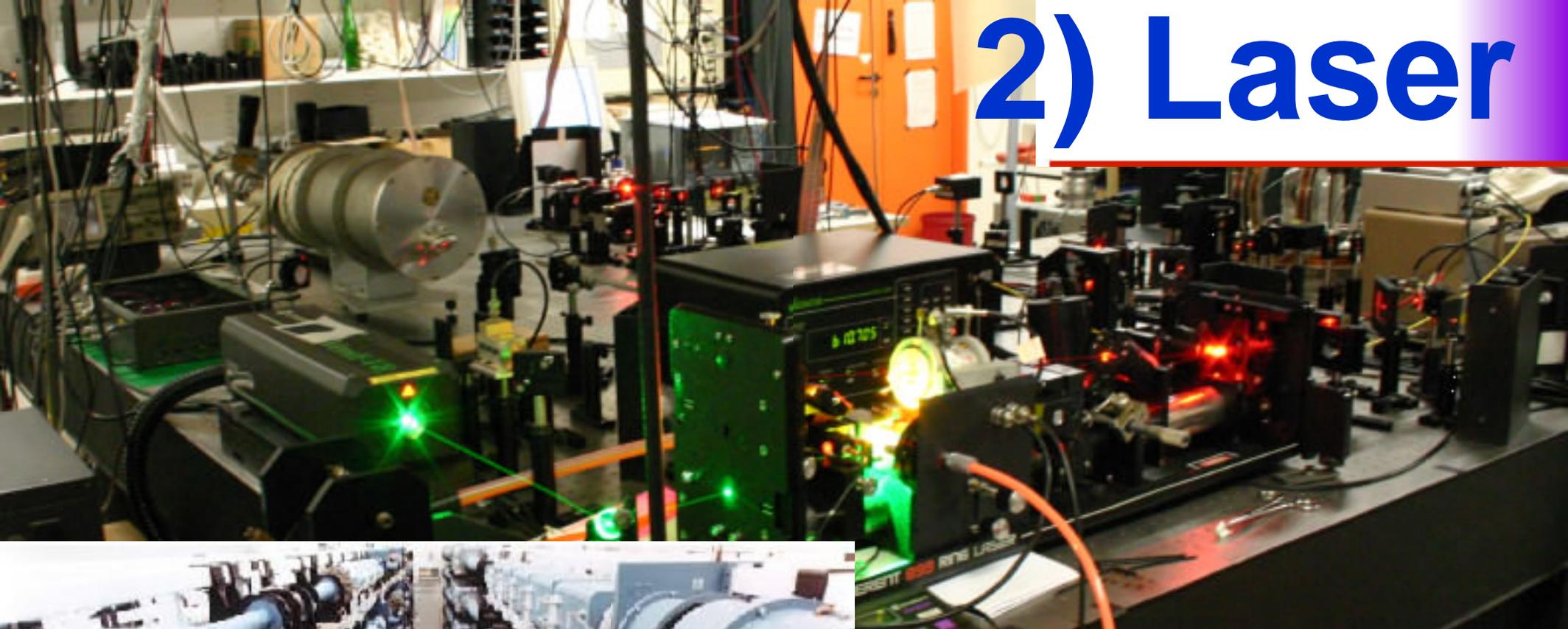


2) Laser

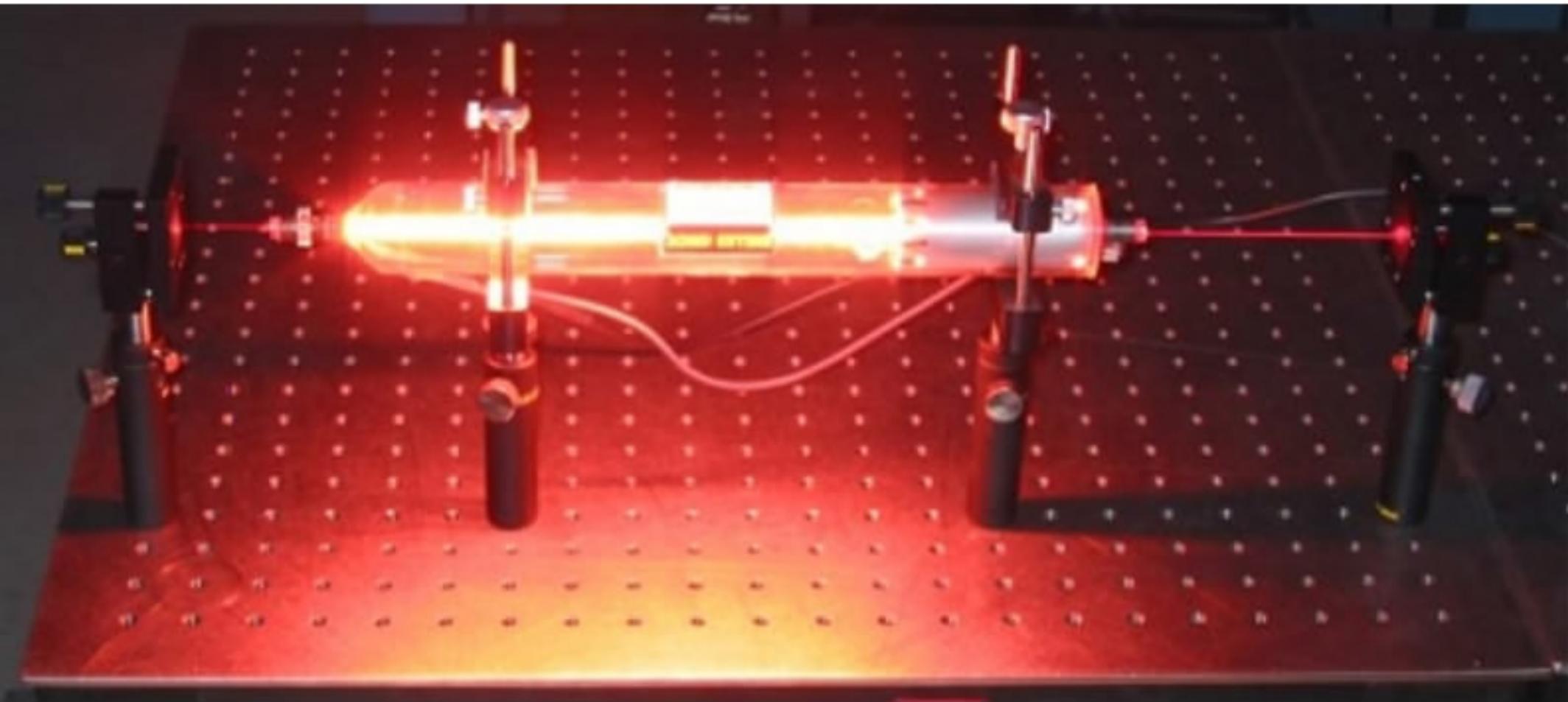


2.1 Grundlagen

2.2 Lasertypen

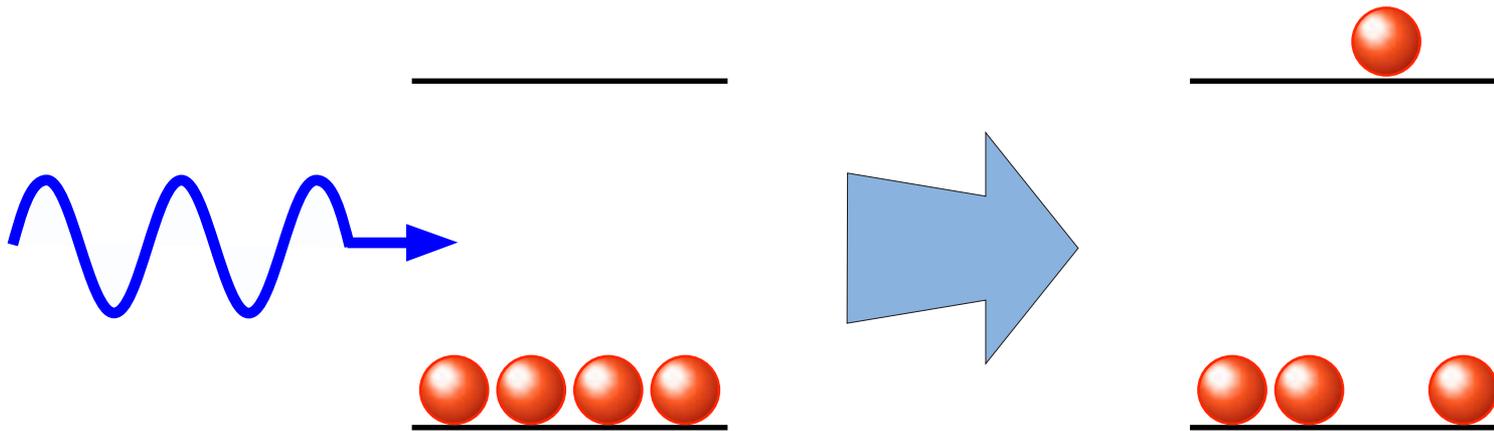
2.3 Lasermedien

2.4 Optische Frequenzmischung

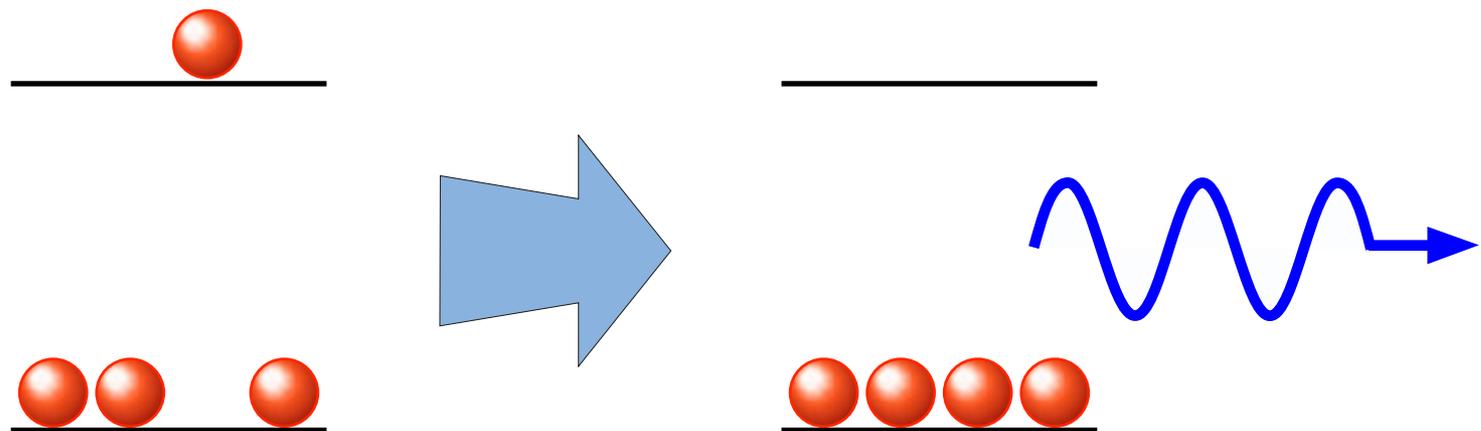


Absorption und Emission

Absorption

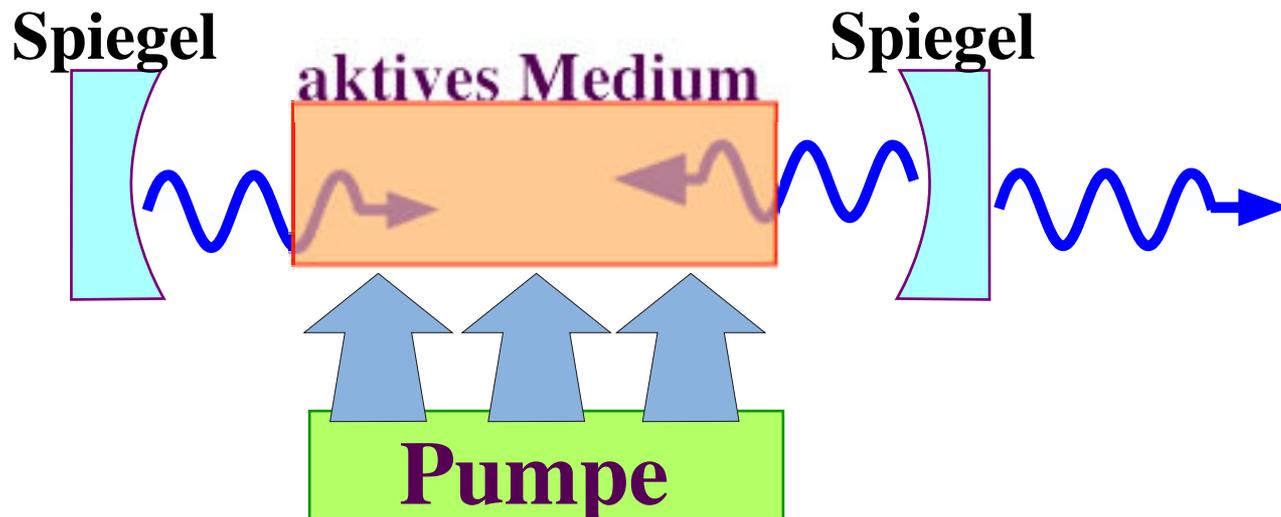
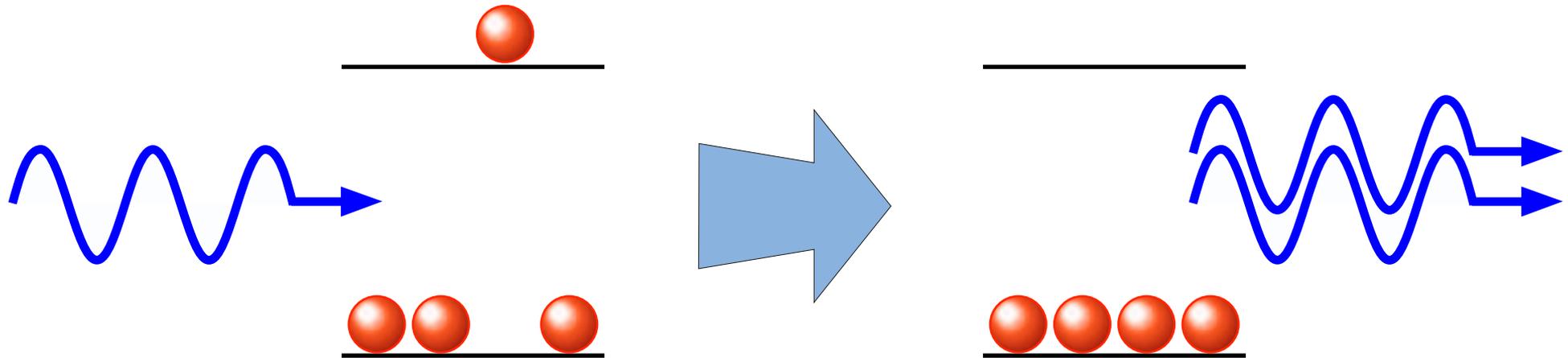


spontane Emission

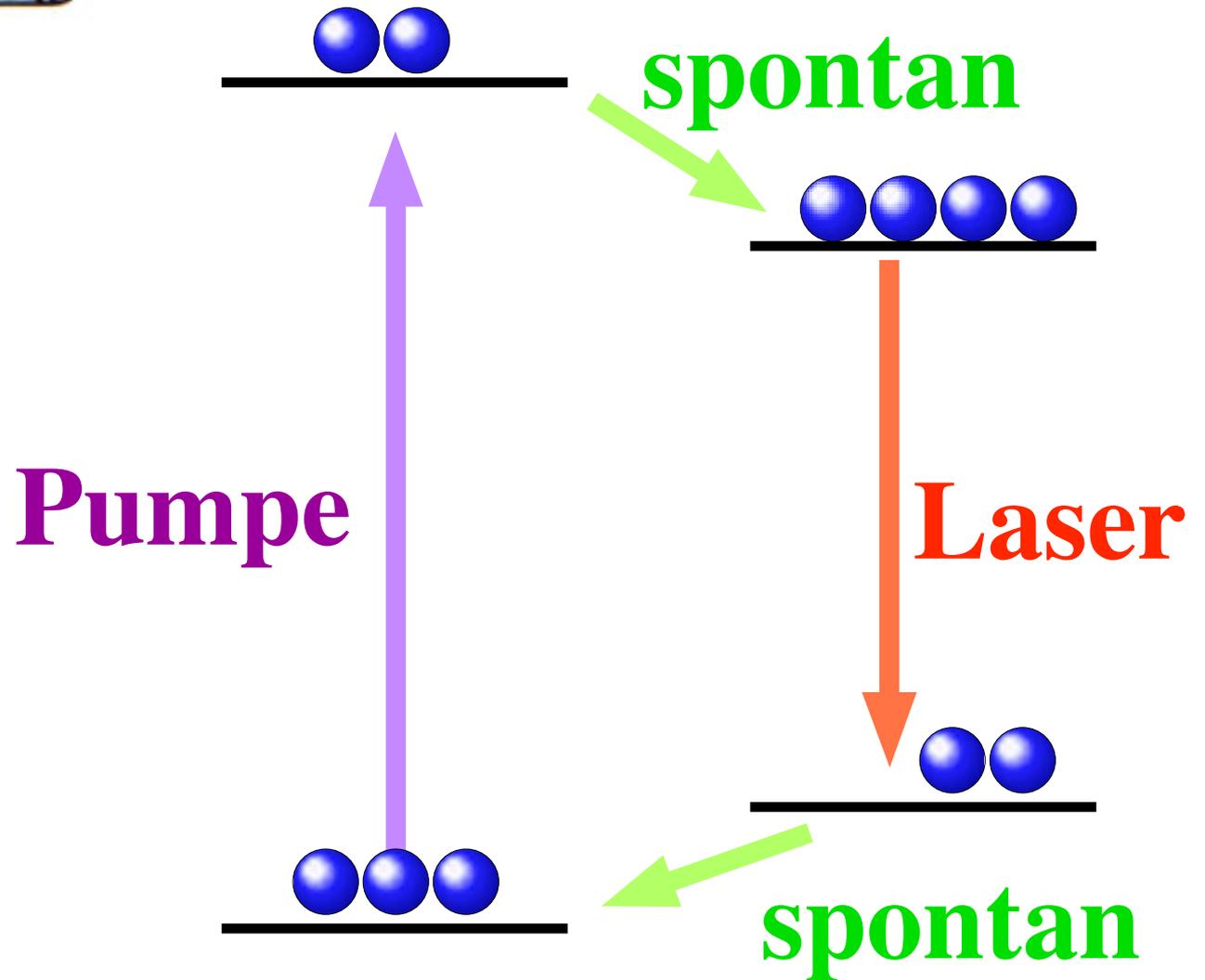
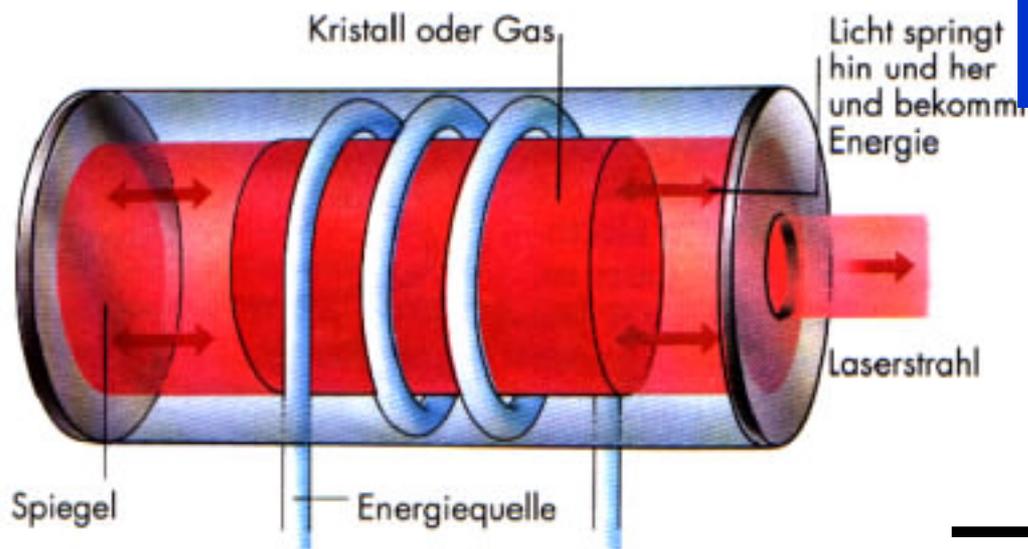


