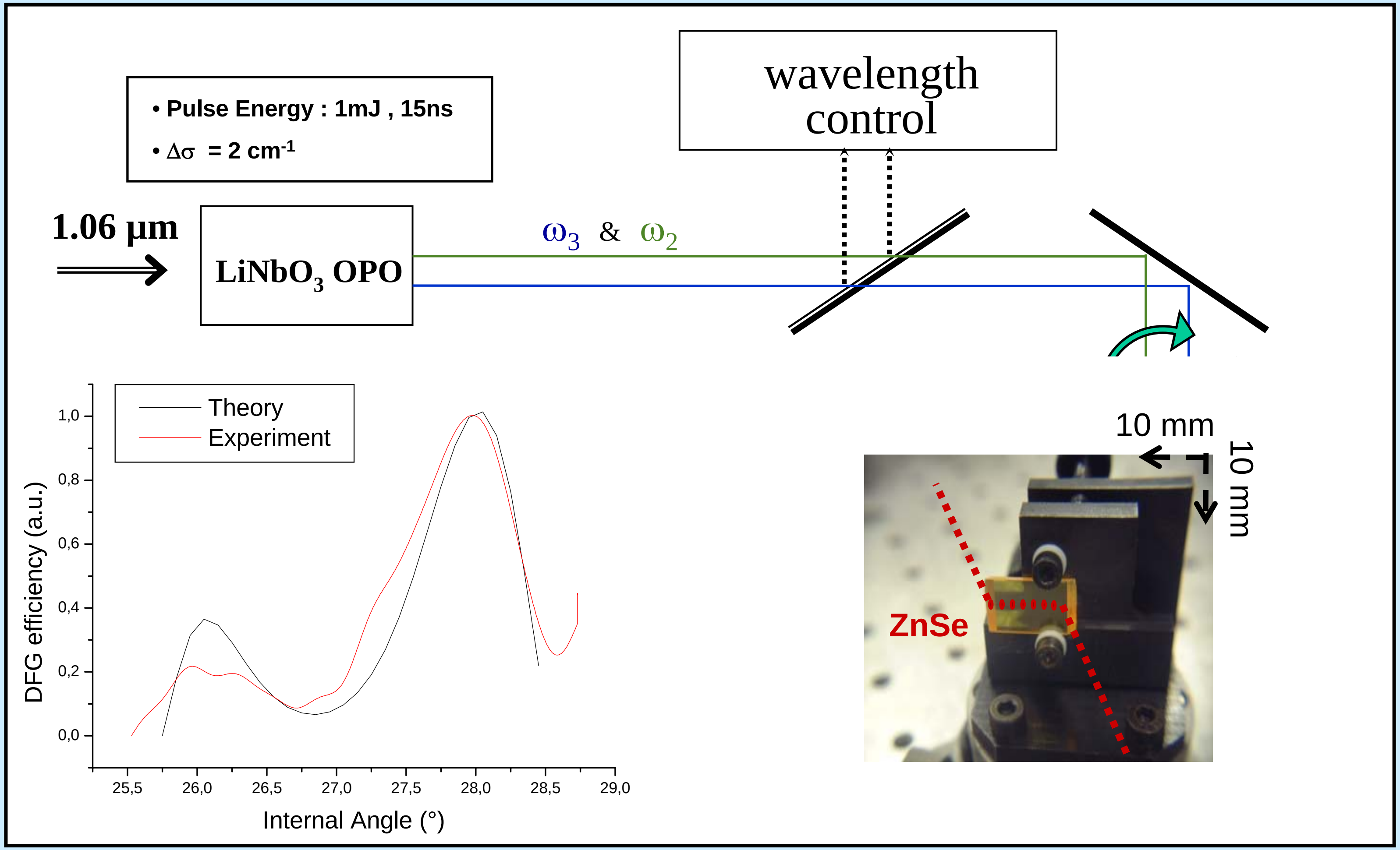
Fresnel phase matching Configuration :
experimental set-up



