Modules of the 2024 Course

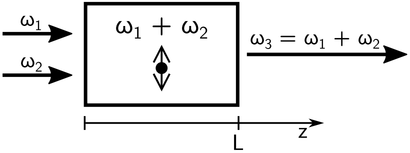
Topics covered	No	Lecture/Date
Introductory presentation; Basic of laser operation I: dispersion theory, atoms	1	11. 09. 2024
Basic of laser operation II: dispersion theory, atoms	2	18. 09. 2024
Laser systems I: 3 and 4 level lasers, gas lasers, solid state lasers, applications	3	25. 09. 2024
Laser systems II: semi-conductor lasers, external cavity lasers, applications	4	02. 10. 2024
Noise characteristics of lasers: linewidth, coherence, phase and amplitude noise, OSA (1)	5	09. 10. 2024
Noise characteristics of lasers: linewidth, coherence, phase and amplitude noise, OSA (2)	6	16. 10. 2024
Optical detection	7	30. 10. 2024
Optical fibers: light propagation in fibers, specialty fibers and dispersion (GVD)	8	06. 11. 2024
Ultrafast lasers I.: Passive mode locking and ultrafast lasers	9	13. 11. 2024
Ultrafast lasers II: mode locking, optical frequency combs / frequency metrology	10	20. 11. 2024
Ultrafast lasers III: pulse characterization, applications	11	27. 11. 2024
Nonlinear frequency conversion I: theory, frequency doubling, applications	12	04. 12. 2024
Nonlinear frequency conversion II: optical parametric amplification (OPA)	13	11. 12. 2024
Laboratory visits (lasers demo)	14	20. 12. 2024

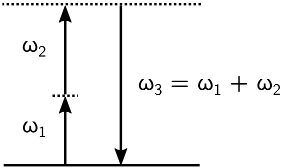
Non-linear frequency conversion II: OPA

- Difference frequency
- Parametric amplification
- Threshold of OPOs

Review: sum-frequency

Sum-frequency





Slowly varying envelope approximation:

$$\left|\frac{d^2 A_3}{dz^2}\right| << \left|k_3 \frac{dA_3}{dz}\right|.$$

Wave-vector mismatch

$$\frac{dA_3}{dz} = \frac{2 i d_{\text{eff}} \omega_3^2}{k_3 c^2} A_1 A_2 e^{i\Delta k z},$$

where $\Delta k = k_1 + k_2 - k_3$.

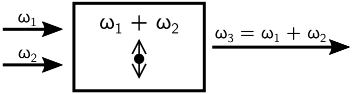
$$\frac{dA_1}{dz} = K_1 A_3 e^{-i\Delta k z}, \; K_1 = \frac{2 i \omega_1^2 d_{\text{eff}}}{k_1 c^2} A_2^*,$$

$$\frac{dA_3}{dz} = K_3 A_1 e^{+i\Delta k z}, \; K_3 = \frac{2 i \omega_3^2 d_{\text{eff}}}{k_3 c^2} A_2,$$

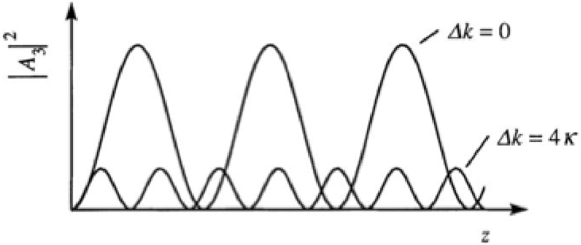
Assume wave A_2 constant:

$$\frac{d^2 A_1}{dz^2} = -\kappa^2 A_1, \quad \kappa^2 \equiv -K_1 K_3 = \frac{4\omega_1^2 \omega_3^2 d_{\text{eff}}^2 \left|A_2\right|^2}{k_1 \mathrm{k}_3 c^4}.$$