Absorption und Emission

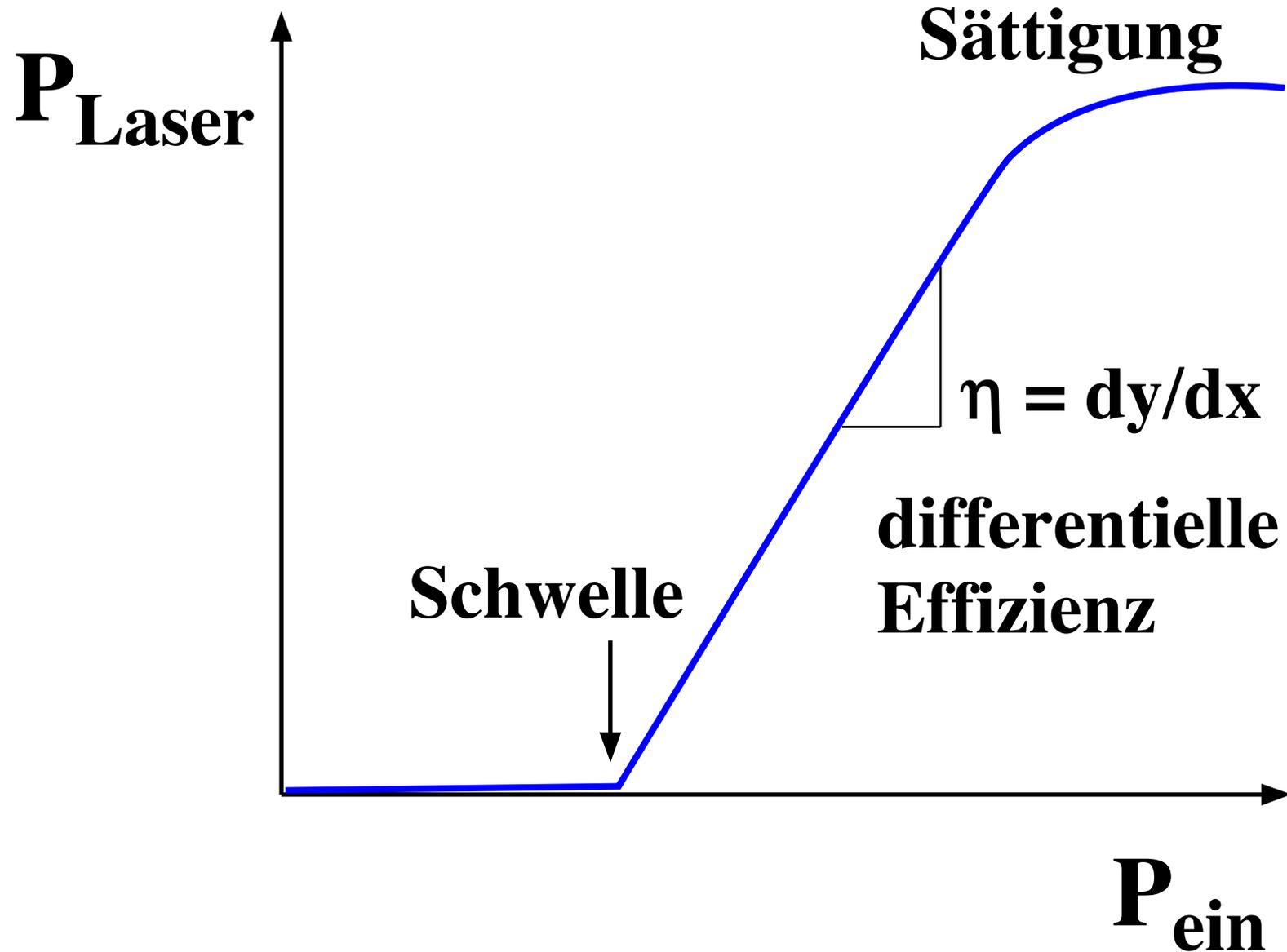
stimulierte Emission



Laser: Prinzip



Ausgangsleistung



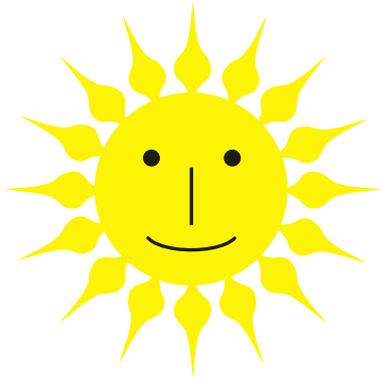
Historische Entwicklung

- 1917** Albert Einstein liefert die erste theoretische Beschreibung der stimulierten Emission
- 1958** Vorschlag zur Verstärkung durch stimulierte Emission im optischen Bereich (A.L. Schawlow und C.H. Townes)
- 1959** Vorschlag zur Verwirklichung eines Gaslasers (A. Javan)
- 1959** Vorschlag zur Verwirklichung eines Halbleiterlasers (N.G. Basov , B.M. Wul, J.N. Popov)
- 1960** erster Festkörperlaser (Rubinlaser) (T.H. Maiman)
- 1961** erster He-Ne Laser (A. Javan, W. Bennett, D.R. Herriott)
- 1964** Nobelpreis an C.H. Townes , N.G. Basov , A.M. Prokhorov

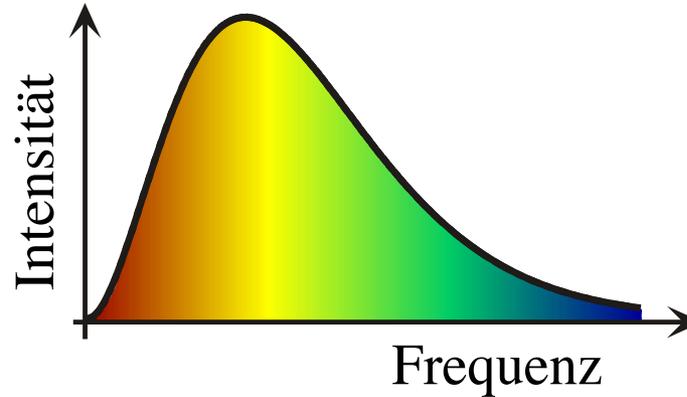
„for fundamental work in the field of quantum electronics, which has led to the construction of oscillators and amplifiers based on the maser-laser principle”

Eigenschaften von Laserlicht

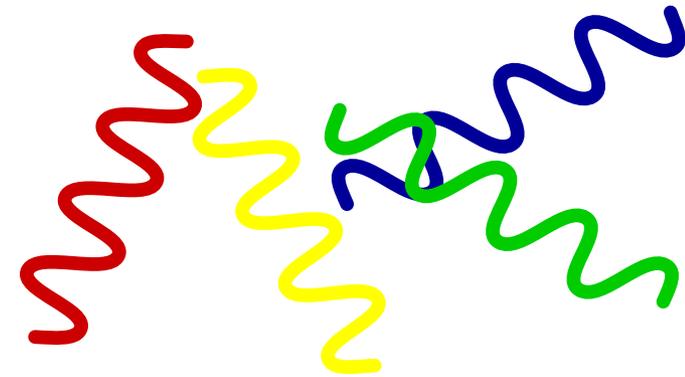
thermische Quelle



erzeugt unabhängige
Photonen

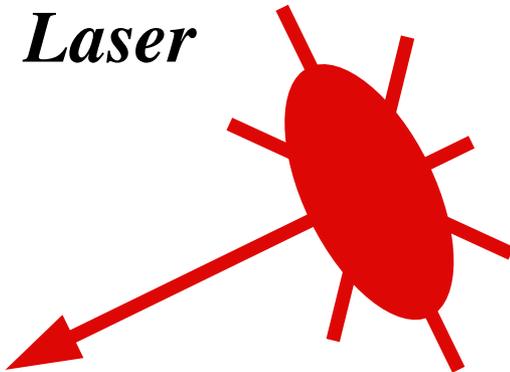


Leistung ist über großen
Frequenzbereich verteilt

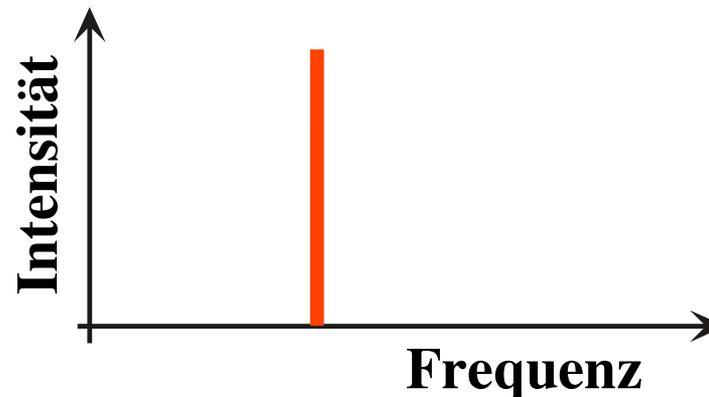


Richtung und Polarisation
sind statistisch verteilt

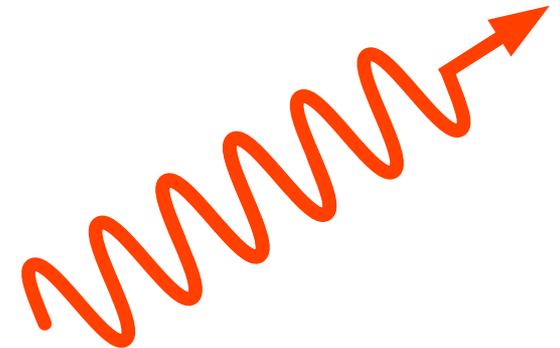
Laser



erzeugt identische
Photonen

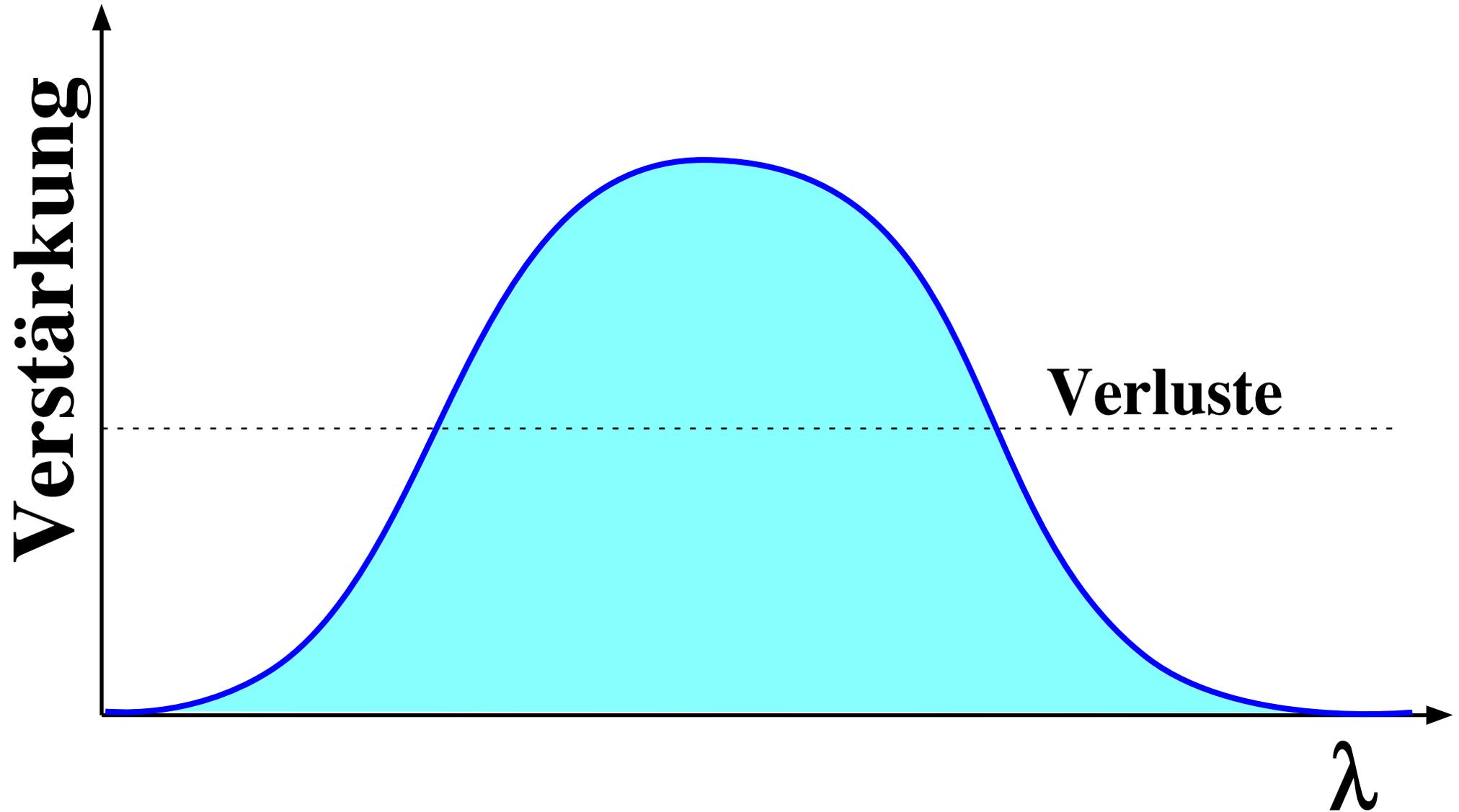


Frequenz, Polarisation und
Richtung sind identisch

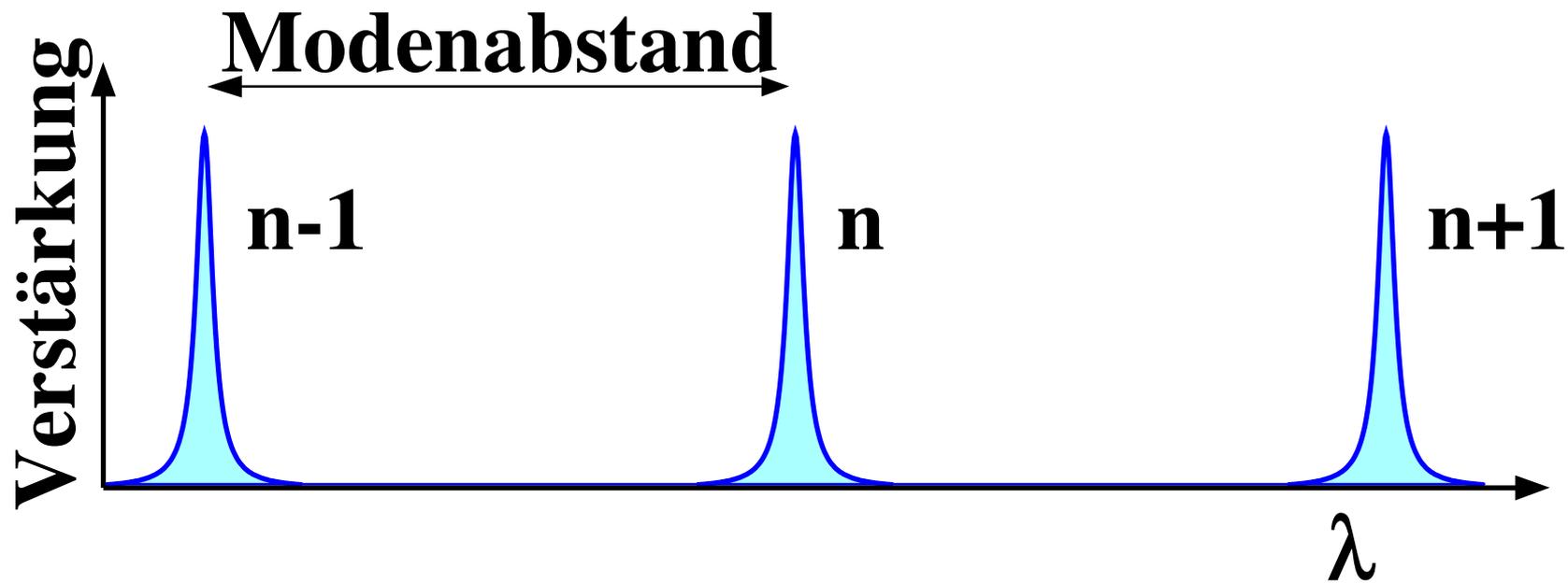
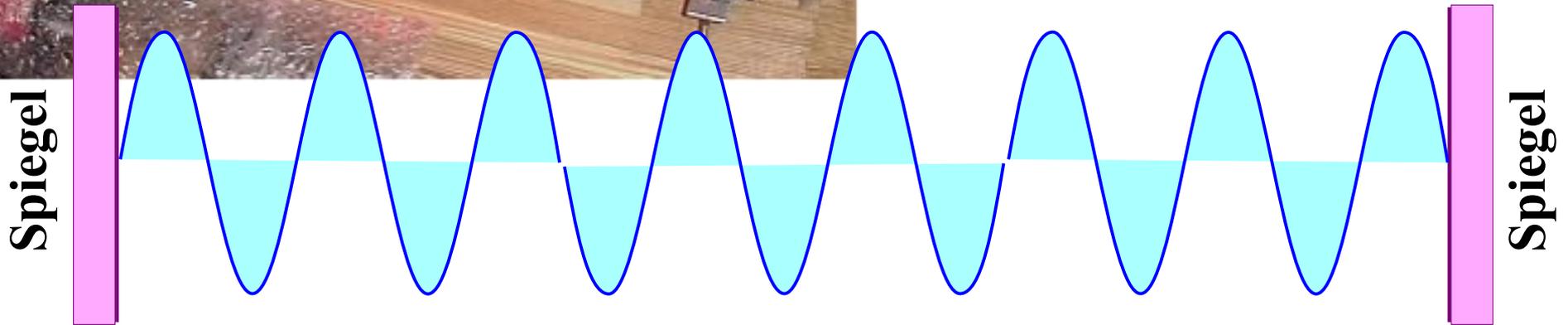


Laserlicht kann leicht kollimiert
und fokussiert werden

Bandbreite

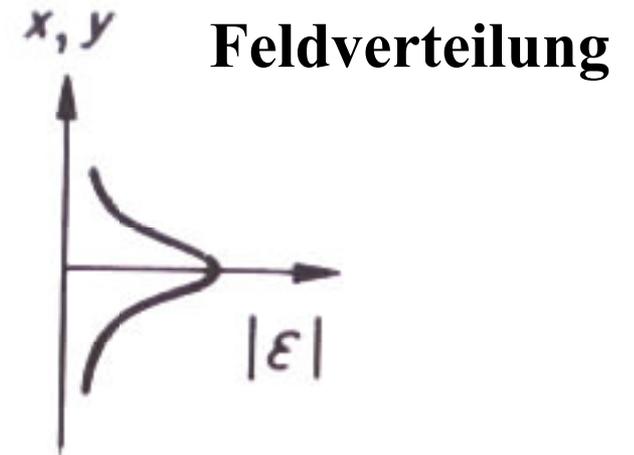
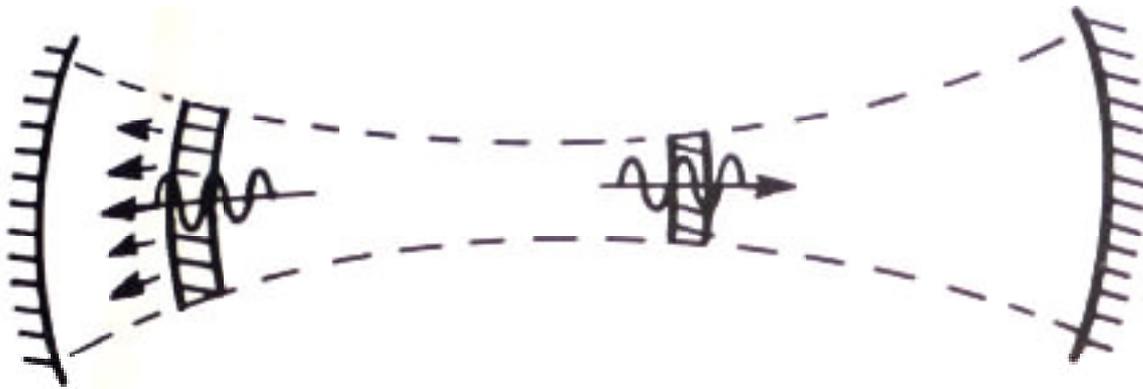