R. Haïdar, A. Mustelier, Ph. Kupecek, E. Rosencher, R. Triboulet, Ph. Lemasson, APL 2002

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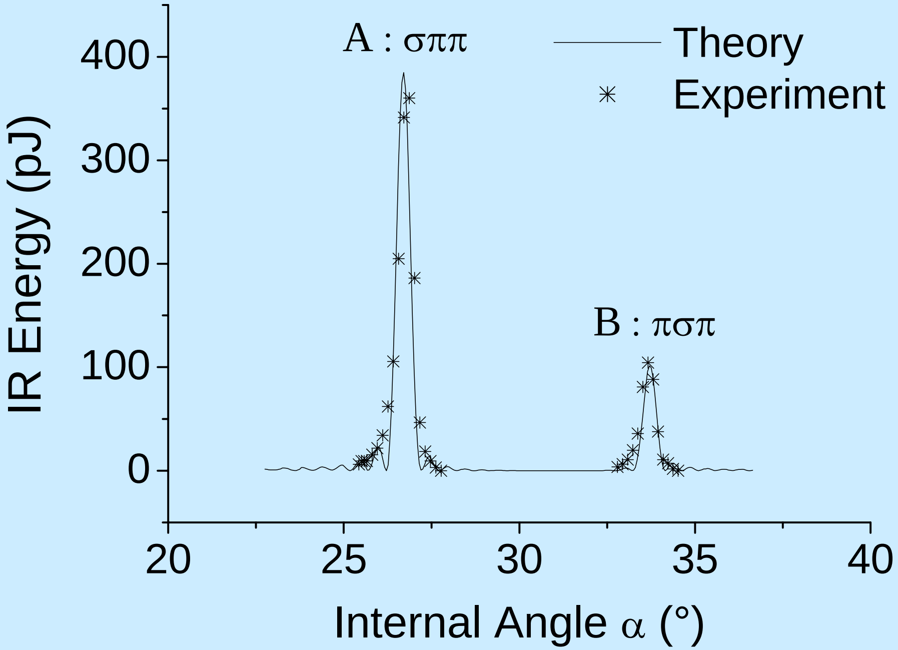
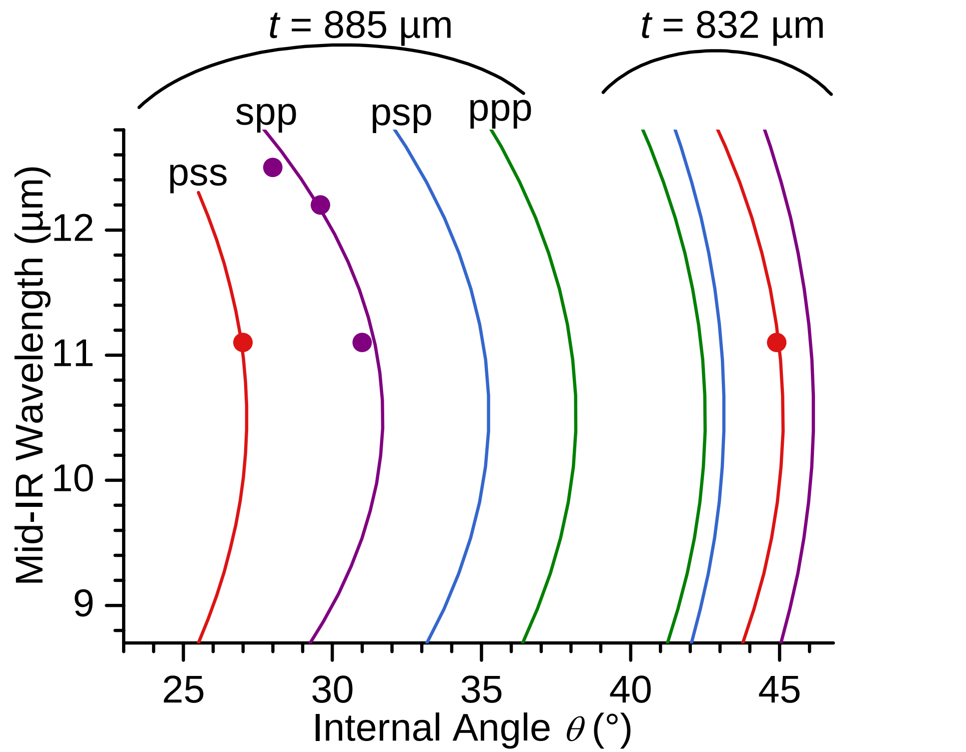
Fresnel quasi-phase matching: GaAs





Pump ω_3 : 150 µJ

MIR Source :.1 µJ between 9 µm and 13 µm

Photonic yield : $$\frac{n_{phot}(10\,\mu m)}{n_{phot}(2\,\mu m)} \approx 10^{-2}$$