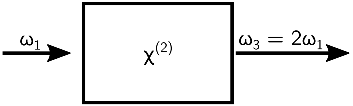
Review: sum-frequency



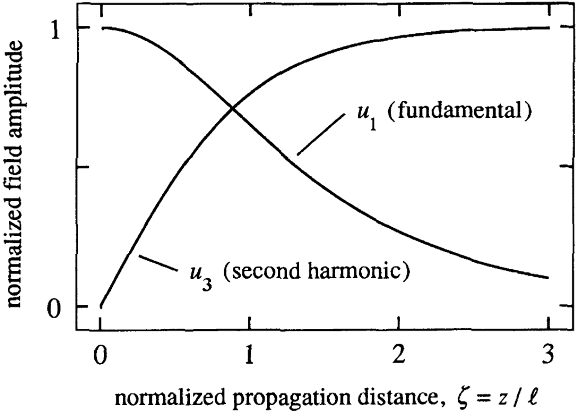
Oscillatory behavior in generated A_3 field



Review: second harmonic frequency generation



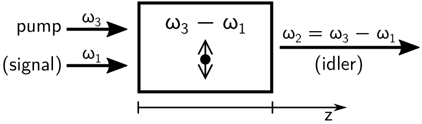
Perfect phase matching $(\Delta k = 0)$:



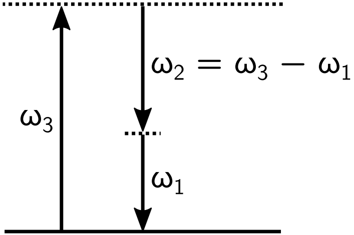
$$u_1(z)^2 + u_2(z)^2 = 1$$

Difference frequency

Difference-frequency

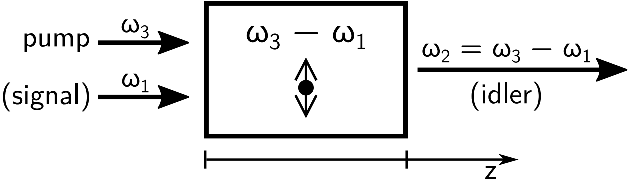


The actual frequency values of the *signal* ω_2 and *idler* ω_1 are determined by the phase matching condition.



Difference frequency

Difference-frequency



$$\frac{dA_1}{dz} = \frac{2i\omega_1^2 d_{\text{eff}}}{k_1 c^2} A_3 A_2^* e^{i\Delta k z}$$
$$\frac{dA_2}{dz} = \frac{2i\omega_2^2 d_{\text{eff}}}{k_2 c^2} A_3 A_1^* e^{i\Delta k z}$$

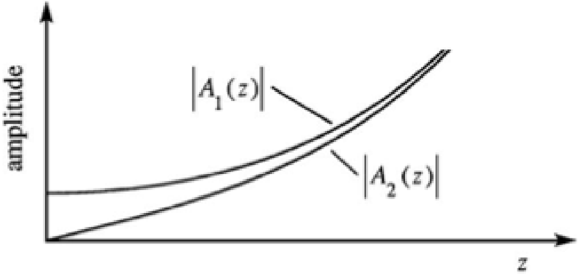
Assumption: pump ω_3 is strong and undepleted

Parametric amplification

$$A_1(z) = A_1(0)\cosh\kappa z$$

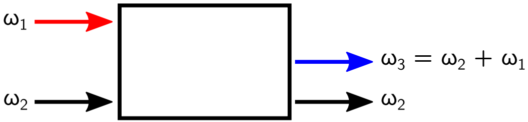
$$A_2(z) = i\left(\frac{n_1\omega_2}{n_2\omega_1}\right)^{1/2}\frac{A_3}{|A_3|}A_1^*(0)\sinh\kappa z$$

Parametric amplification

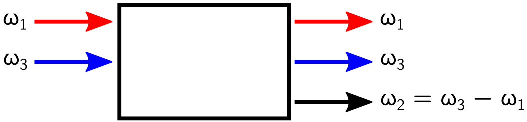


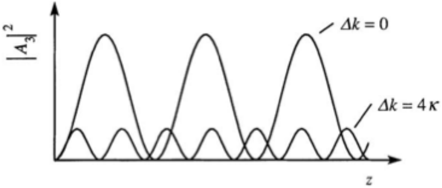
Sum vs. Difference frequency

Sum



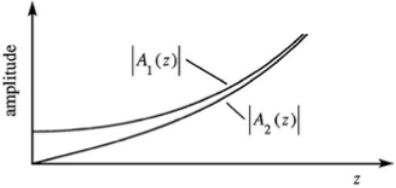
Difference





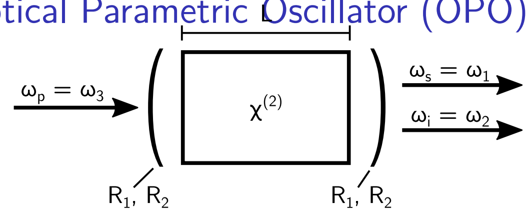
Oscillatory behavior

Parametric amplification



Gain: amplitude grows exponentially

Optical Parametric Oscillator (OPO)