Resonatormoden

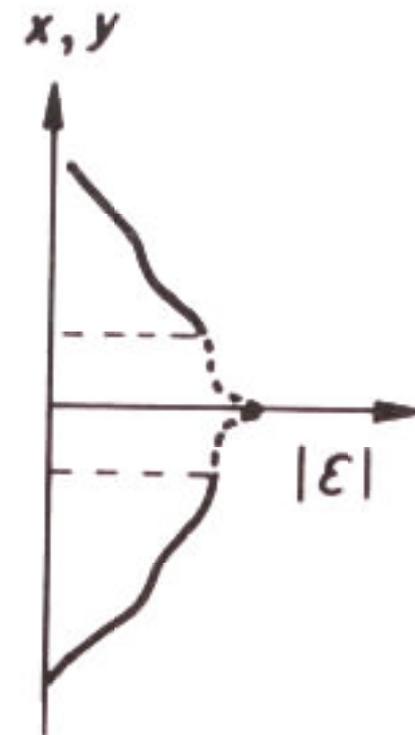
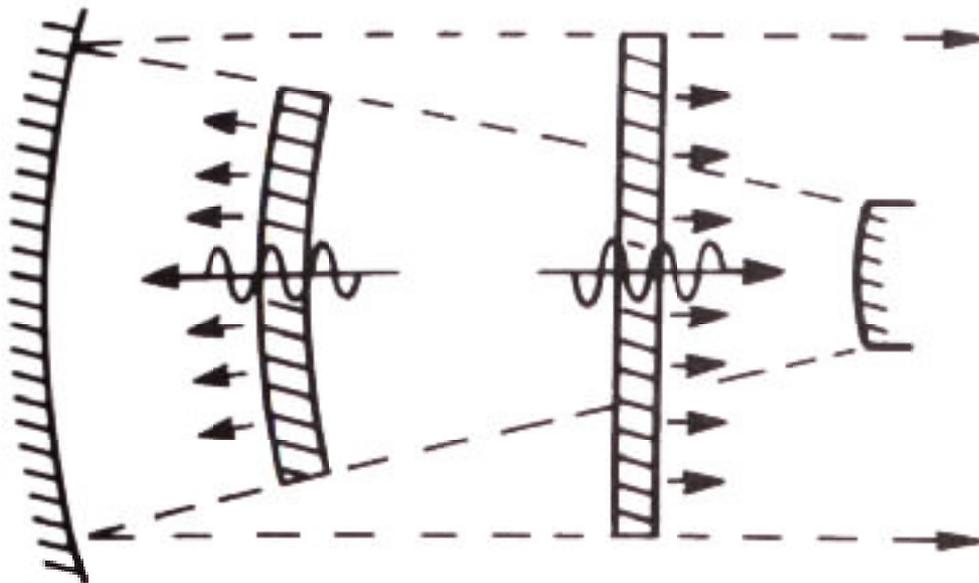


Stabile Resonatoren

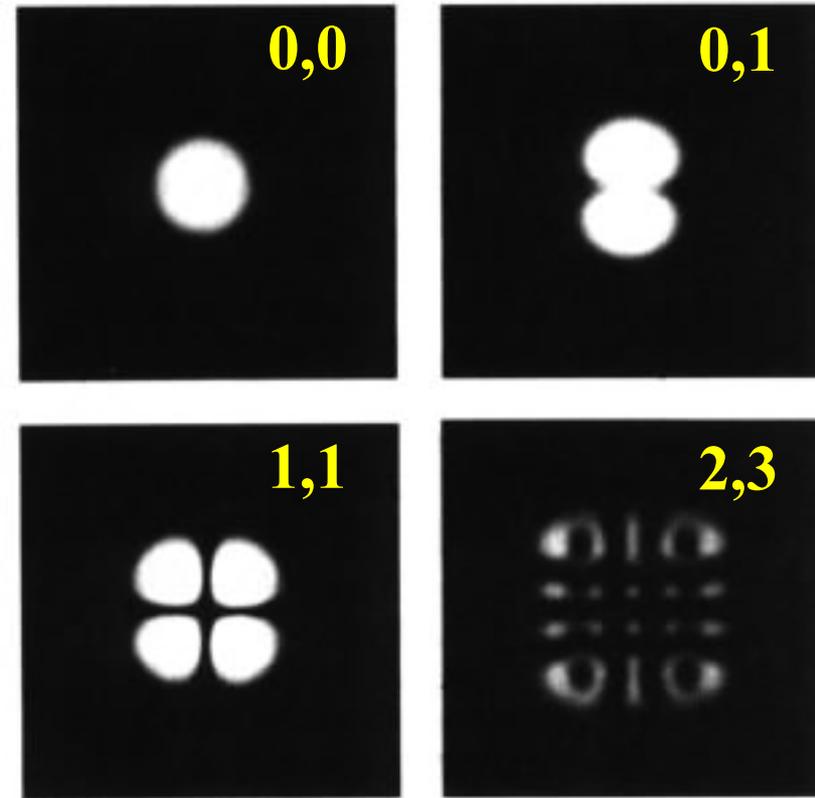
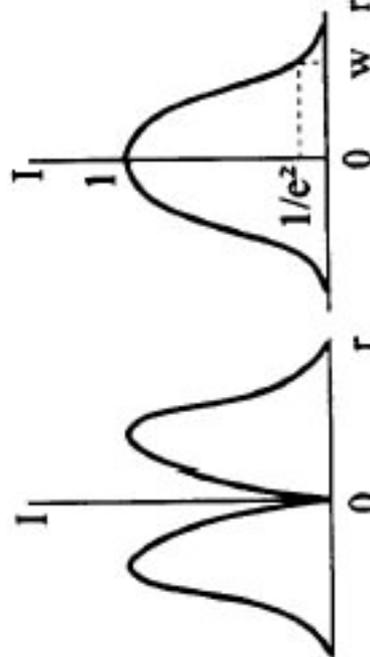
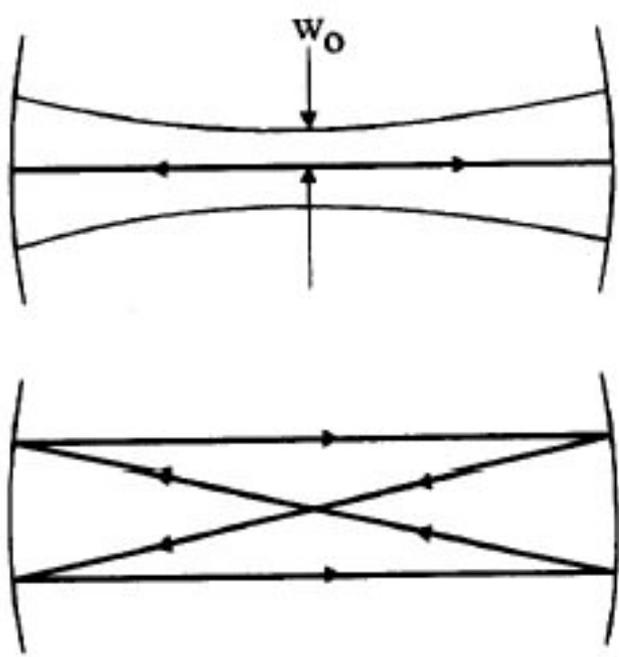
stabiler Resonator



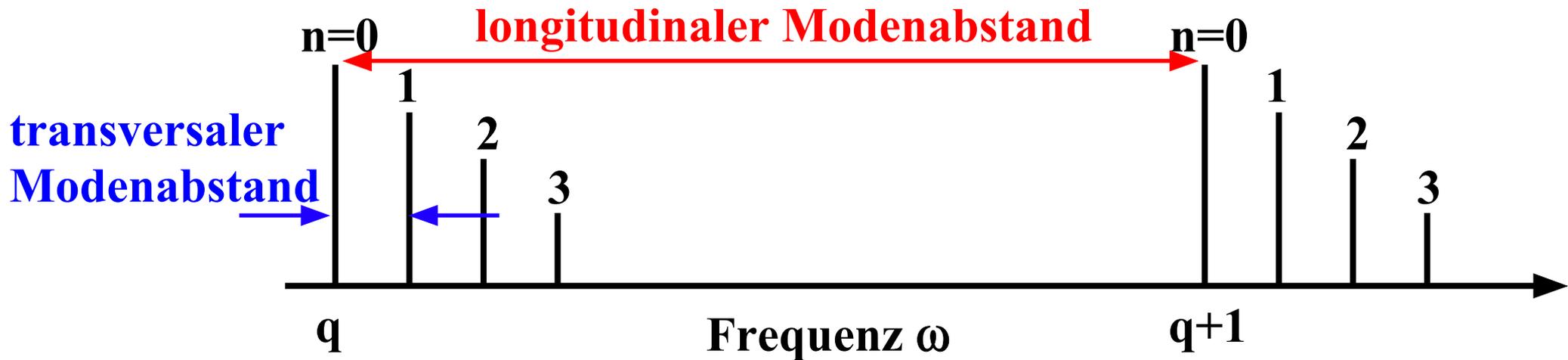
instabiler Resonator



Transversale Moden

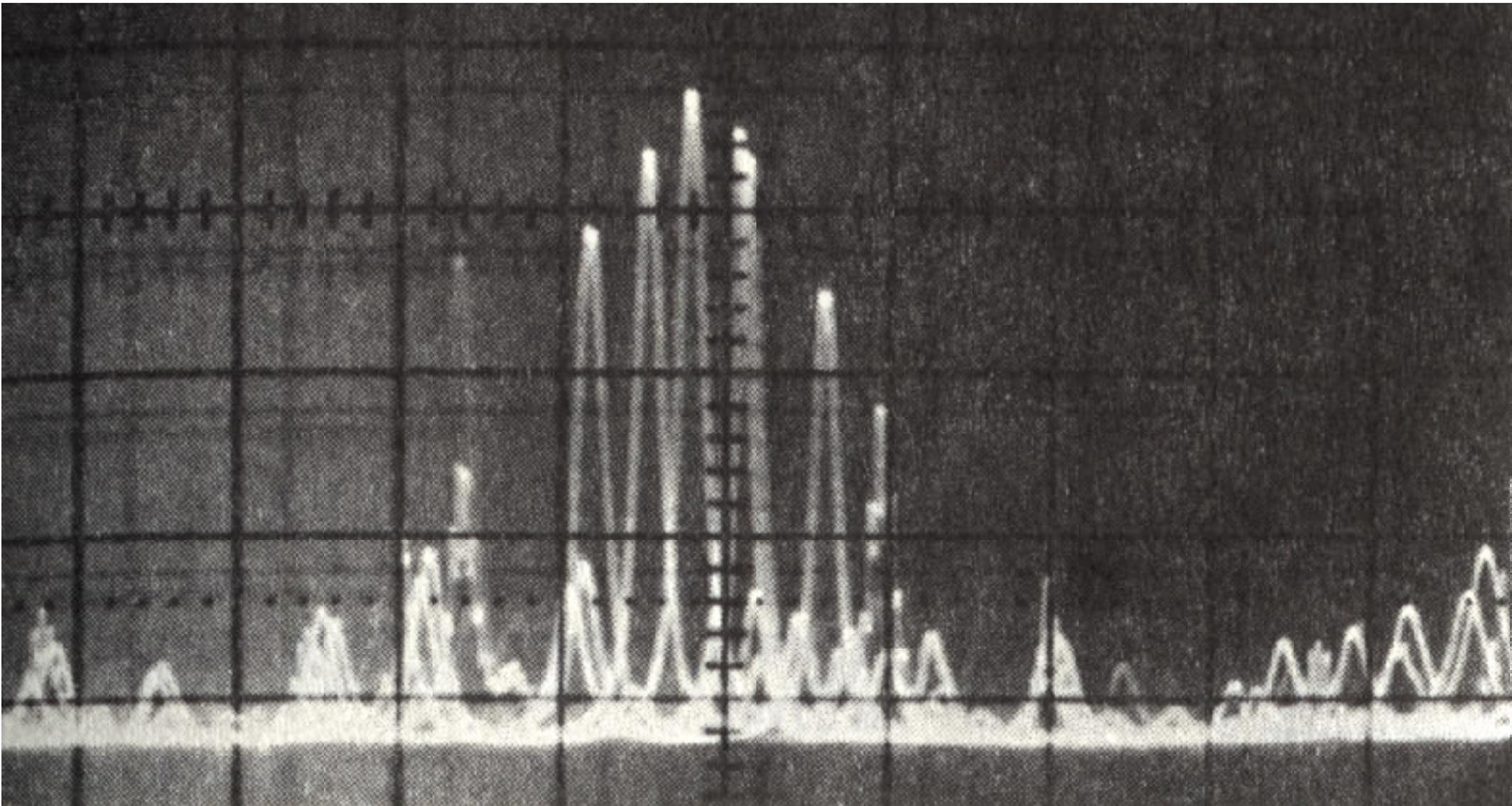


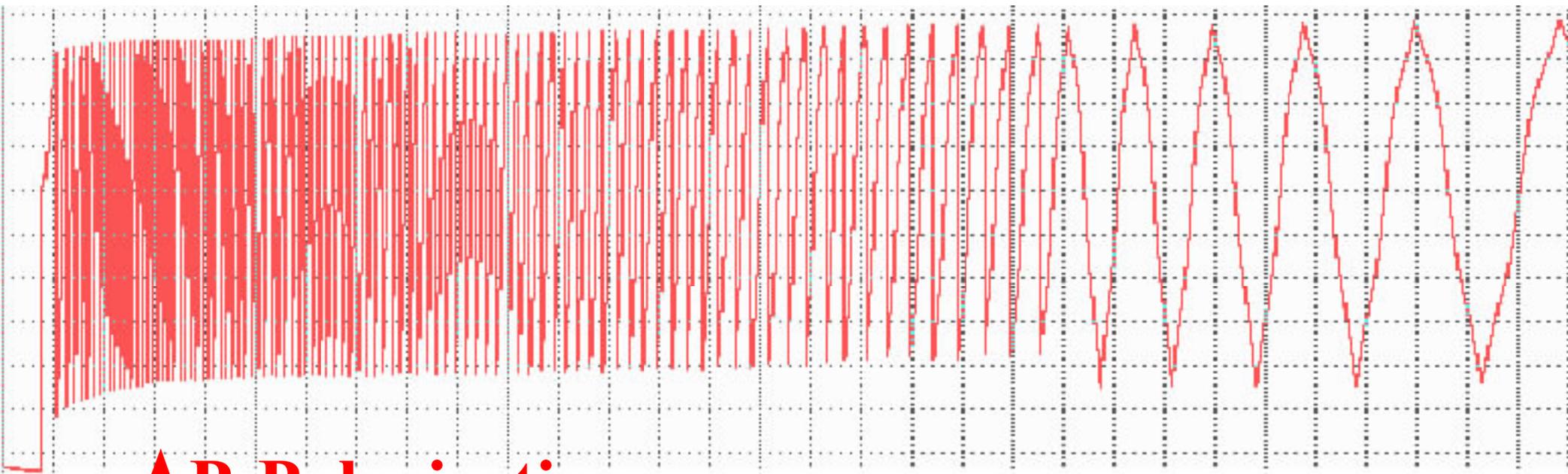
Gesamt-Modenstruktur



Modensprünge

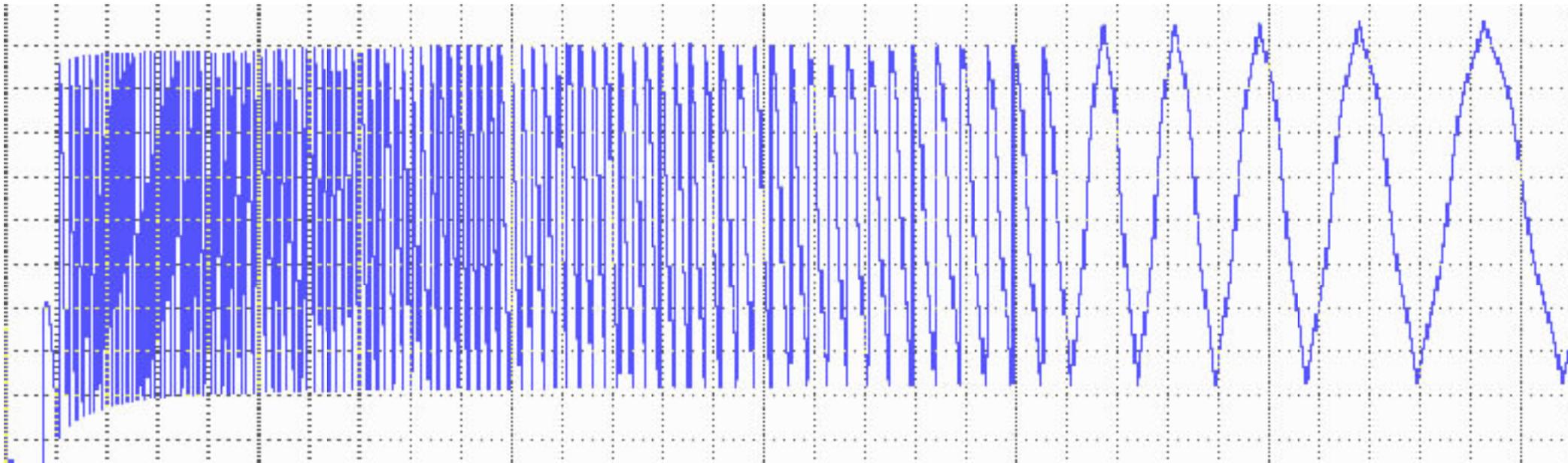
Variable Modenstruktur in einem Ar-Ionen Laser



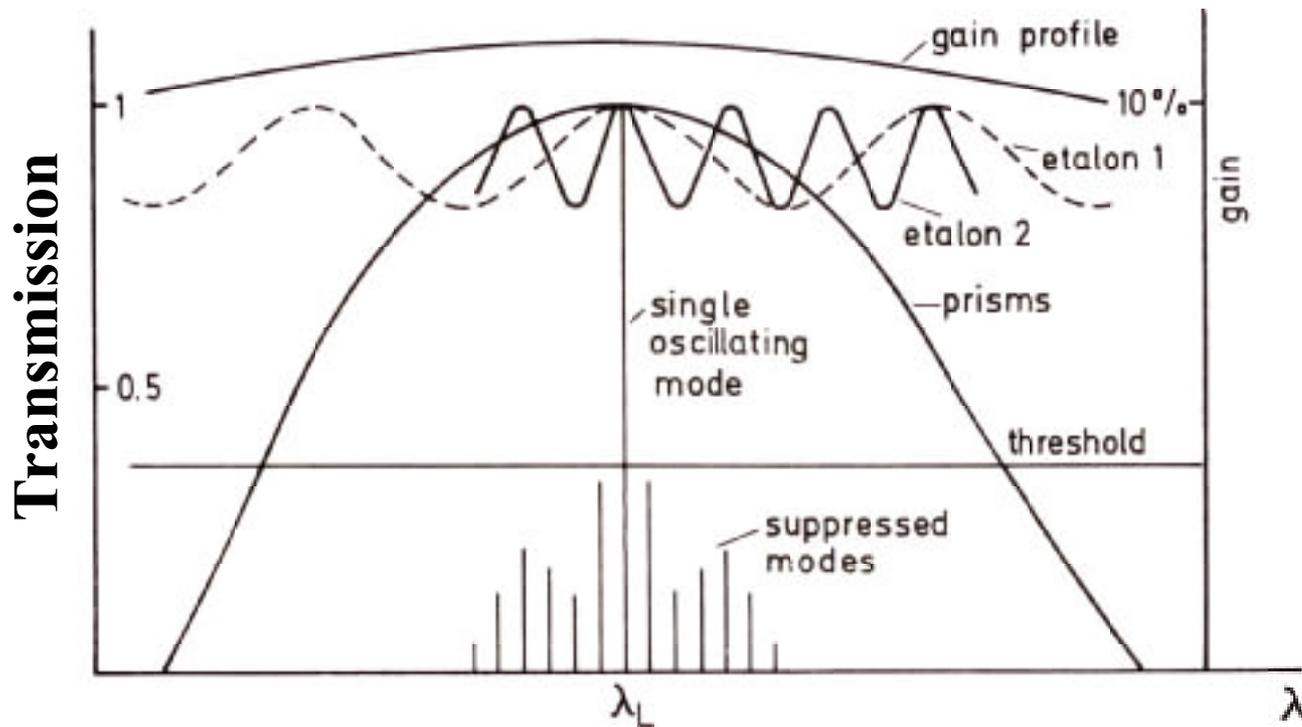
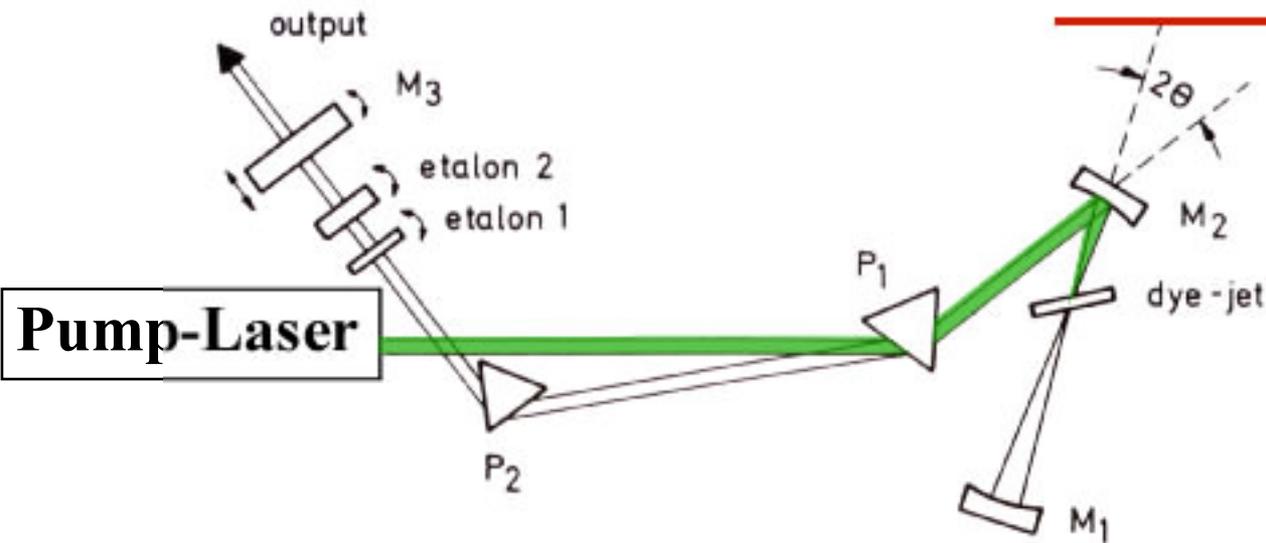