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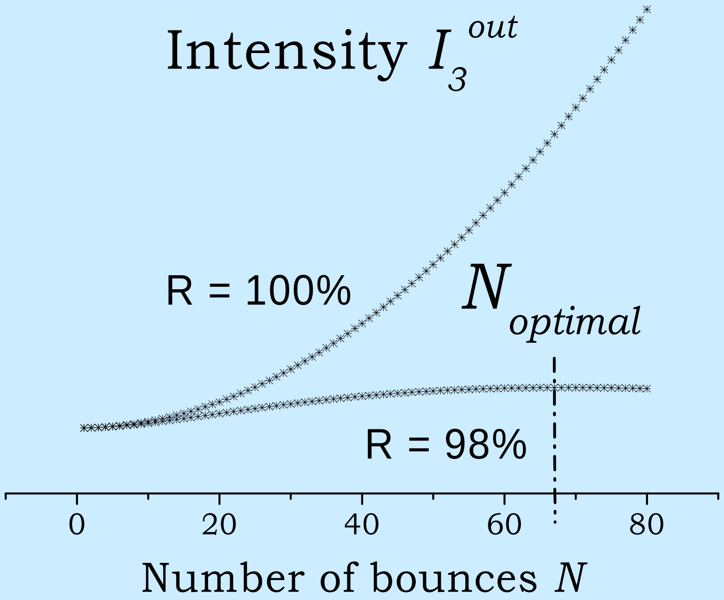
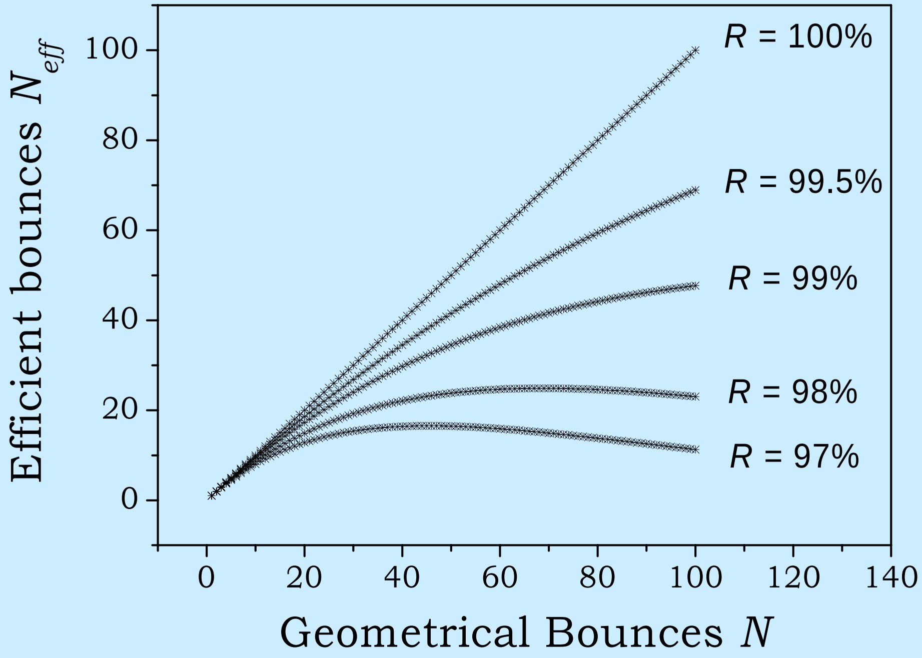
Limitations of Fresnel QPM: influence of wafer roughness





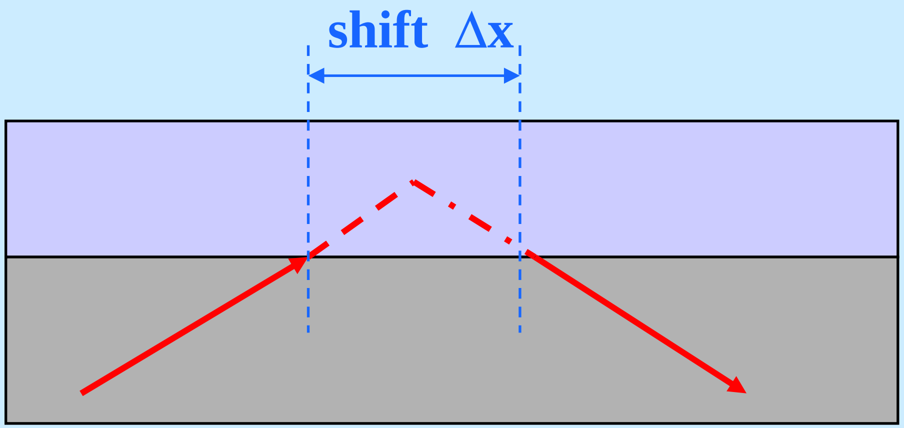
$$g\,\Lambda_c \approx 1 - R$$

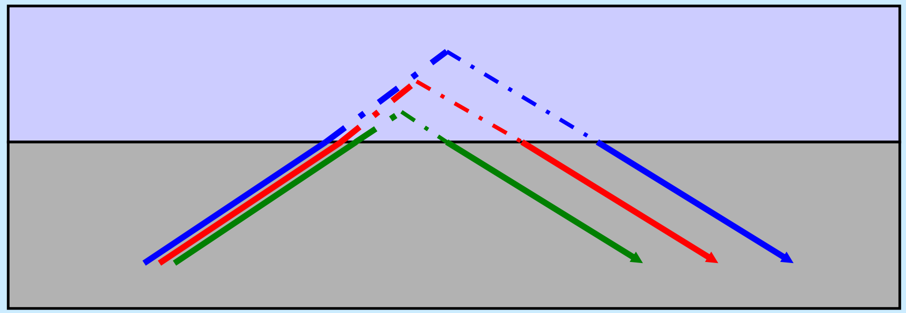
⇓

$$g = \frac{4\times 10^{-3}}{40\,\mu m} \approx 1\,cm^{-1}$$

	ZnSe		GaAs	
$\sigma\,(nm)$	11		4	
$\theta\,(°)$	27	45	25	45
$R\,(\%)$	98	98.6	99.4	99.6