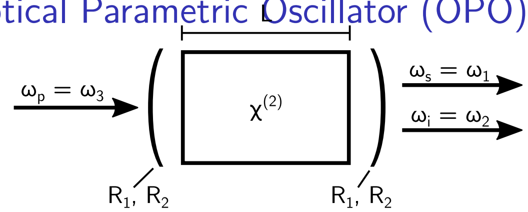


General solution for nonzero Δk (see exercises):

$$A_1(z) = \left[A_1(0)\left(\cosh gz - \frac{i\Delta k}{2g}\sinh gz\right) + \frac{\kappa_1}{g}A_2^*(0)\sinh gz\right]e^{i\Delta kz/2},$$

$$A_2(z) = \left[A_2(0)\left(\cosh gz - \frac{i\Delta k}{2g}\sinh gz\right) + \frac{\kappa_2}{g}A_1^*(0)\sinh gz\right]e^{i\Delta kz/2}$$

Optical Parametric Oscillator (OPO)



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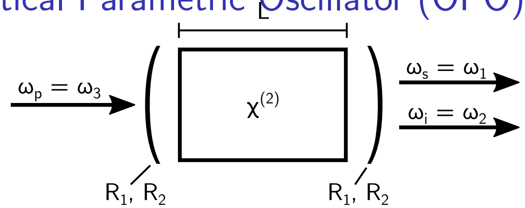
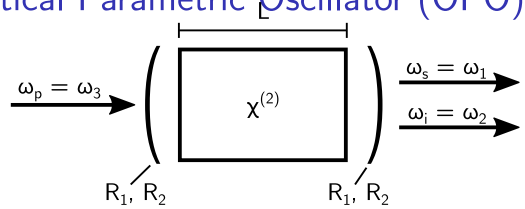
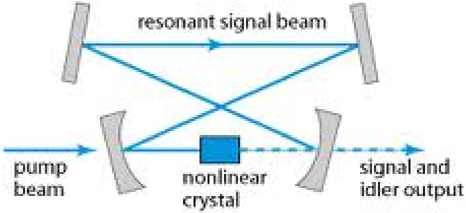
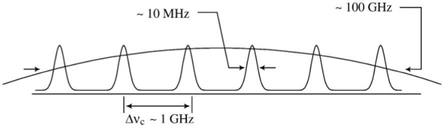


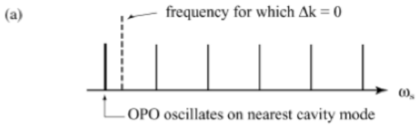
Optical Parametric Oscillator (OPO)

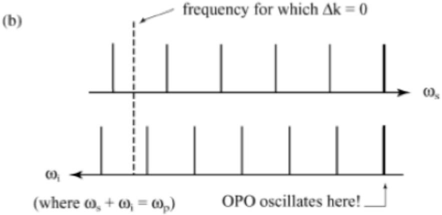


OPO bandwidth





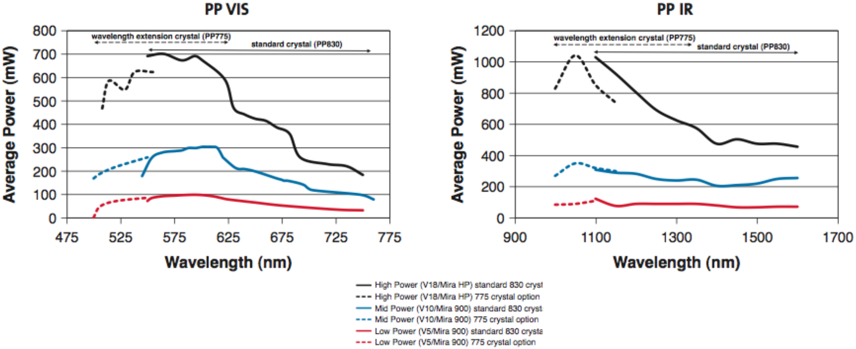




Commercial OPO

Tuning Range (nm)	
Signal SHG[4,5]	550 to 740
Signal[4,5]	1100 to 1600
Idler (option)	1750 to 3300
Nominal Pump Wavelength (nm)	830