↑ P-Polarisation

↓ S-Polarisation

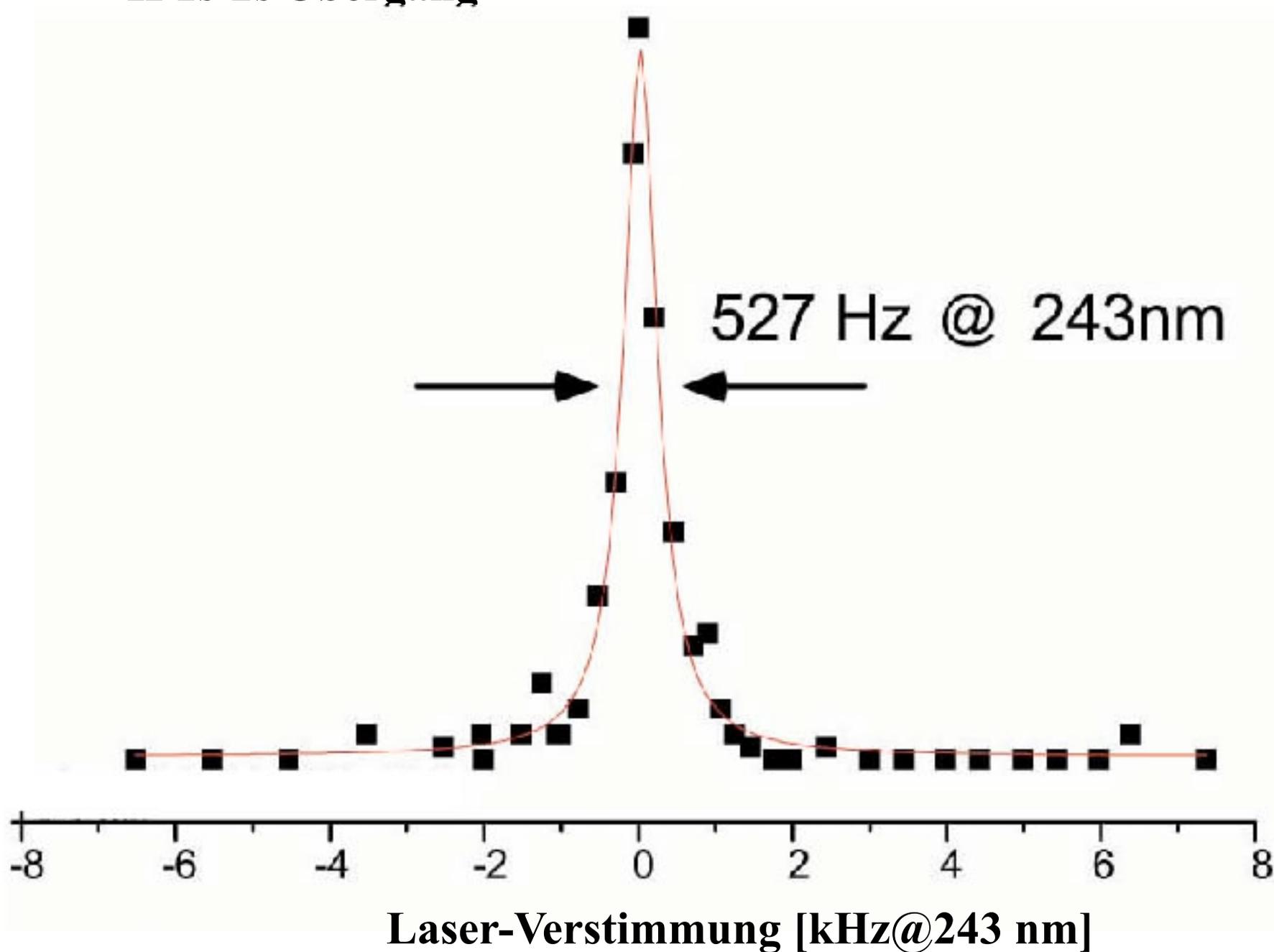


Modenselektion



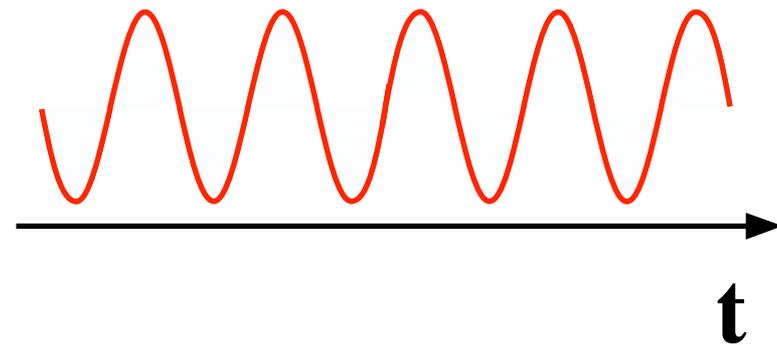
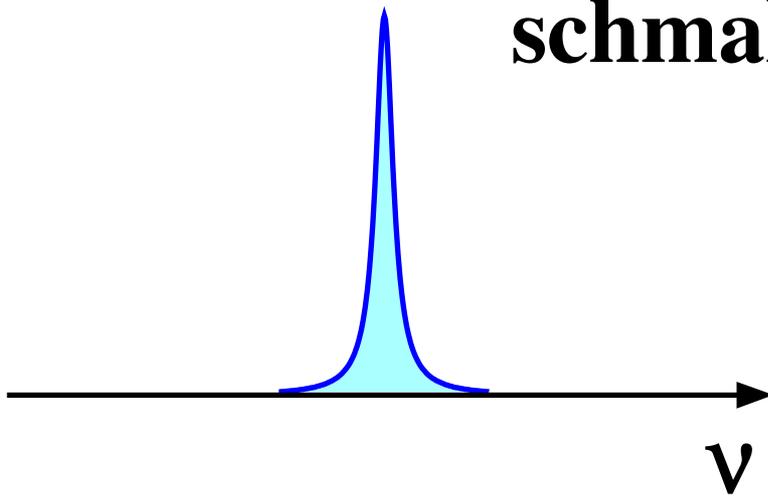
Linienbreiten

^1H 1s-2s Übergang

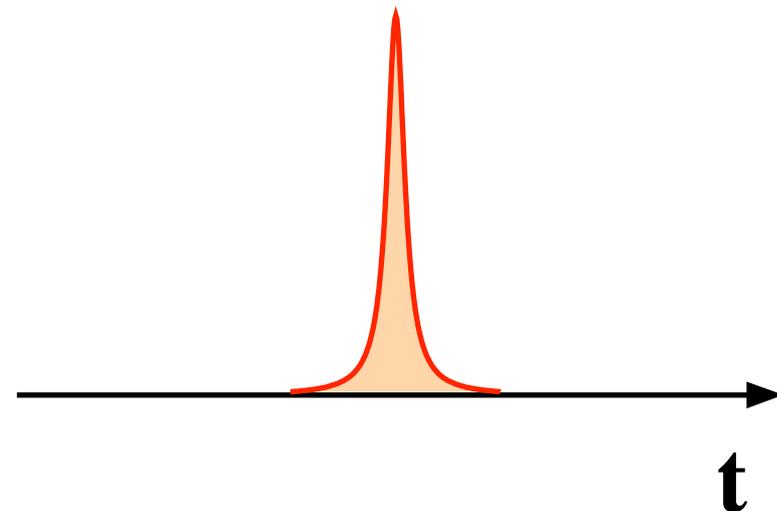
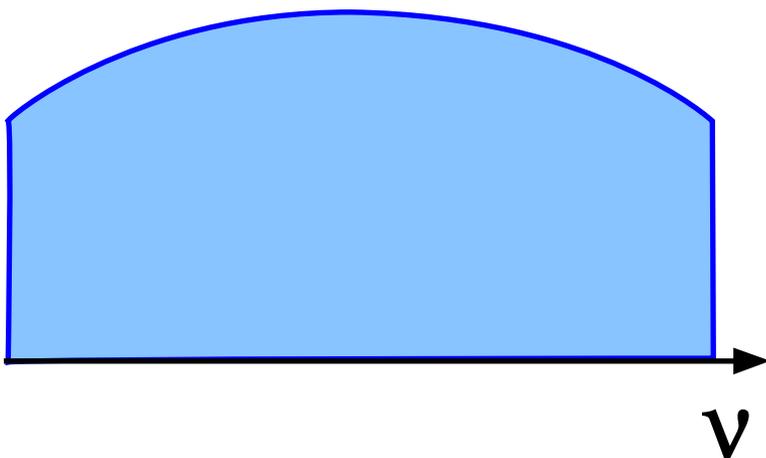


Pulslaser

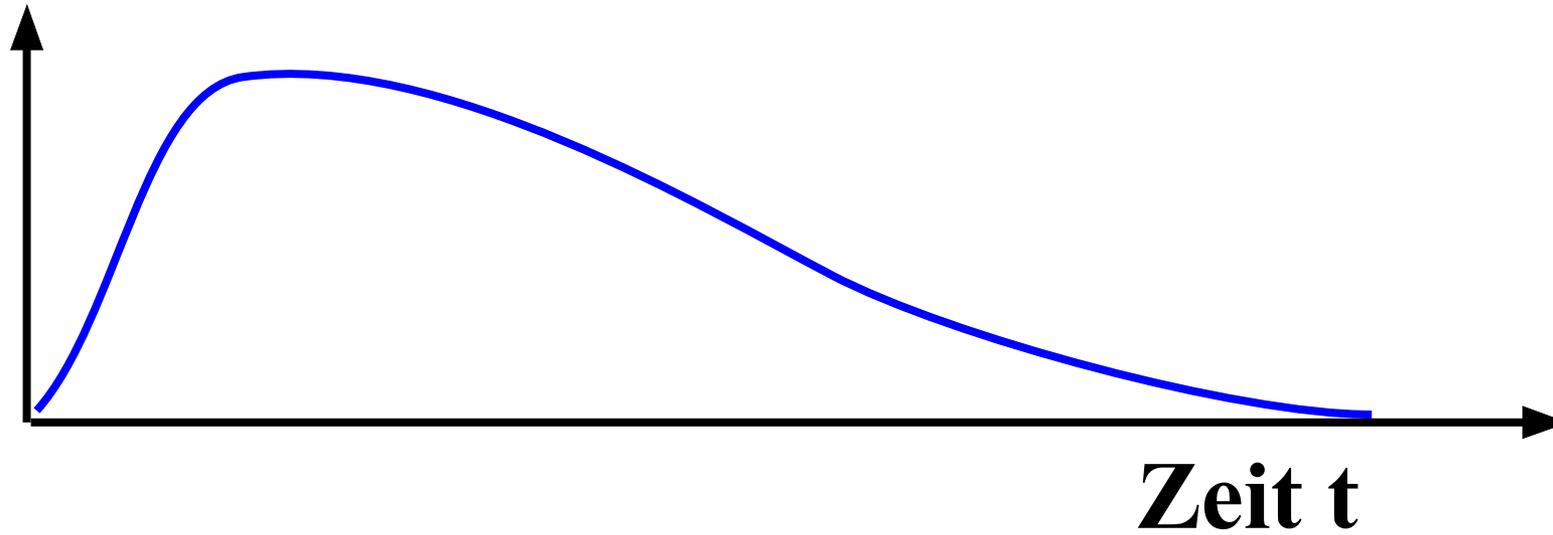
schmalbandiger Laser



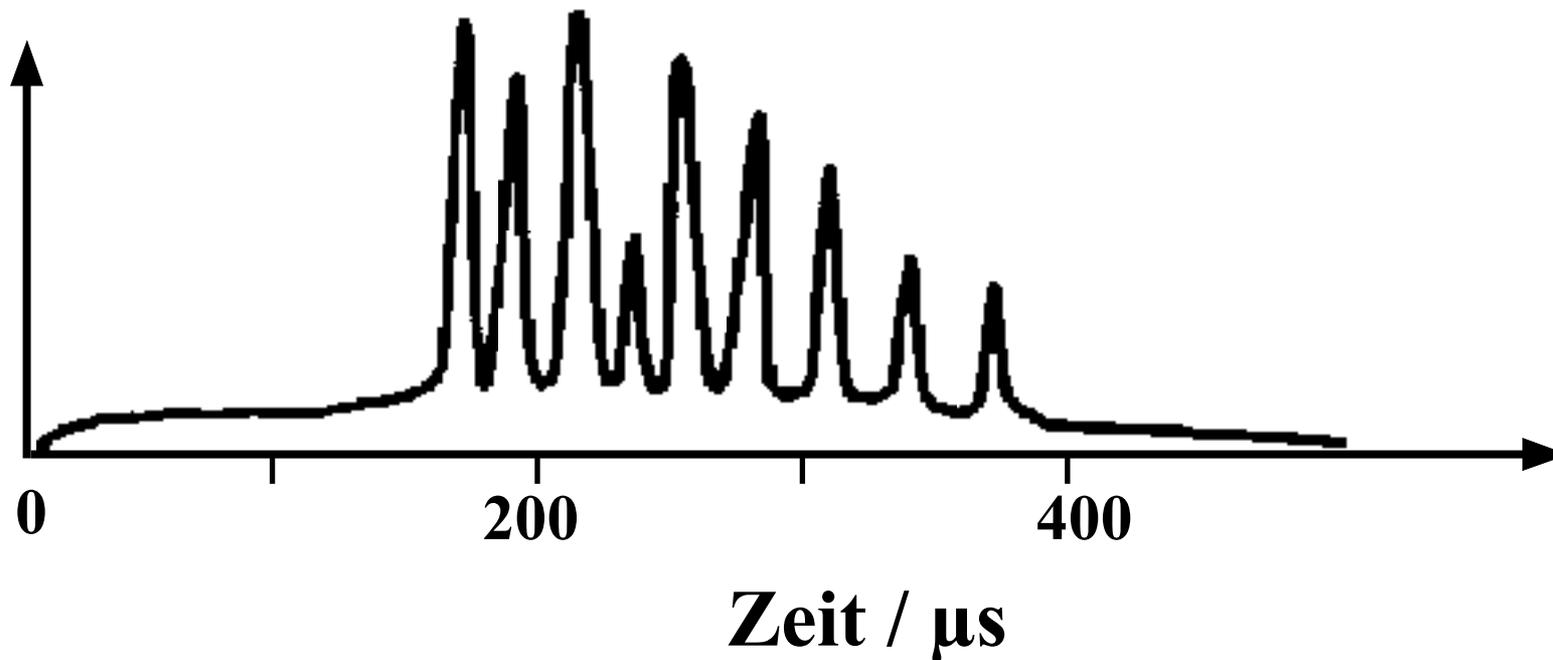
Kurzpulslaser



Pumppuls (Blitzlampe)

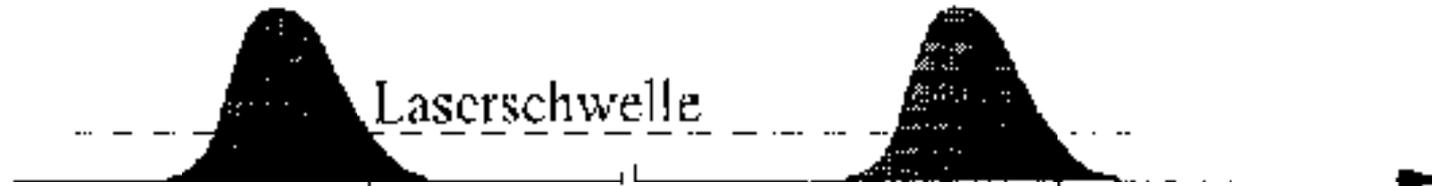


Resultierender Puls eines Rubinlasers mit "spiking"