Limitation to Fresnel QPM: Goos-Hänchen shift





$N_{max} \approx 200$ ⟺ **Equivalent to walk off**

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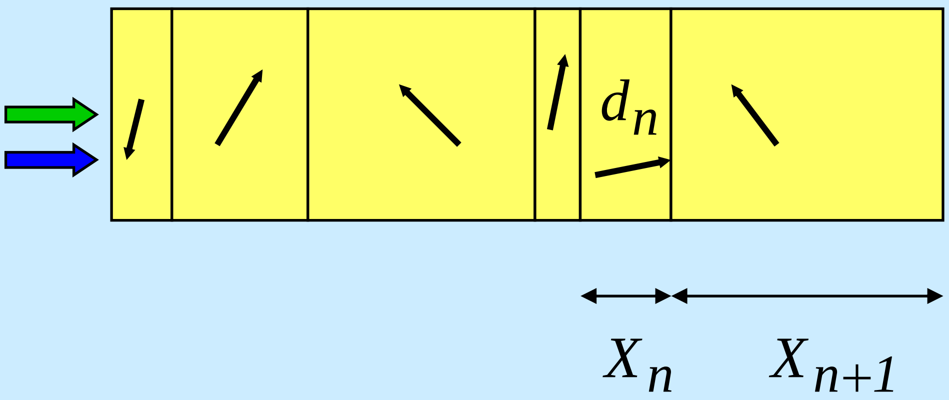
Few lines of trivial theory



Non depletion approximation

$$E_1^N \propto E_3 E_2^* \sum_m d_m \frac{e^{-i\,\Delta k\, X_{m-1}}}{\Delta k}\; e^{-i\Delta k \sum_{j=1}^{m} X_j}$$

3 processes independant

$$I_1^N \propto \left\langle |d|^2 \right\rangle \left\langle X^2 \sin c^2 \frac{\Delta k\, X}{2} \right\rangle N\, I_2 I_3 = N_{eff}\, I_1^{coh}$$ **with** $$N_{eff} = N \frac{\left\langle |d|^2 \right\rangle}{|d|^2} \left\langle \sin c^2 \frac{\Delta k\, X}{2} \right\rangle$$

Very predictive:

- **conversion yield proportional to sample length**
- **independant on polarisation**
- **resonant for** $\left\langle |X| \right\rangle = \Lambda_c$
- **N/N_{eff} easily measurable and compared with materials**

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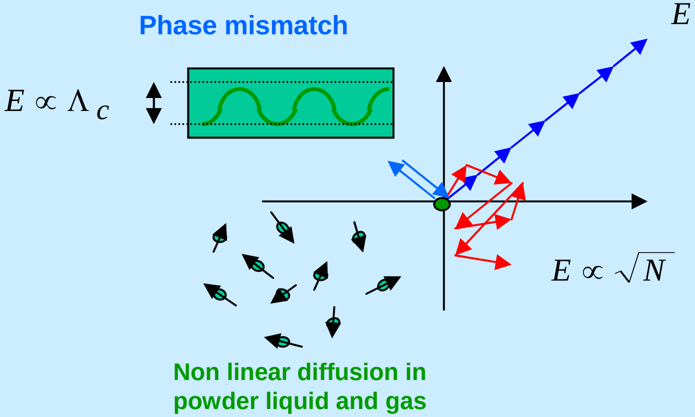
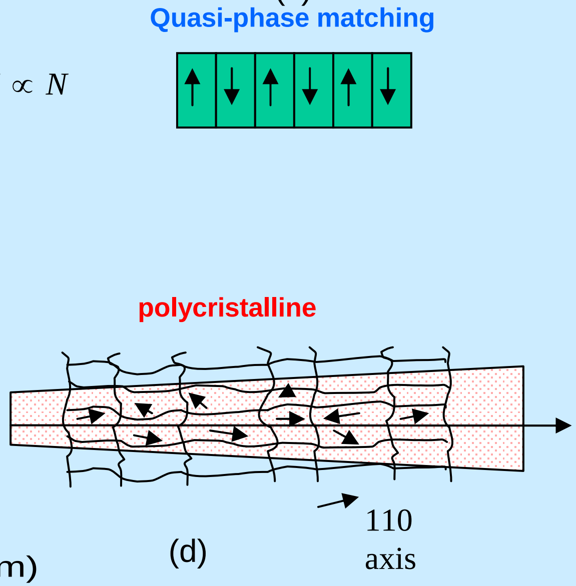
RANDOM PHASE MATCHING