Typical Tuning Curves for Femtosecond Mira-OPO PP-Automatic



Raman laser

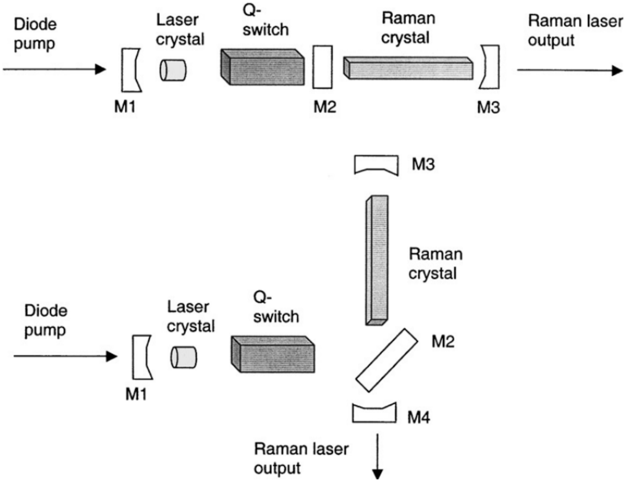
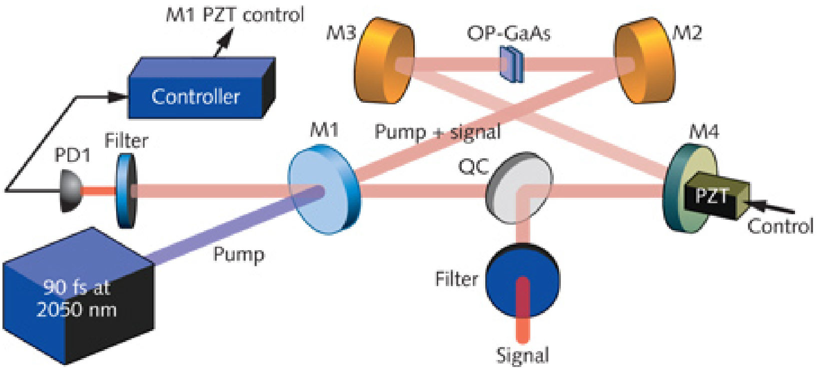
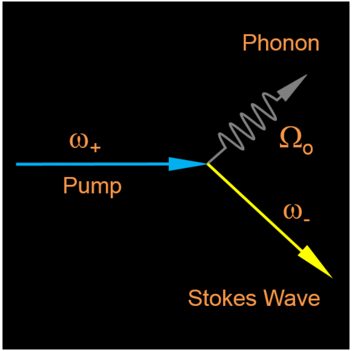


Fig. 14. Schematic diagrams showing coupled cavity Raman laser configurations (a) linear configuration and (b) folded configuration.

MID IR OPO


M1 PZT control
M3
OP-GaAs
M2
Controller
M1
Pump + signal
M4
Filter
PD1
QC
PZT
Control
Pump
90 fs at
2050 nm
Filter
Signal

Brillouin laser



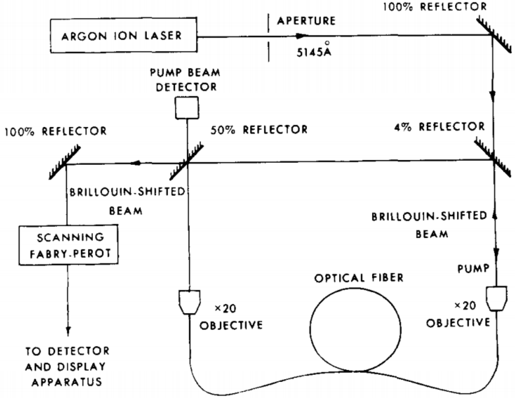


FIG. 1. Schematic of Brillouin ring-laser apparatus. The ring consists of the optical fiber together with the beam paths defined by the 4% and 50% partial reflectors. The pump-beam throughput is monitored by the pump-beam detector.