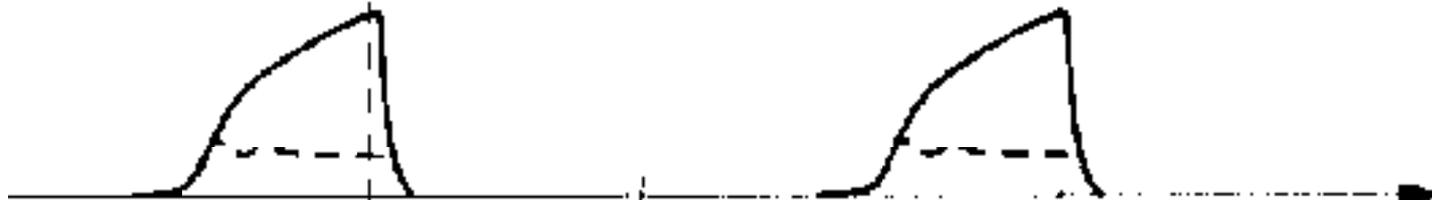


Güteschaltung

Pumintensität



**Inversion mit / ohne
Güteschaltung**



Resonatorverluste

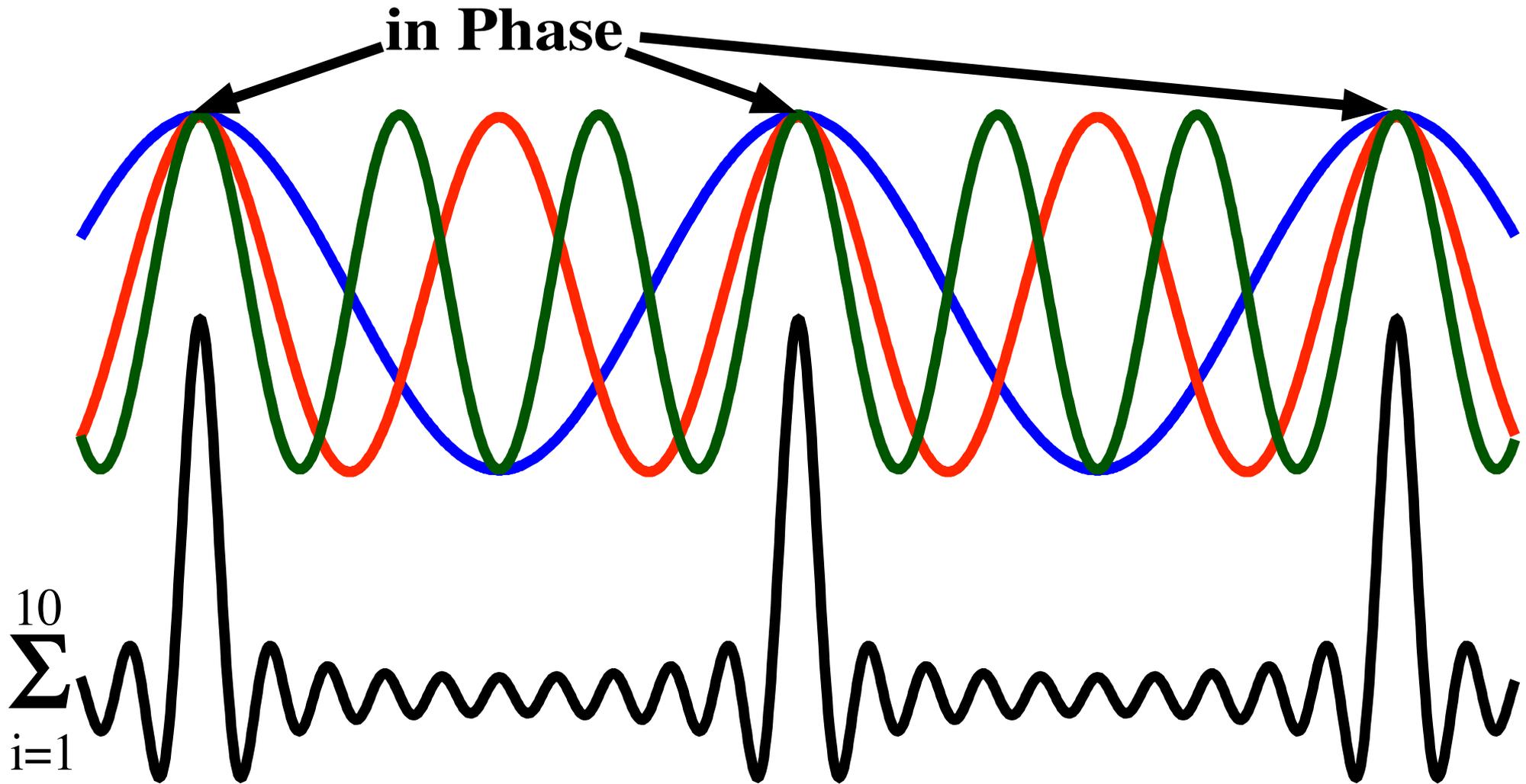


**Intensität mit / ohne
Güteschaltung**

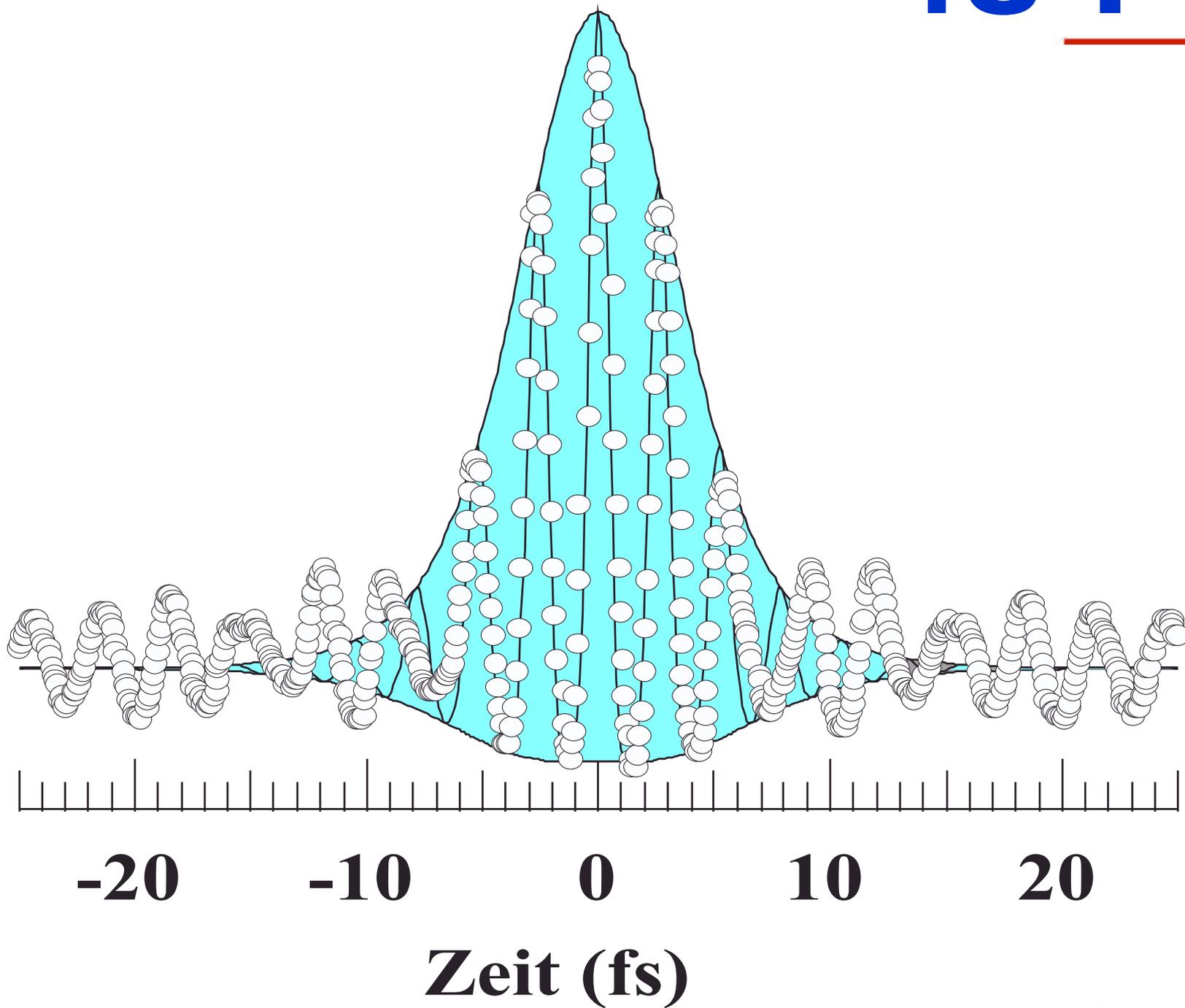


Zeit t

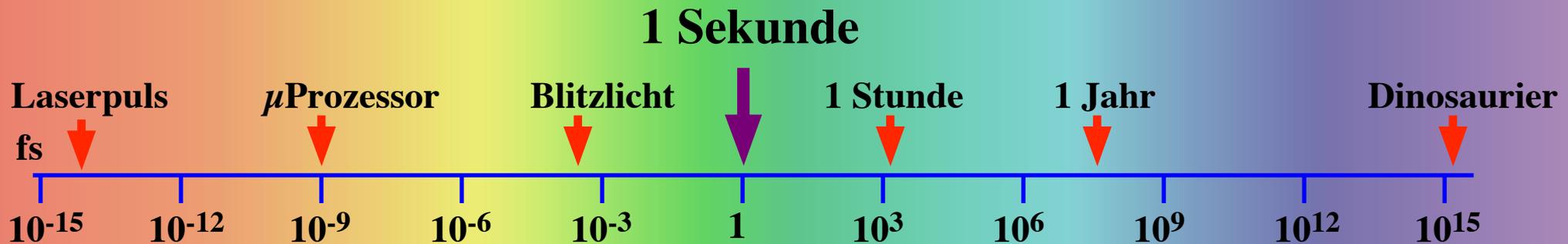
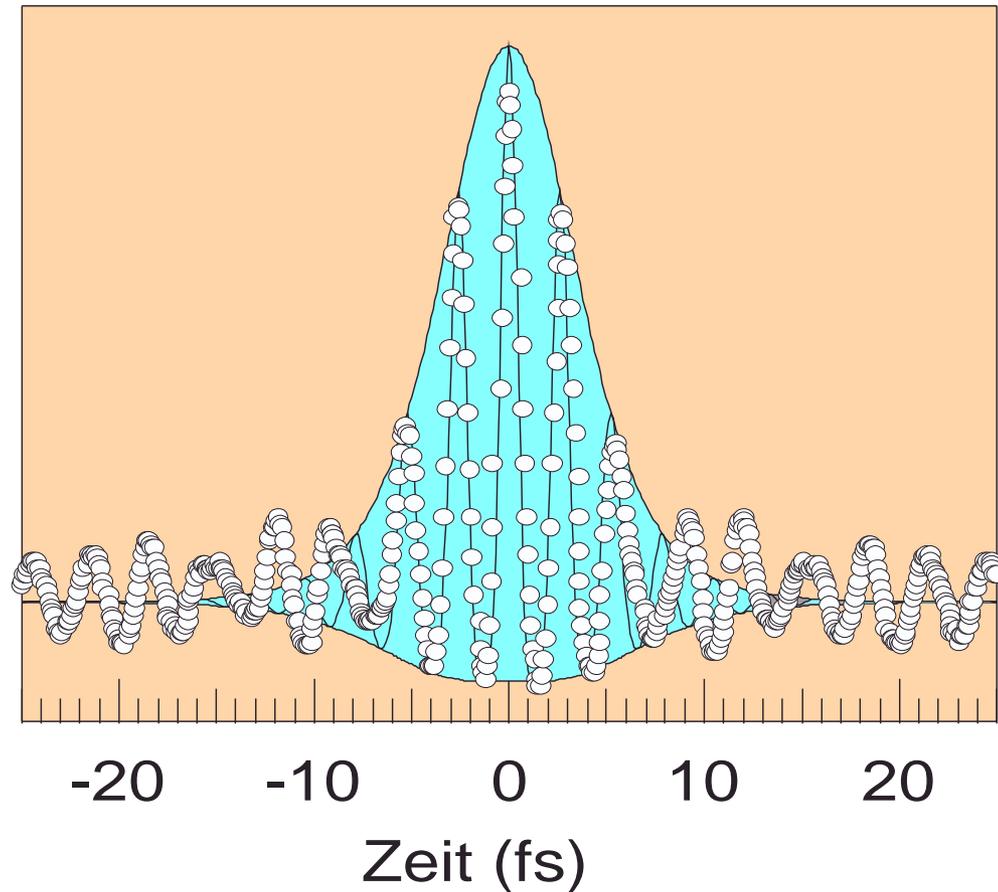
Modenkopplung



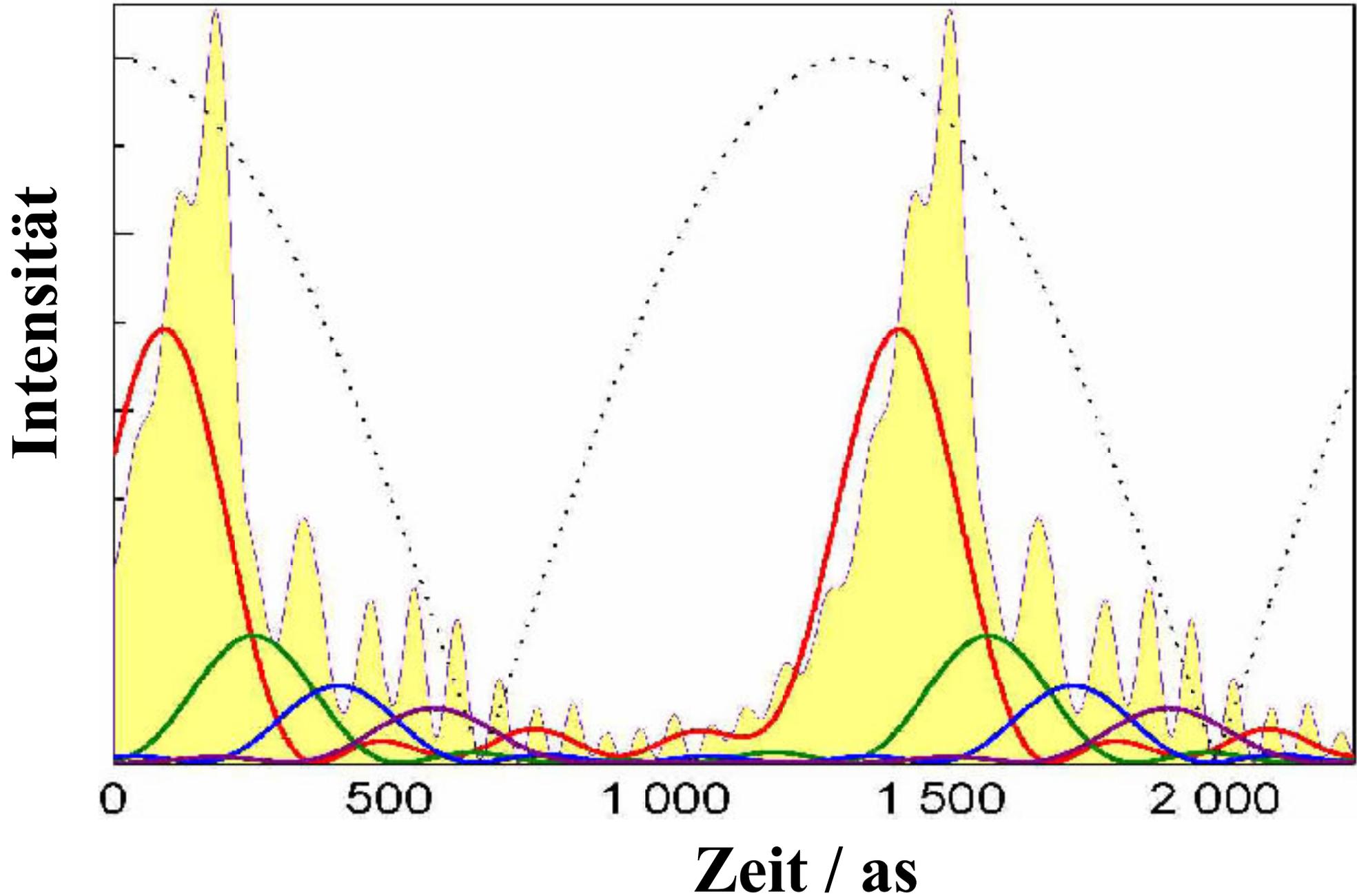
fs-Puls



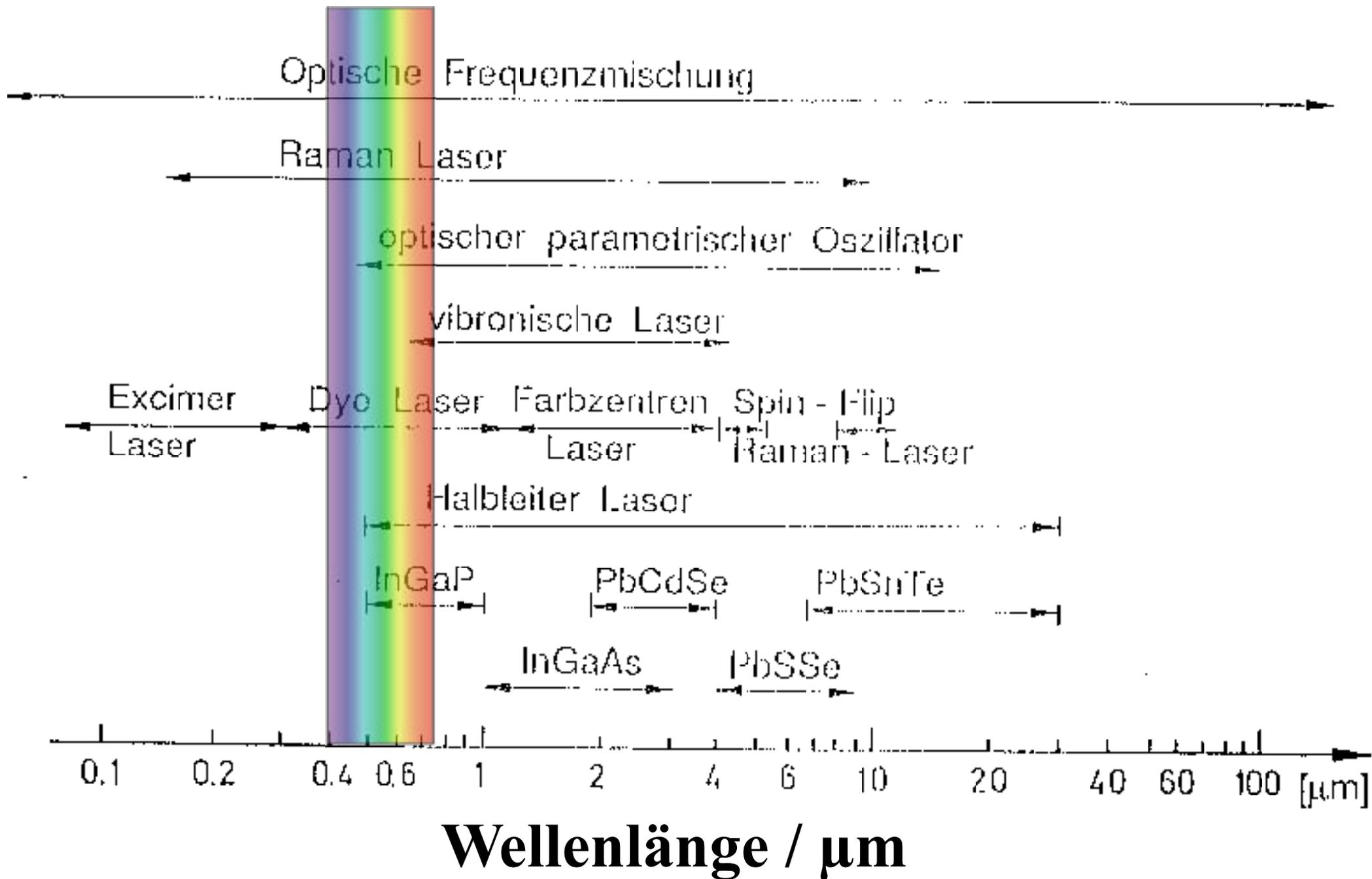
Wie lang ist 1 fs ?