(a)



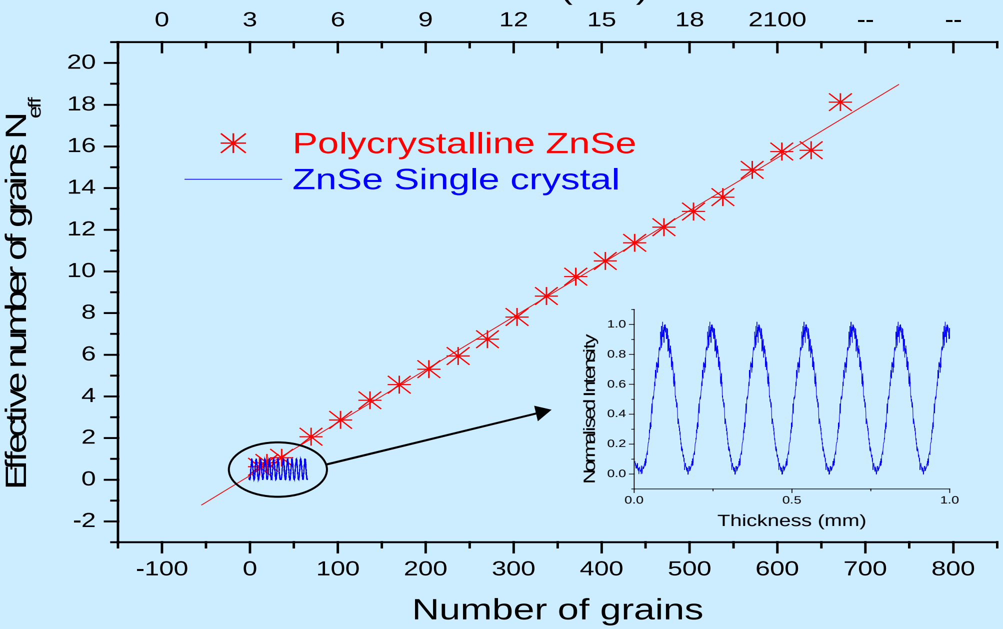
(c)

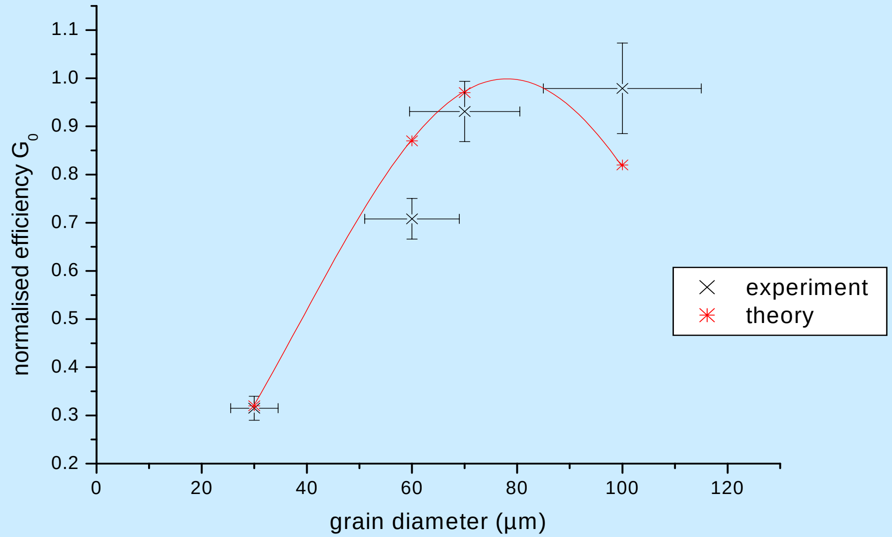


Baudrier, Haidar, Kupecek, Rosencher (Nature, 2004.)

(b)

(d)