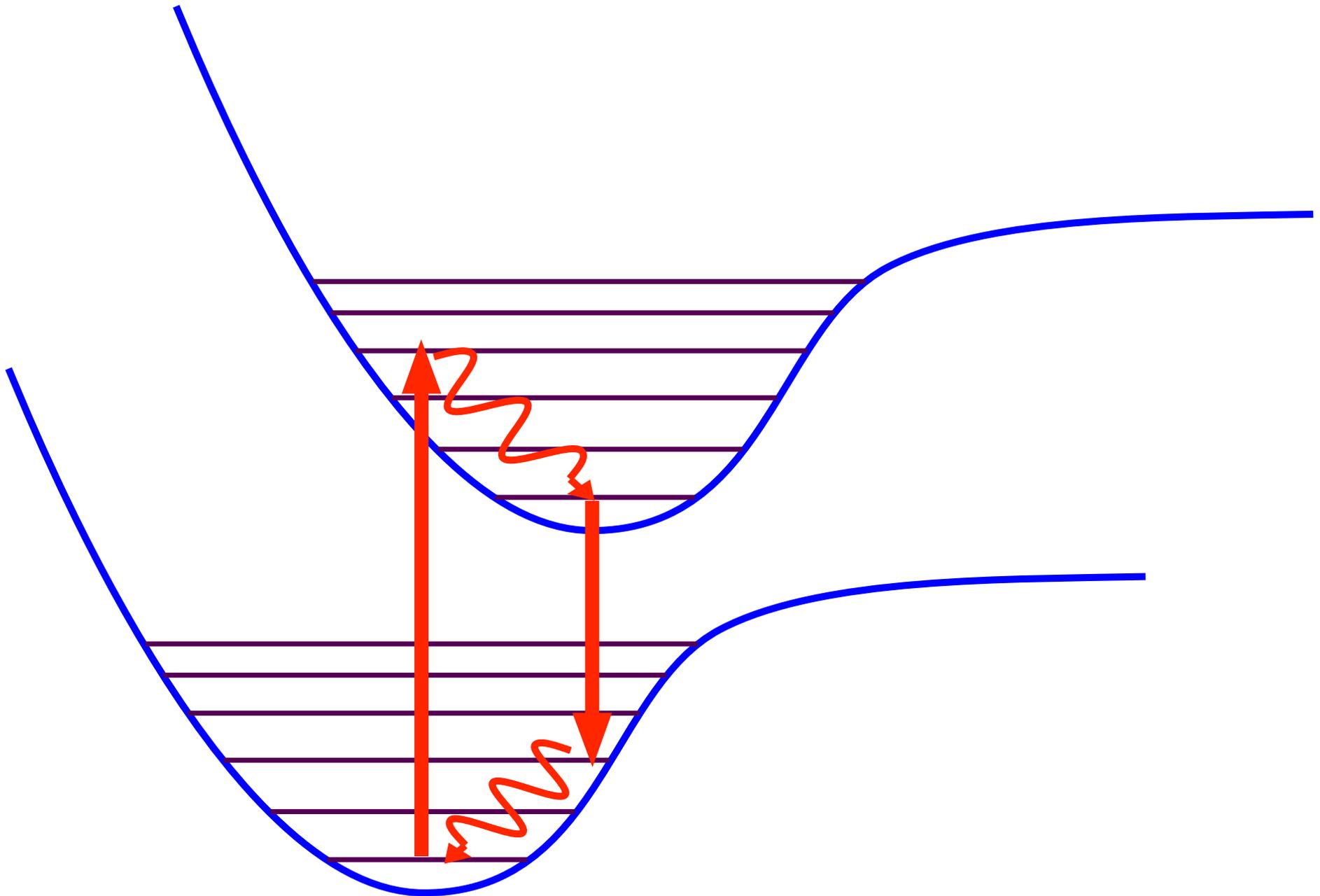
as-Puls



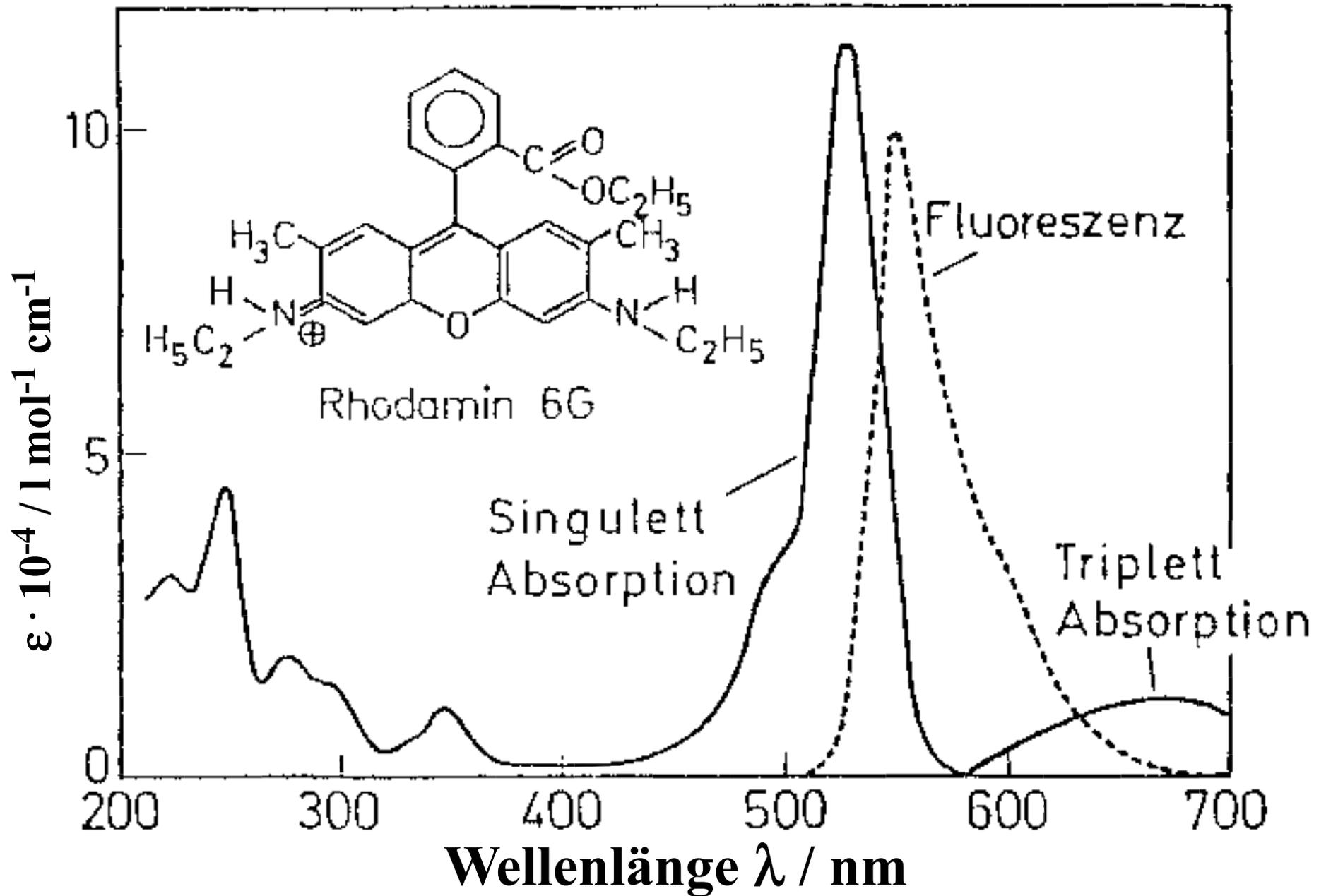
Lasermедien



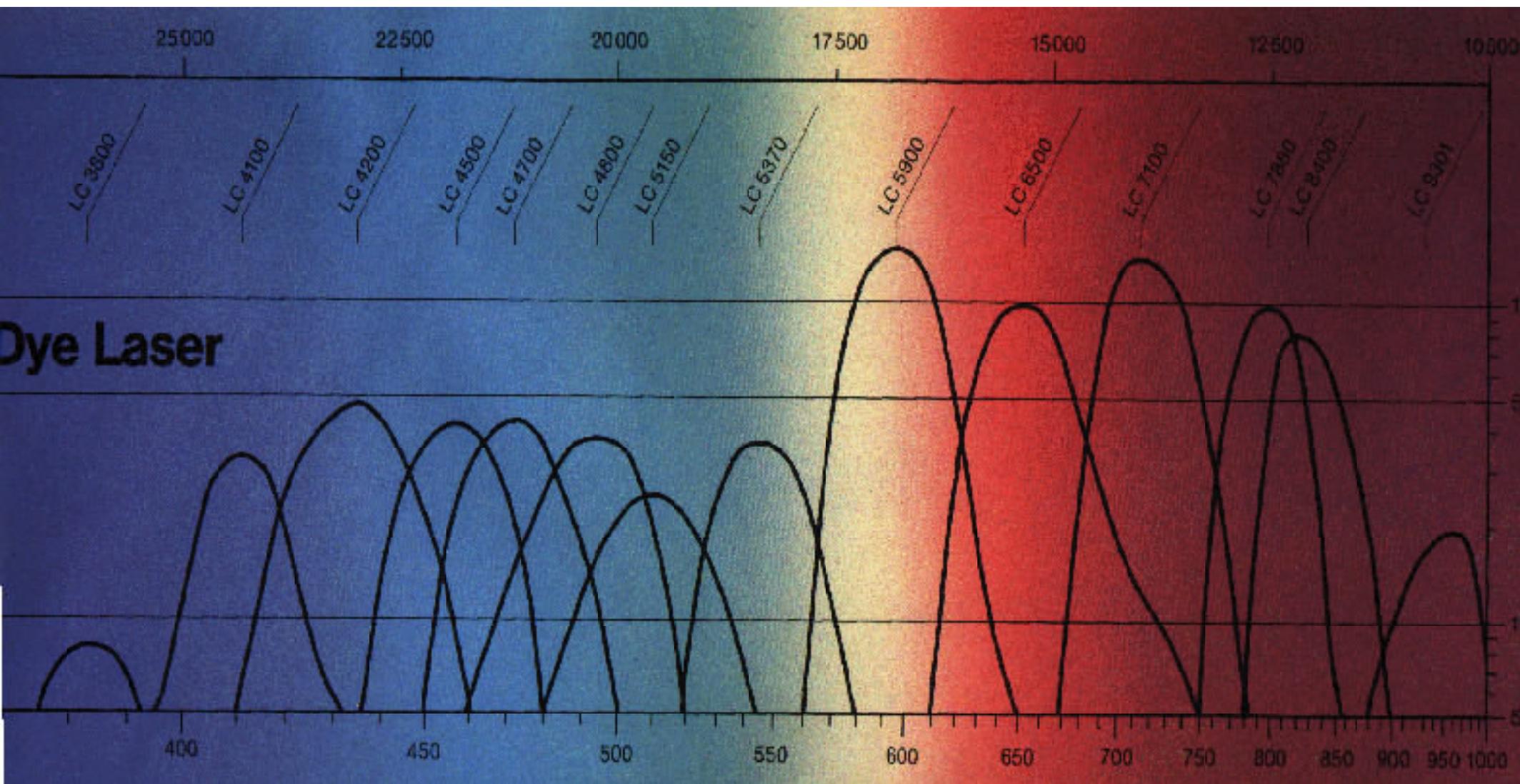
Laserzyklus in Molekül



Rhodamin 6G



Laserfarbstoffe

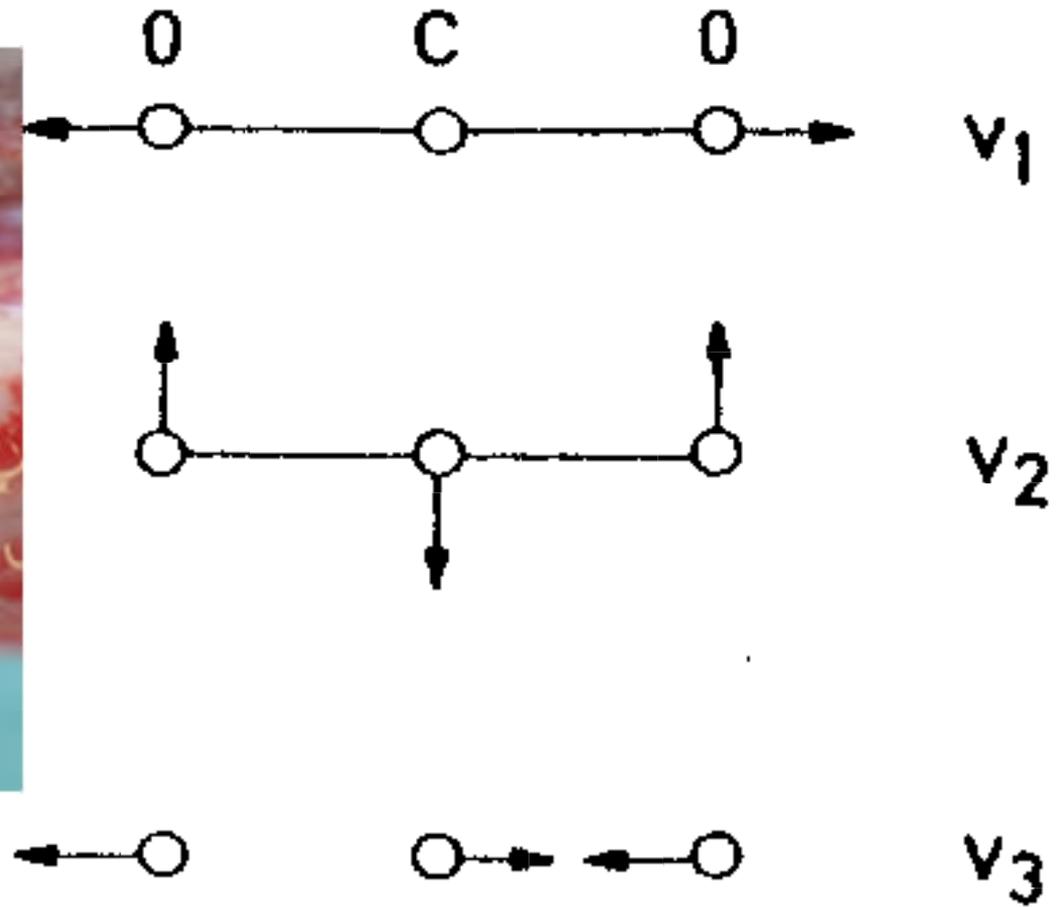
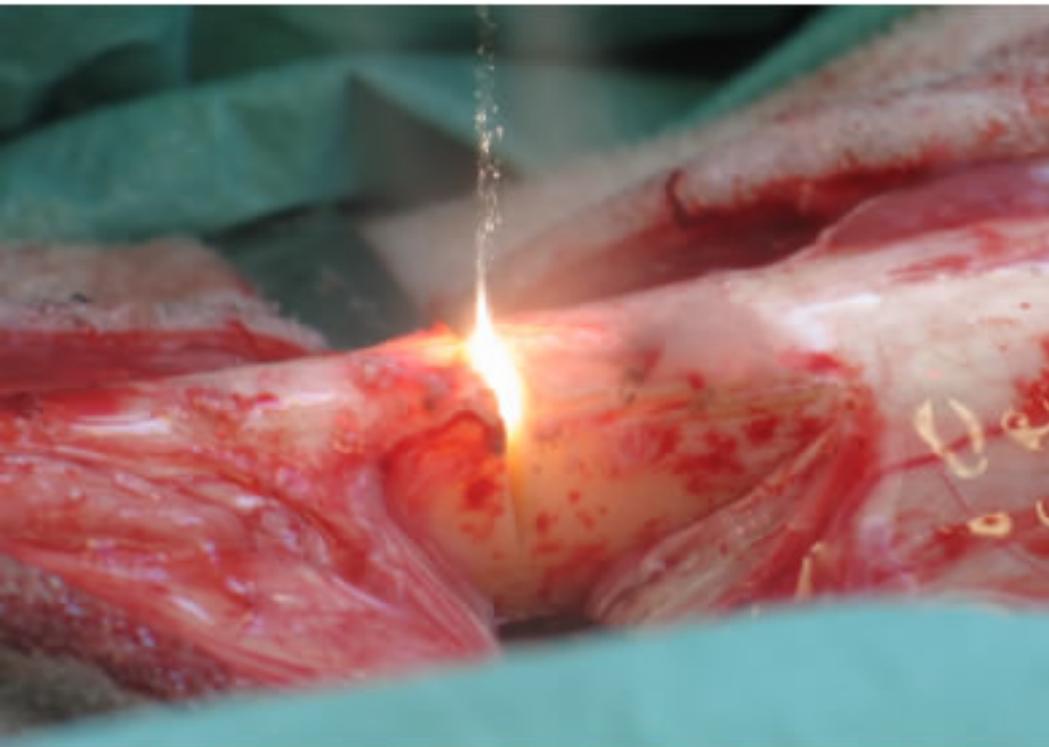


Farbstofflaserdaten bei verschiedenen Pumpquellen

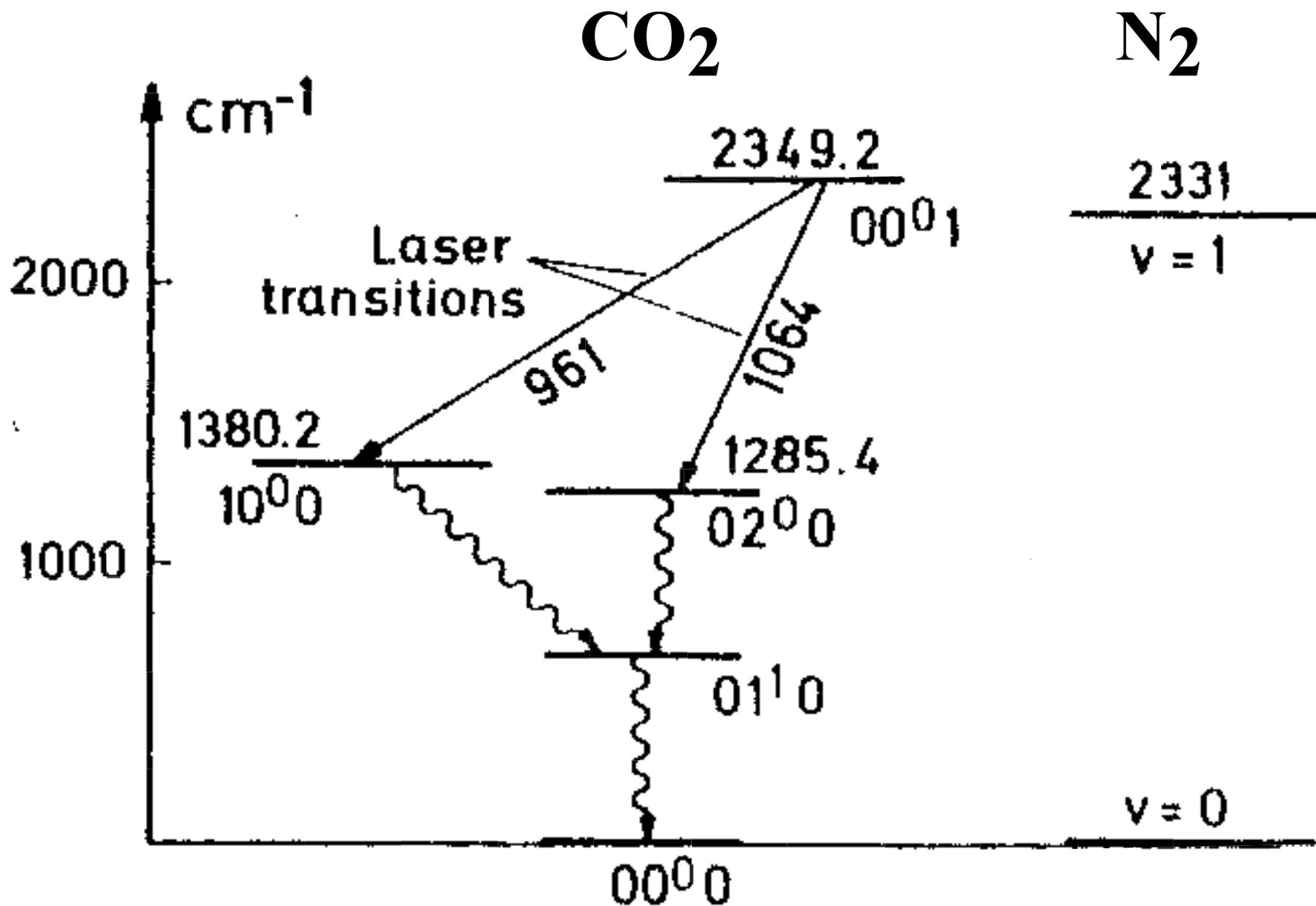
Pumplaser

Pumpe	Abstimm- bereich [nm]	Puls- dauer [ns]	Spitzen- leistung [W]	Puls- energie [mJ]	Pulsfolge- frequenz [s ⁻¹]	Mittlere Ausgangs- leistung [W]
Exzimer- Laser	370-985	10-200	$\leq 10^7$	≤ 300	20-200	0.1-10
N ₂ -Laser	370-1020	1-10	$< 10^5$	< 1	$< 10^3$	0.01-0.1
Blitz- lampen	300-800	300-10000	$10^2 - 10^4$	< 5000	1-100	0.1-200
Ar ⁺ Laser Kr ⁺ Laser	400-1100	cw	cw	-	cw	0.1-5
Nd:YAG- Laser $\lambda/2: 530\text{nm}$ $\lambda/3: 355\text{nm}$	400-920	10-20	$10^5 - 10^7$	10-100	10-30	0.1-1
Kupfer- dampf- laser	530-890	30-50	$\approx 10^4 - 10^5$	$\sim 1\text{mJ}$	$\leq 10^4$	≤ 10