Résonance pour taille de grain = longueur de cohérence

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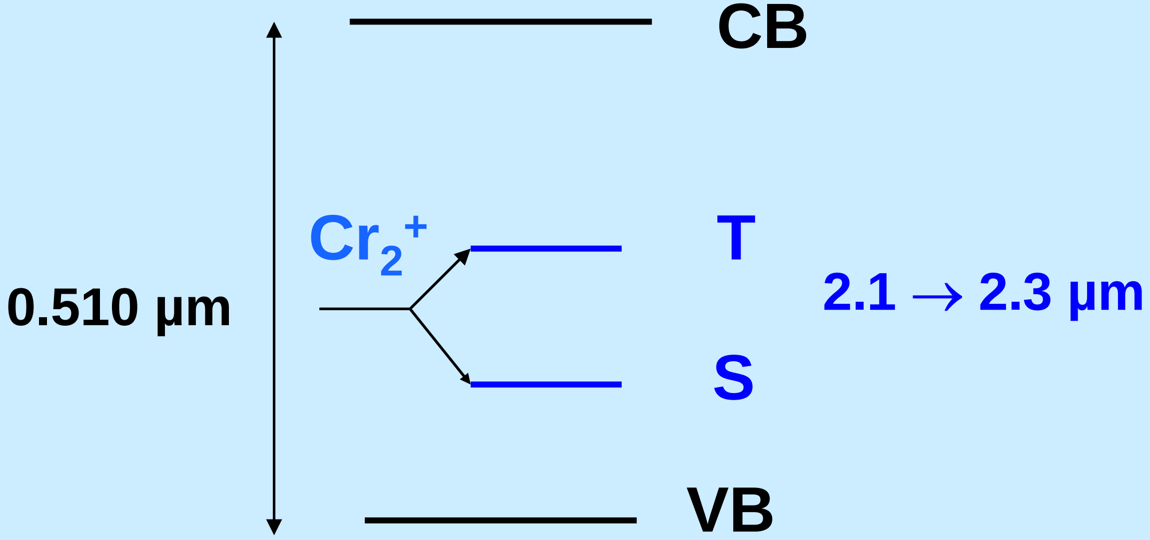
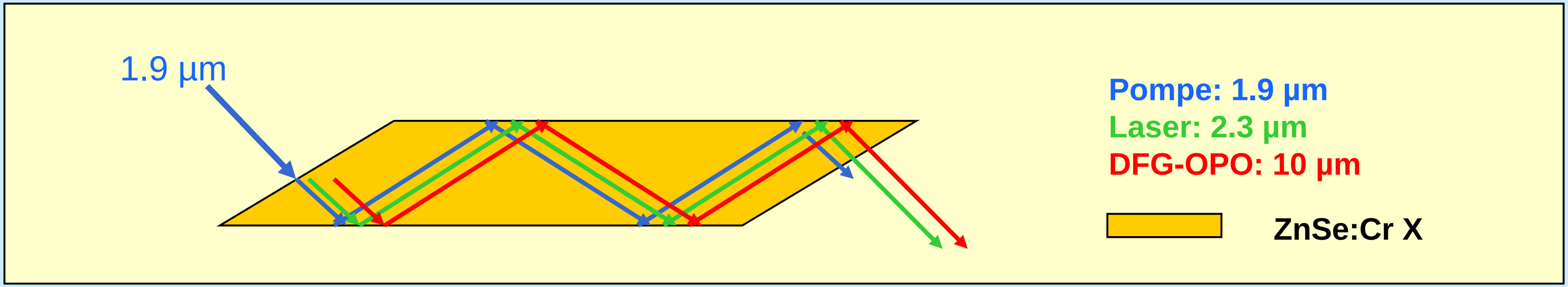
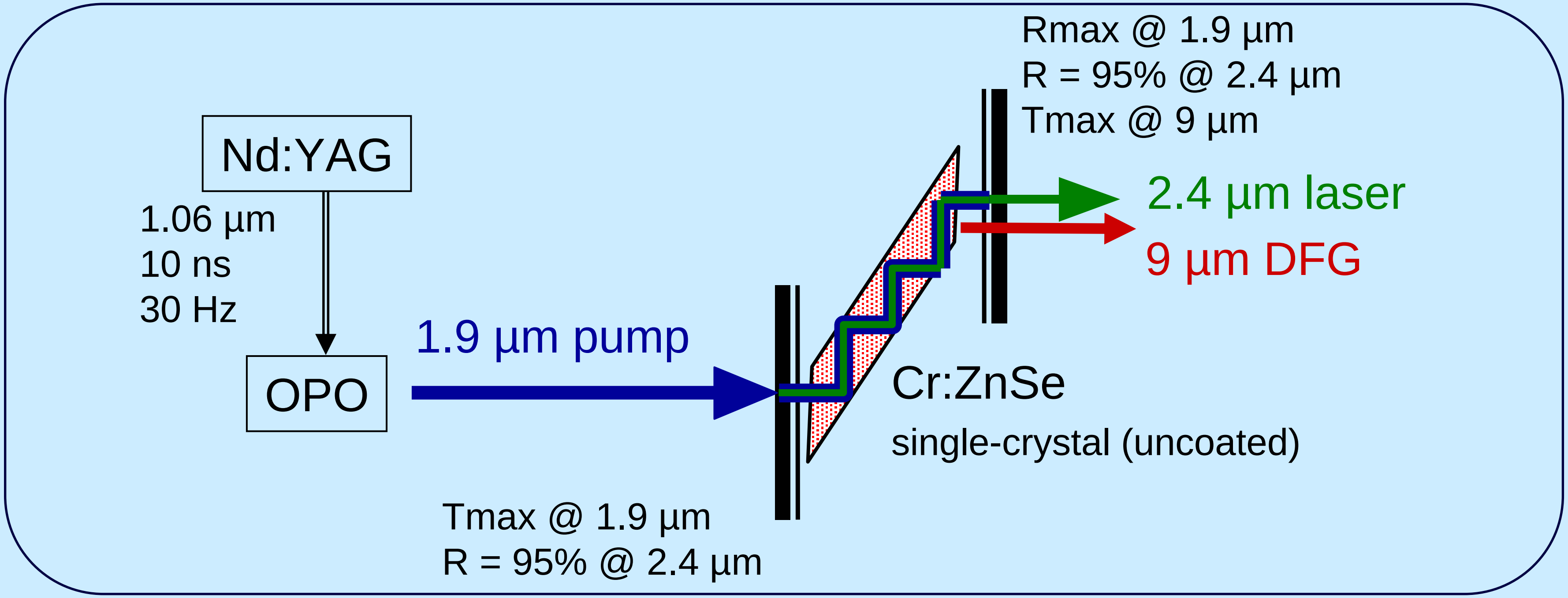
Cr^{2+}-doped ZnSe