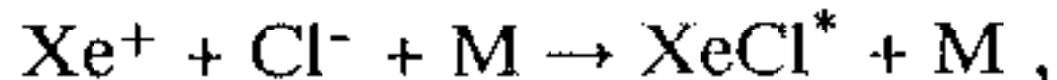
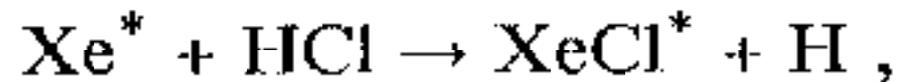
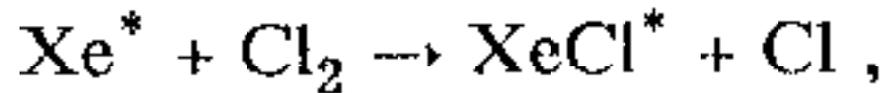
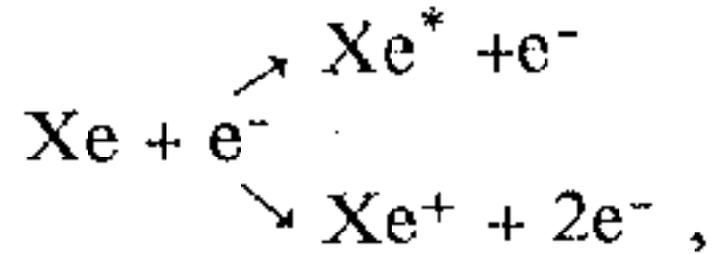
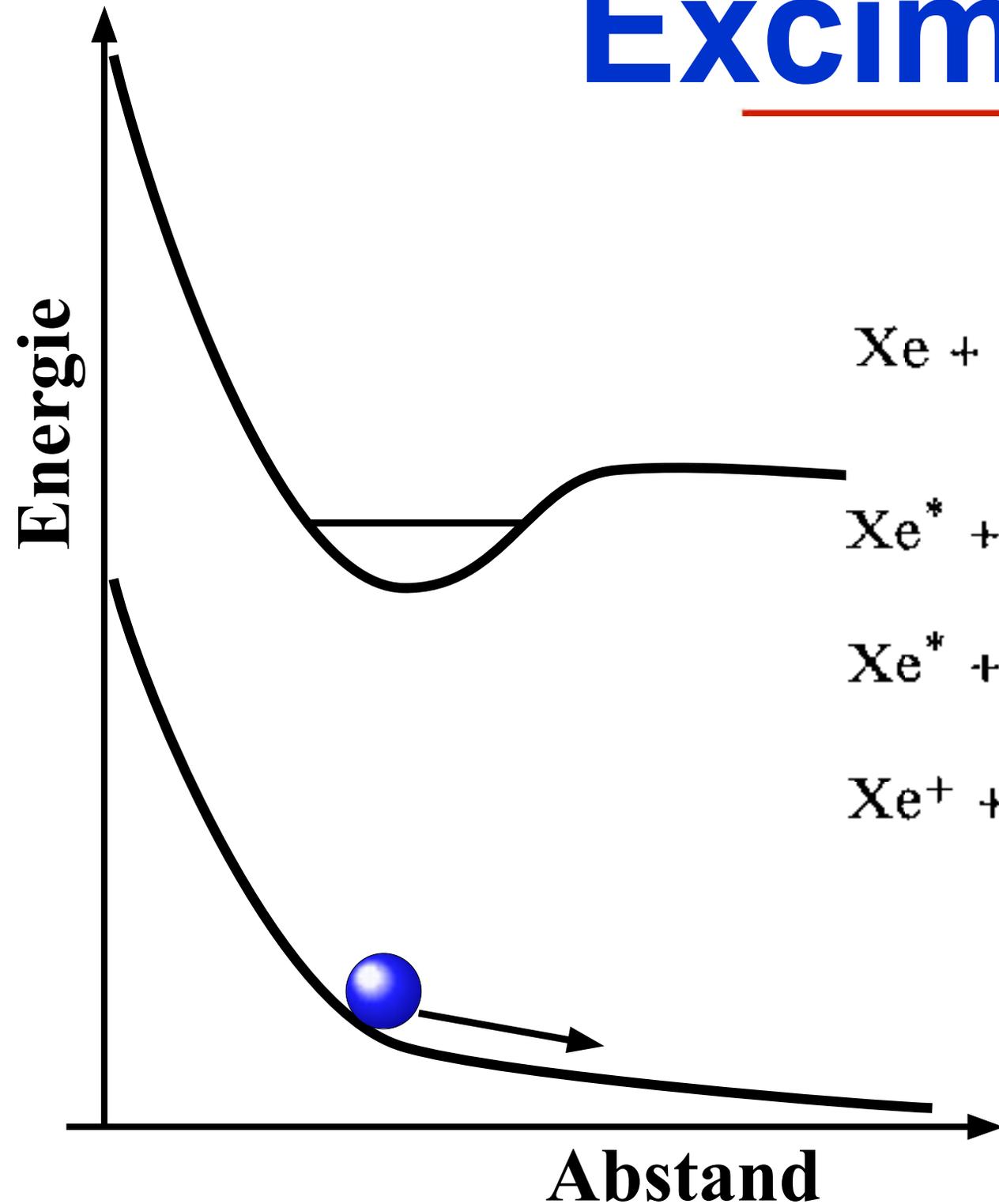
CO₂-Laser



Niveauschema



Excimer-Laser



Excimer-Laser

Charakteristische Daten einiger Excimerlaser

Lasermedium	F ₂	ArF	KrCl	KrF	XeCl	XeF
Wellenlänge [nm]	157	193	222	248	308	357
Pulsenergie [mJ]	15	≤500	≤60	≤1000	≤500	200

Pulsbreiten: 10-200 ns

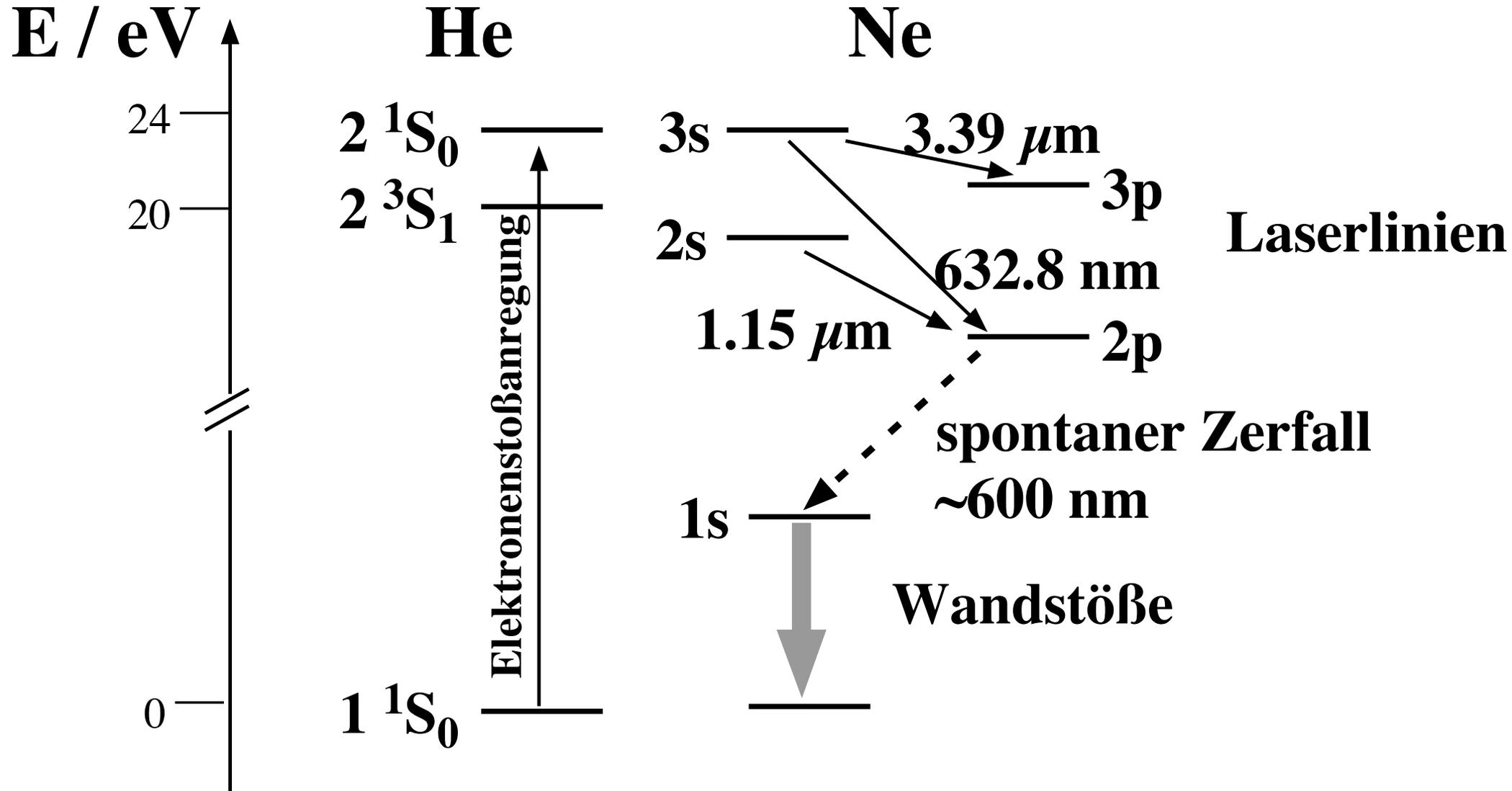
Repetition: 1-200 Hz, je nach Ausstattung