WiFi collapse !



Self-DFG Cr:ZnSe laser—set-up



50% single-pass absorption of the 1.9-µm pump energy

45° internal phase-matching angle (spp), 13 internal reflections

Simple design: easy alignments, but high losses

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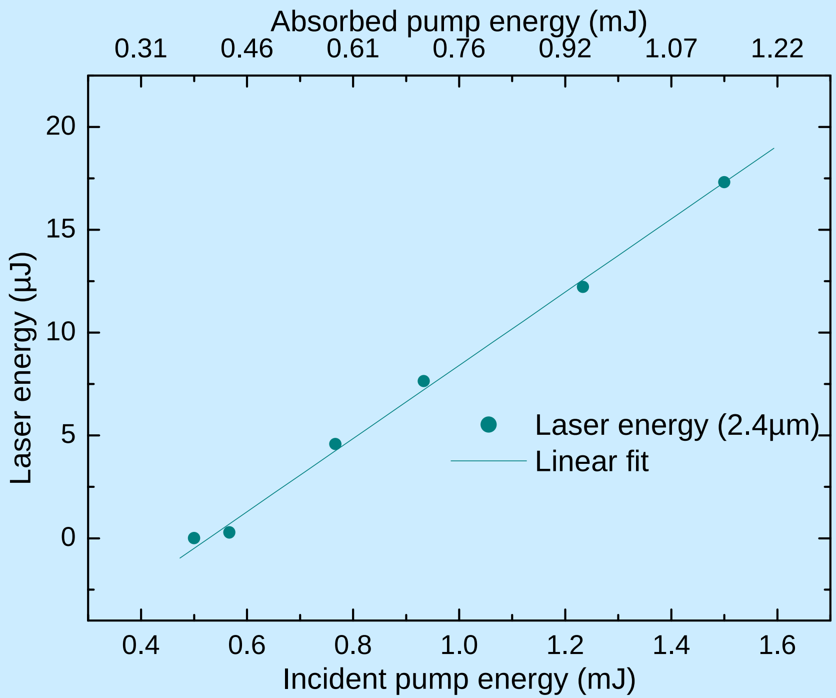
Self-DFG Cr:ZnSe laser – first results

Laser (2.4 µm)

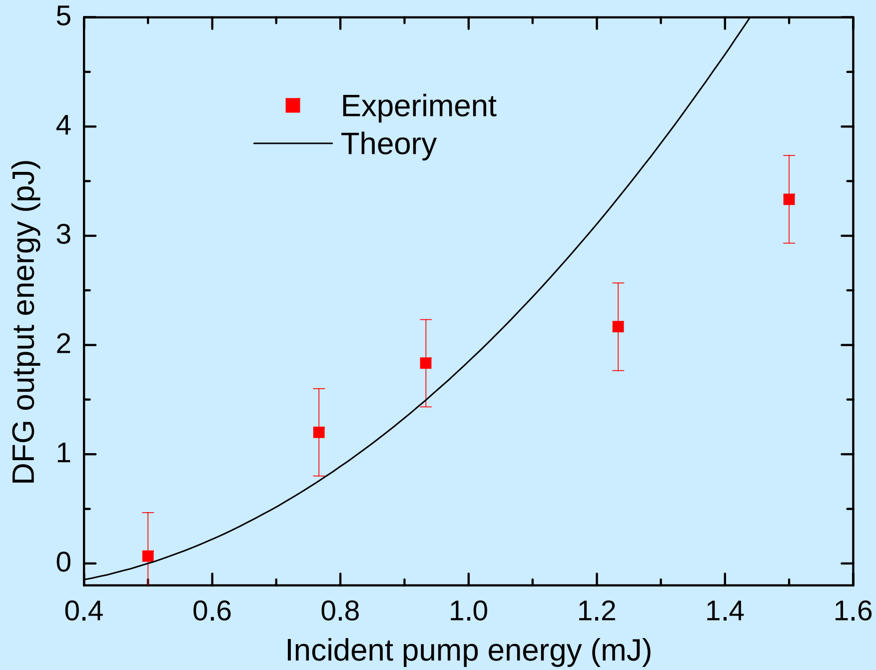
5% yield (/absorbed energy)



Small coupler transmission to maximize the 2.4-µm intracavity electric field

9-µm DFG preliminary results

Note: thresholdless emission !



First demonstration of self-DFG in Cr:ZnSe laser

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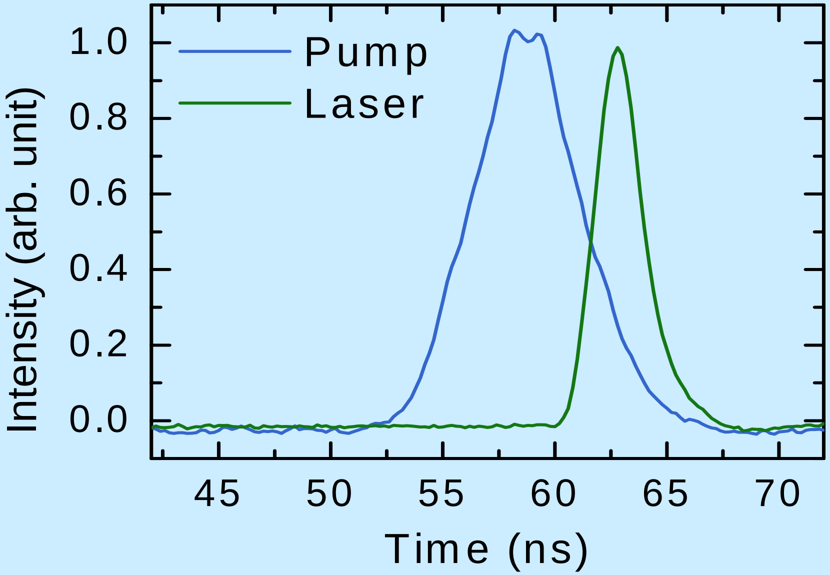
Self-DFG Cr:ZnSe laser – discussions

Small temporal overlap of pump and laser pulses

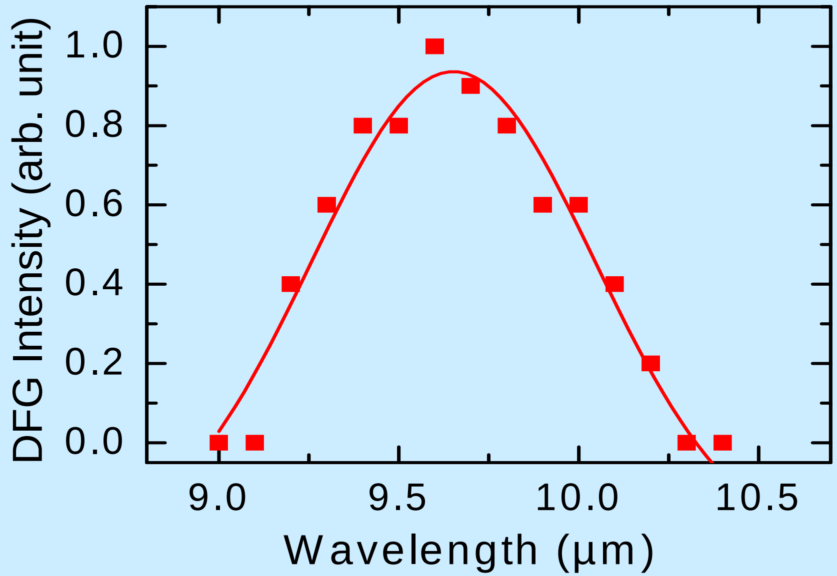
Limited DFG efficiency



- **Solution: longer pulse pump source**

Emitted DFG spectrum

- **Broad line (no intracavity spectral filter)**
- **Fixed central wavelength**



- **Possible tuning schemes: pump or laser tuning + crystal rotation**

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Conclusions

• Isotropic semiconductors are becoming viable solutions for non linear optical sources in the mid-infrared

• Fresnel phase matching allows very large tunability from the mid-IR to the terahertz

•Surface roughness principal limitations to Fresnel QPM

•Random phase matching works in poly ZnSe and allows very large samples

•Cr_2^+ doped ZnSe allows thresholdless self DFG generation which greatly simplify source architectures:
first realisation presented!

Next step: electrical pumping of OPO !

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