Strahldivergenz: 1x3 mrad

Schwankung der Pulsenergie von Puls zu Puls : ca. 3-10 %

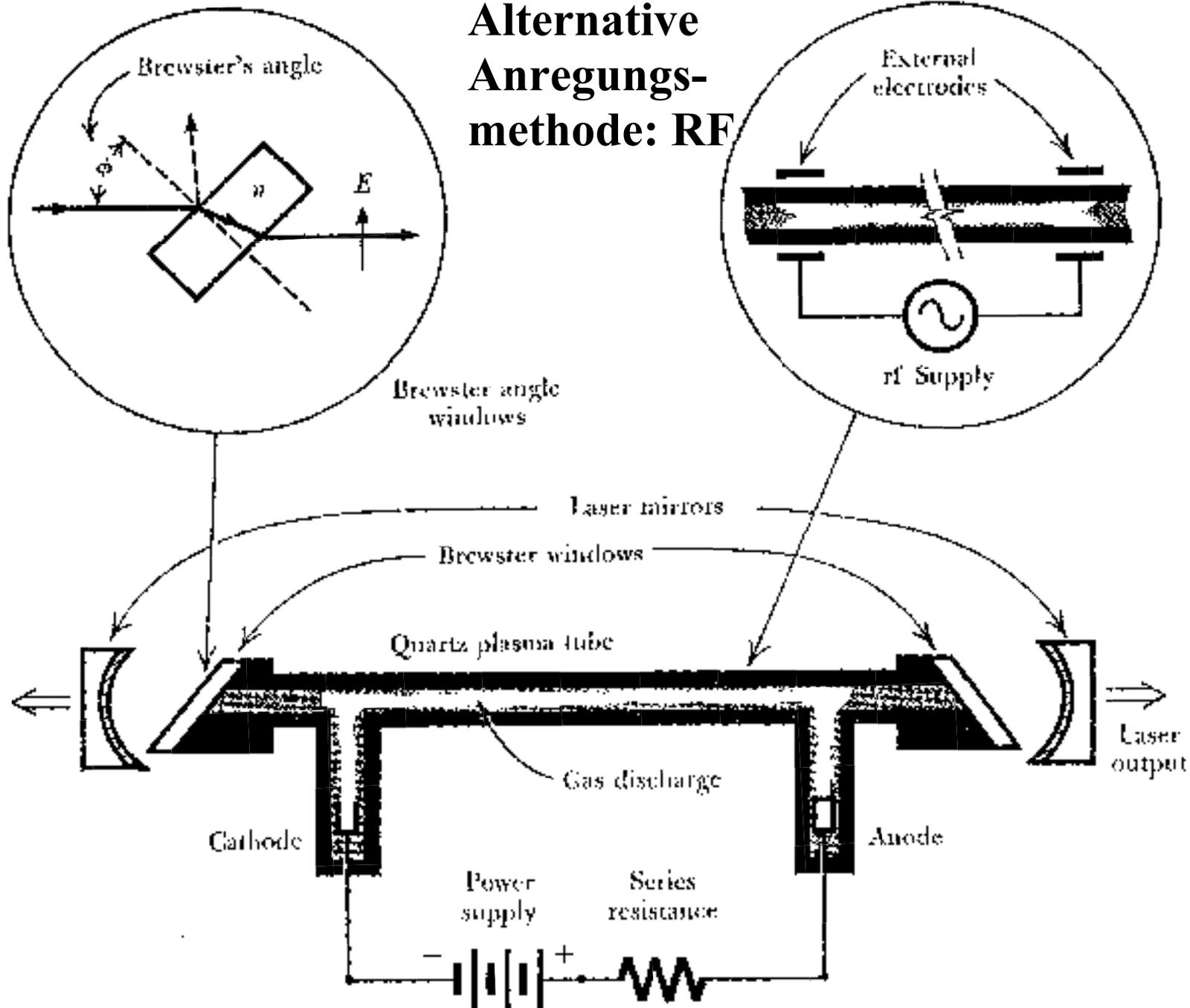
Zeitjitter: ~1-3 ns

HeNe-Laser

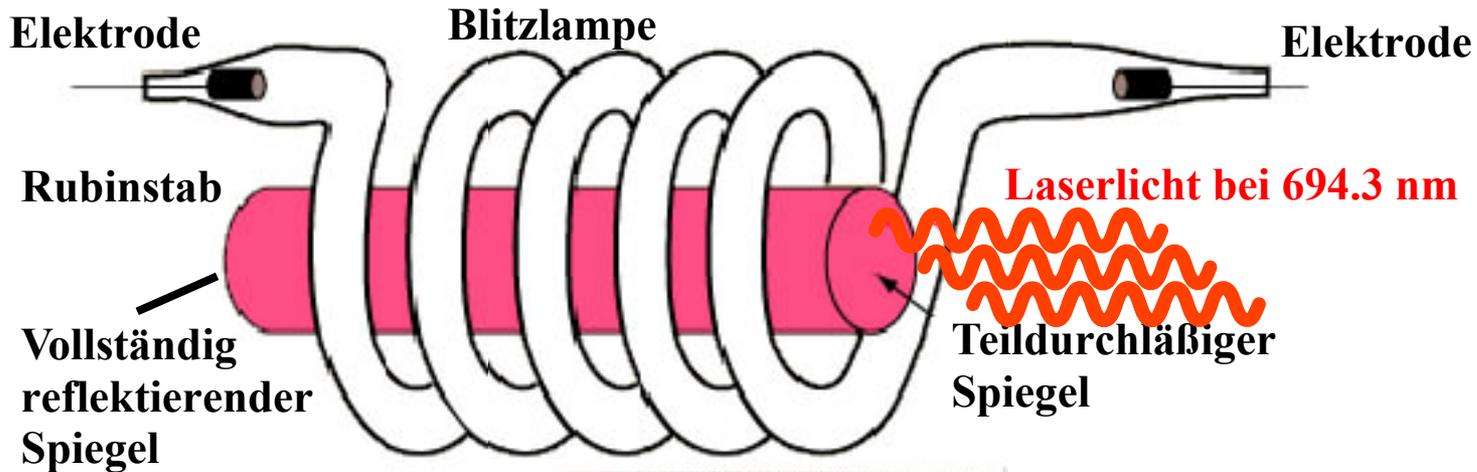


HeNe-Laser

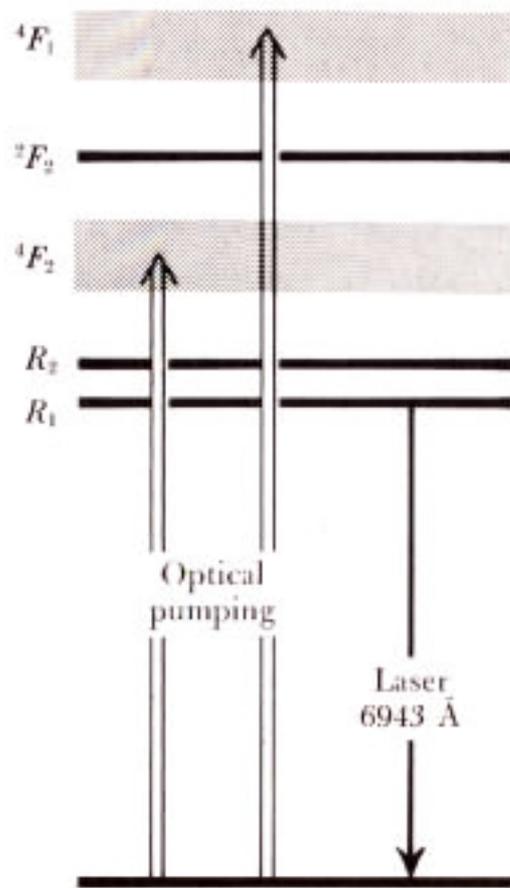
Alternative
Anregungs-
methode: RF



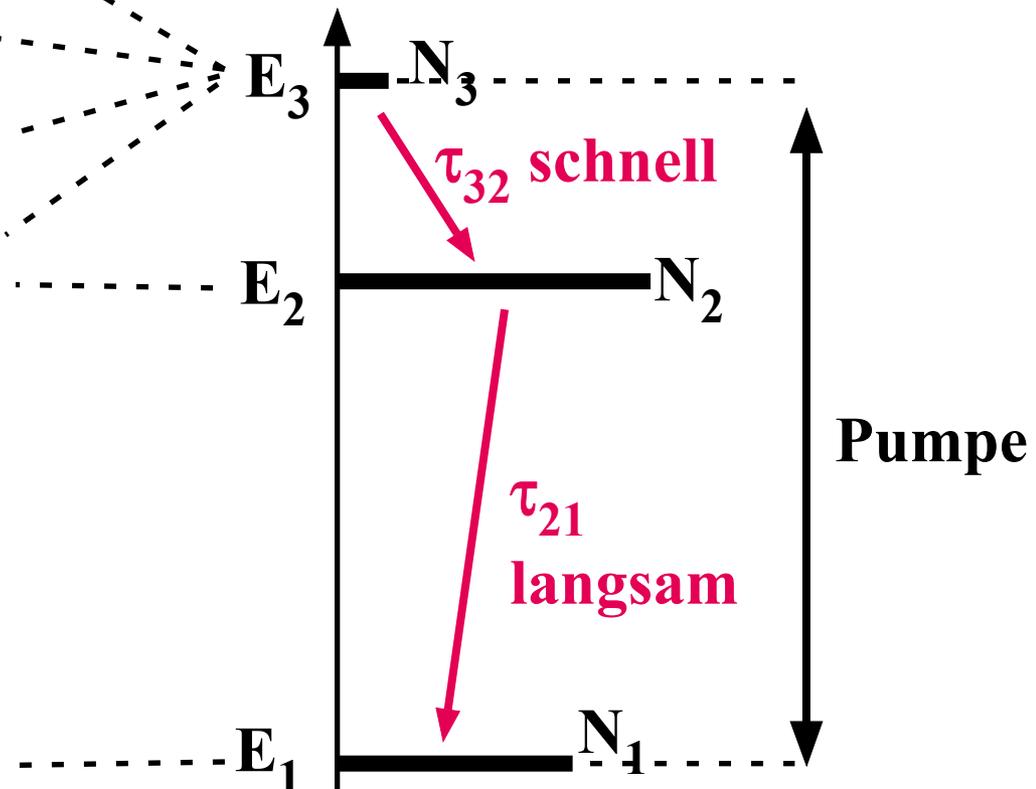
Rubinlaser



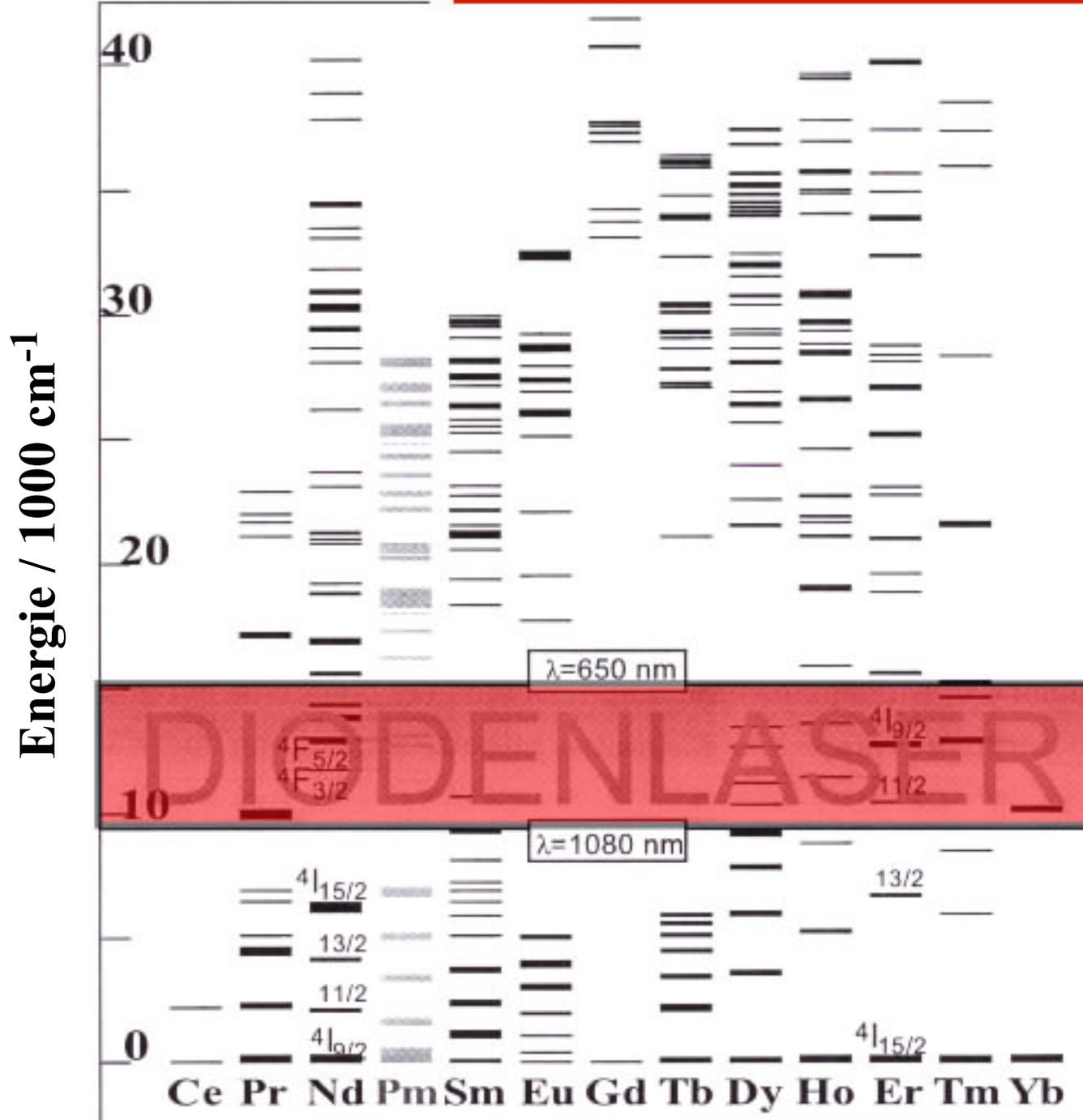
Niveauschema



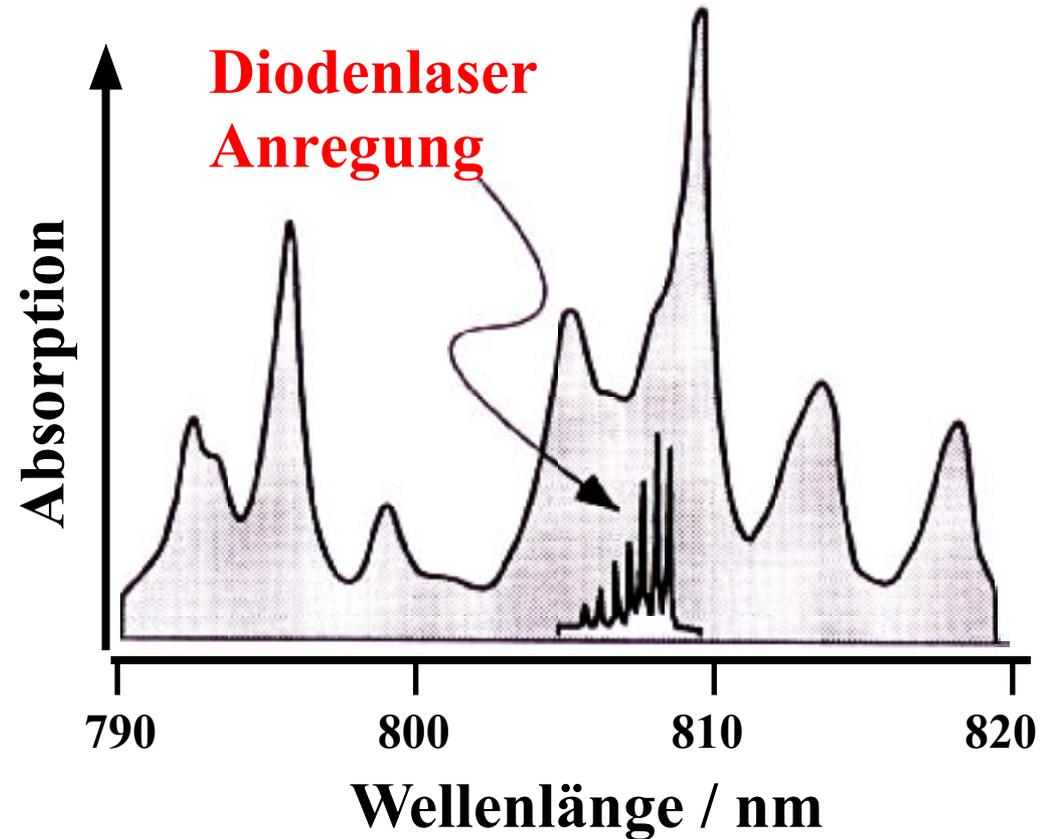
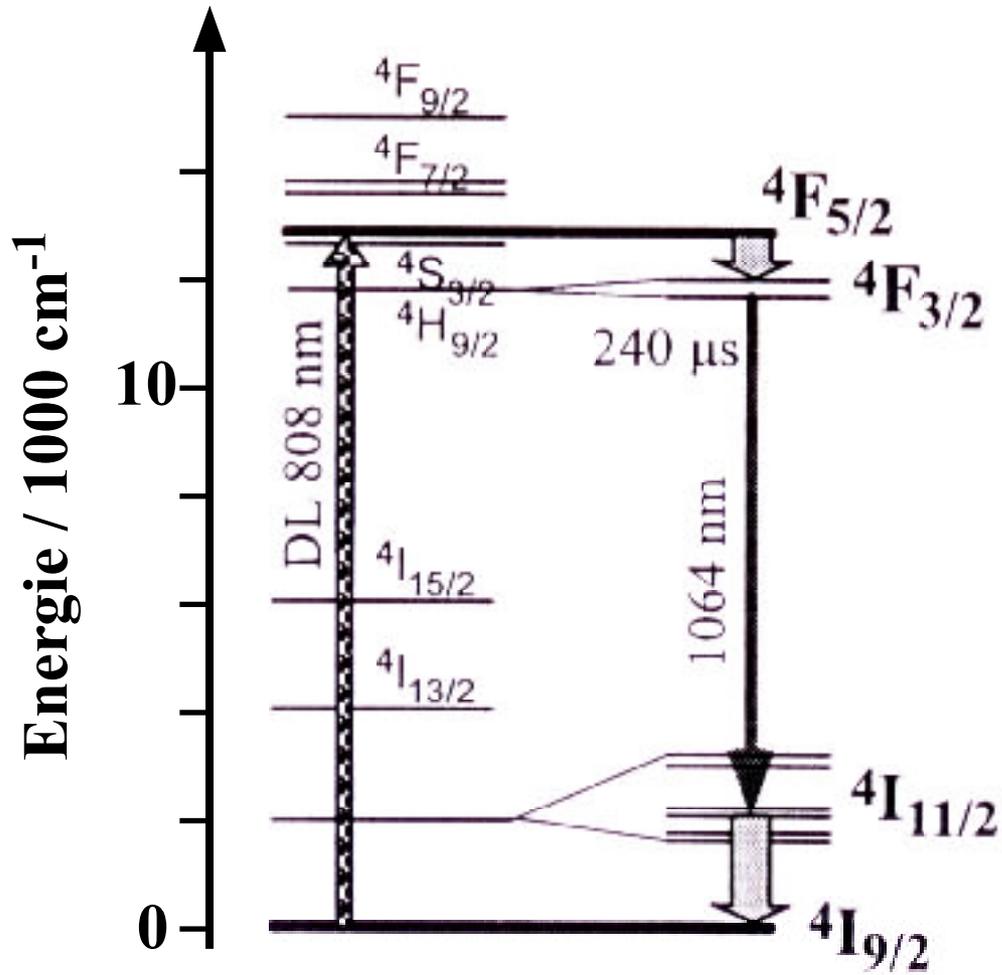
Vereinfachtes Niveauschema



Seltene Erden

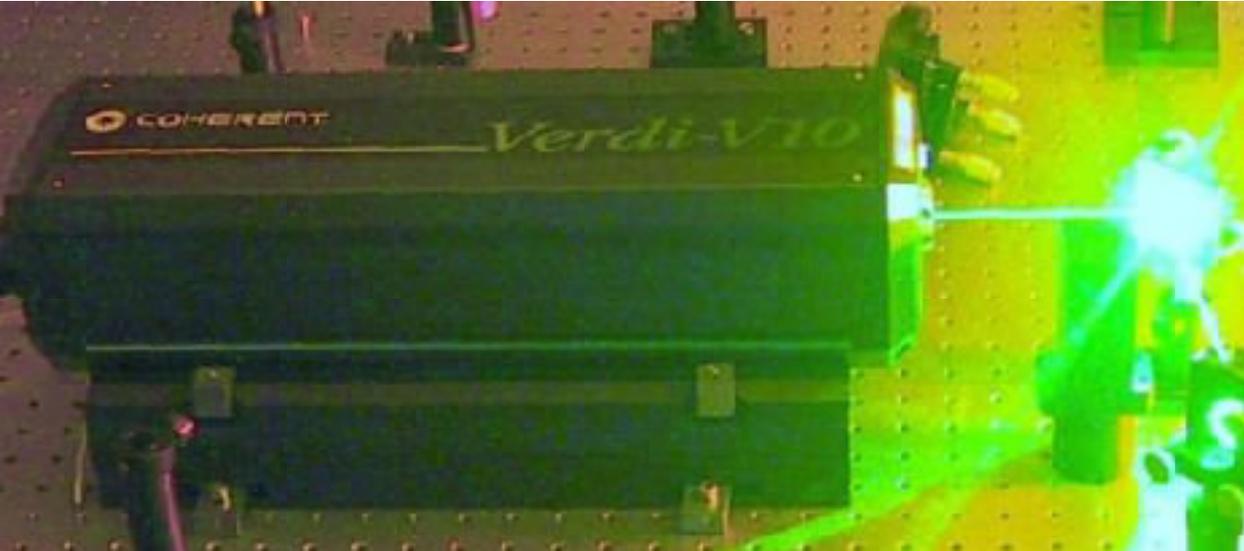
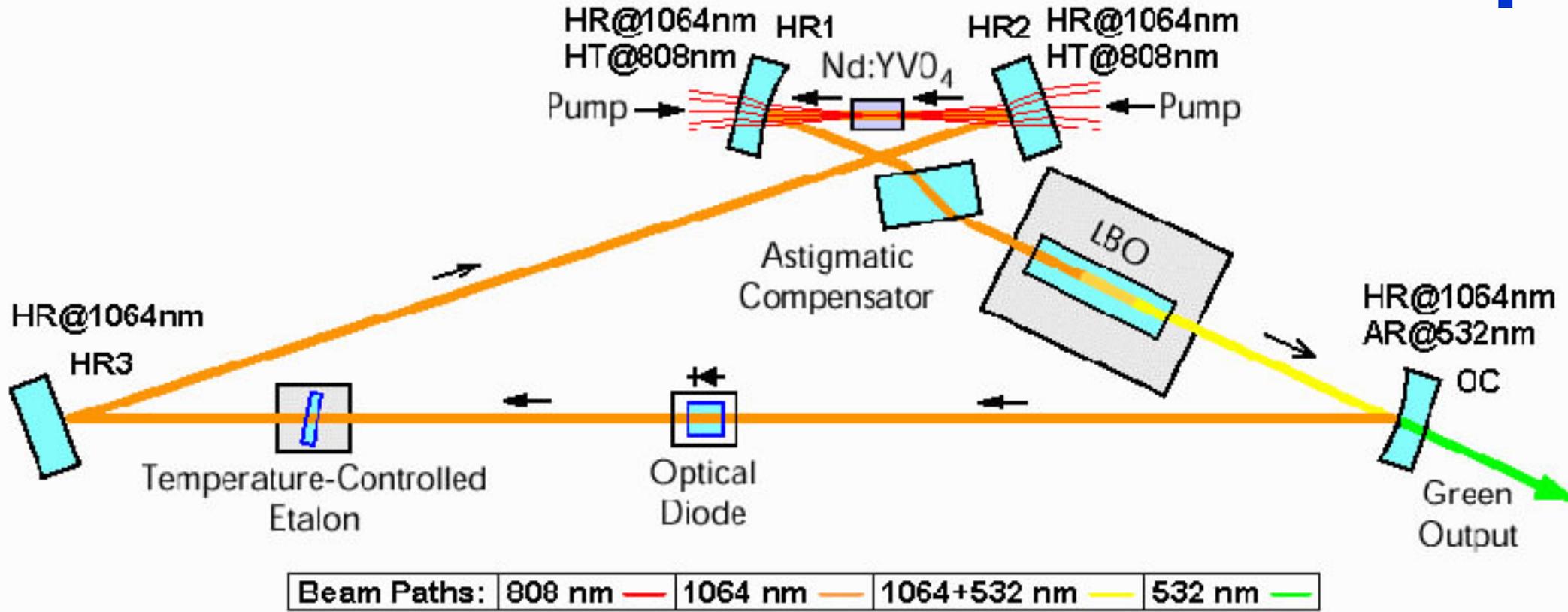


Nd:YAG



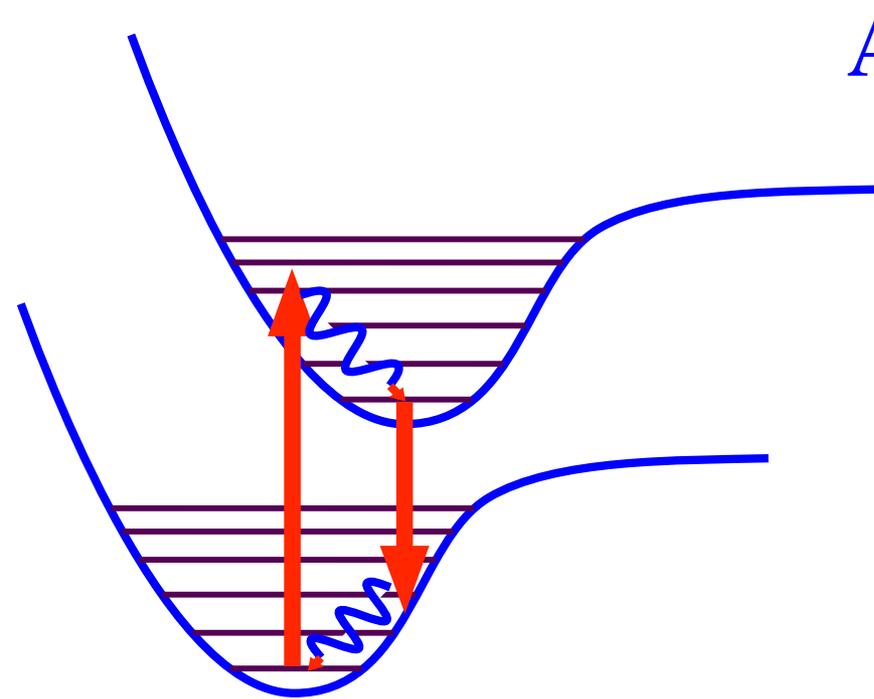
Frequenzverdoppelter Festkörperlaser

Nd:YVO₄

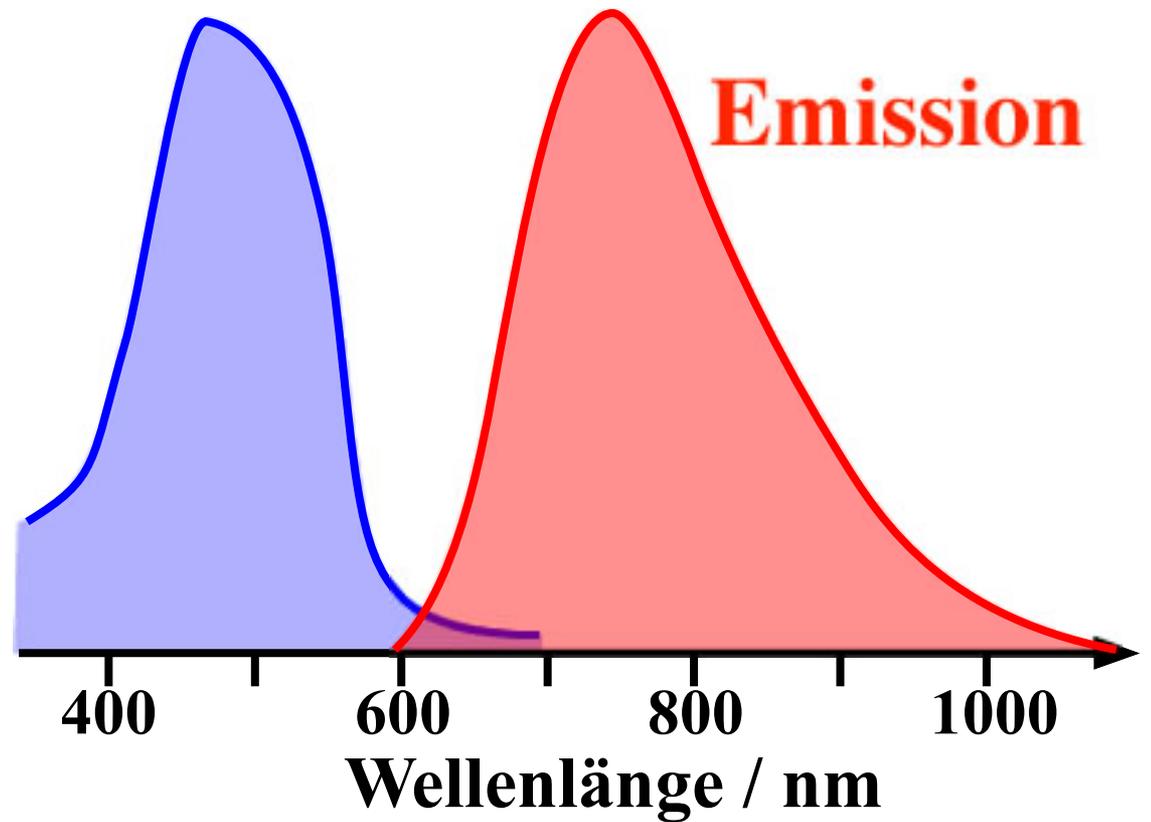


TiSa-Laser

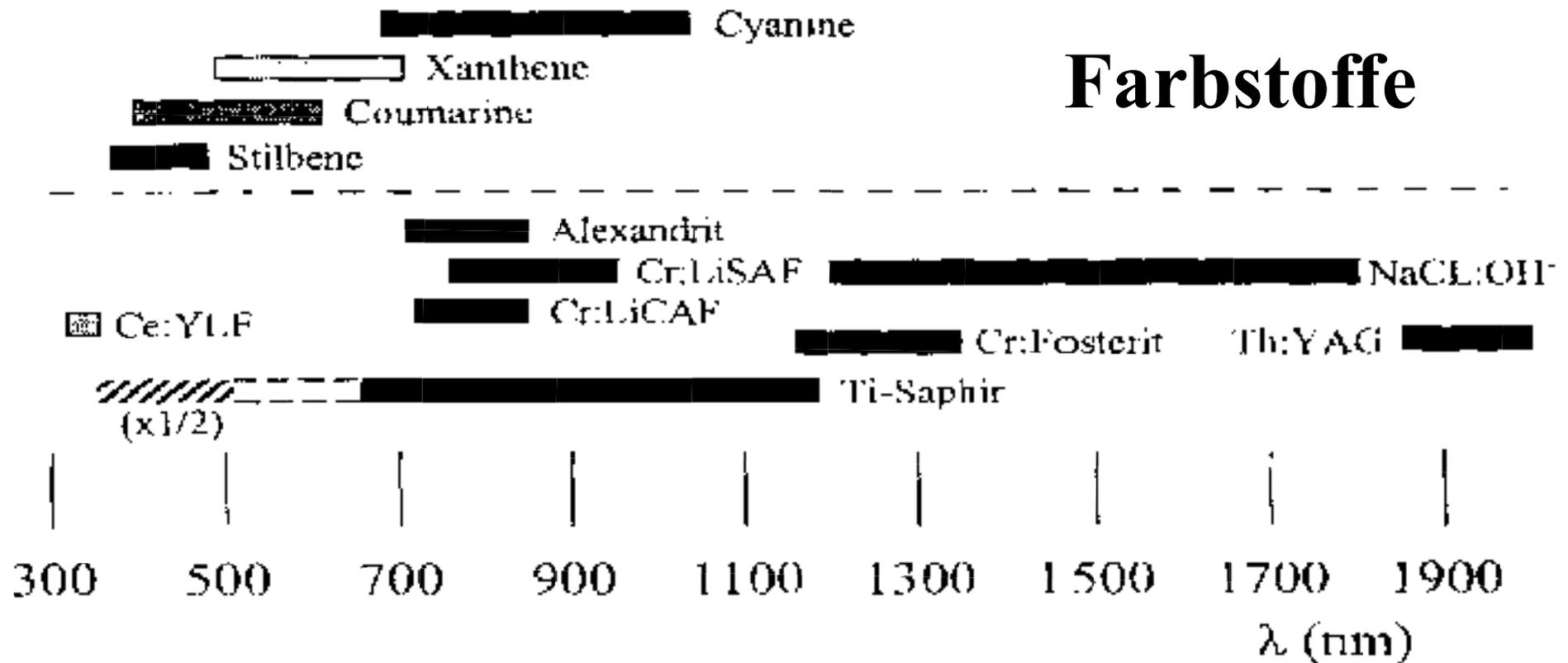
Vibronische Verbreiterung



Absorption

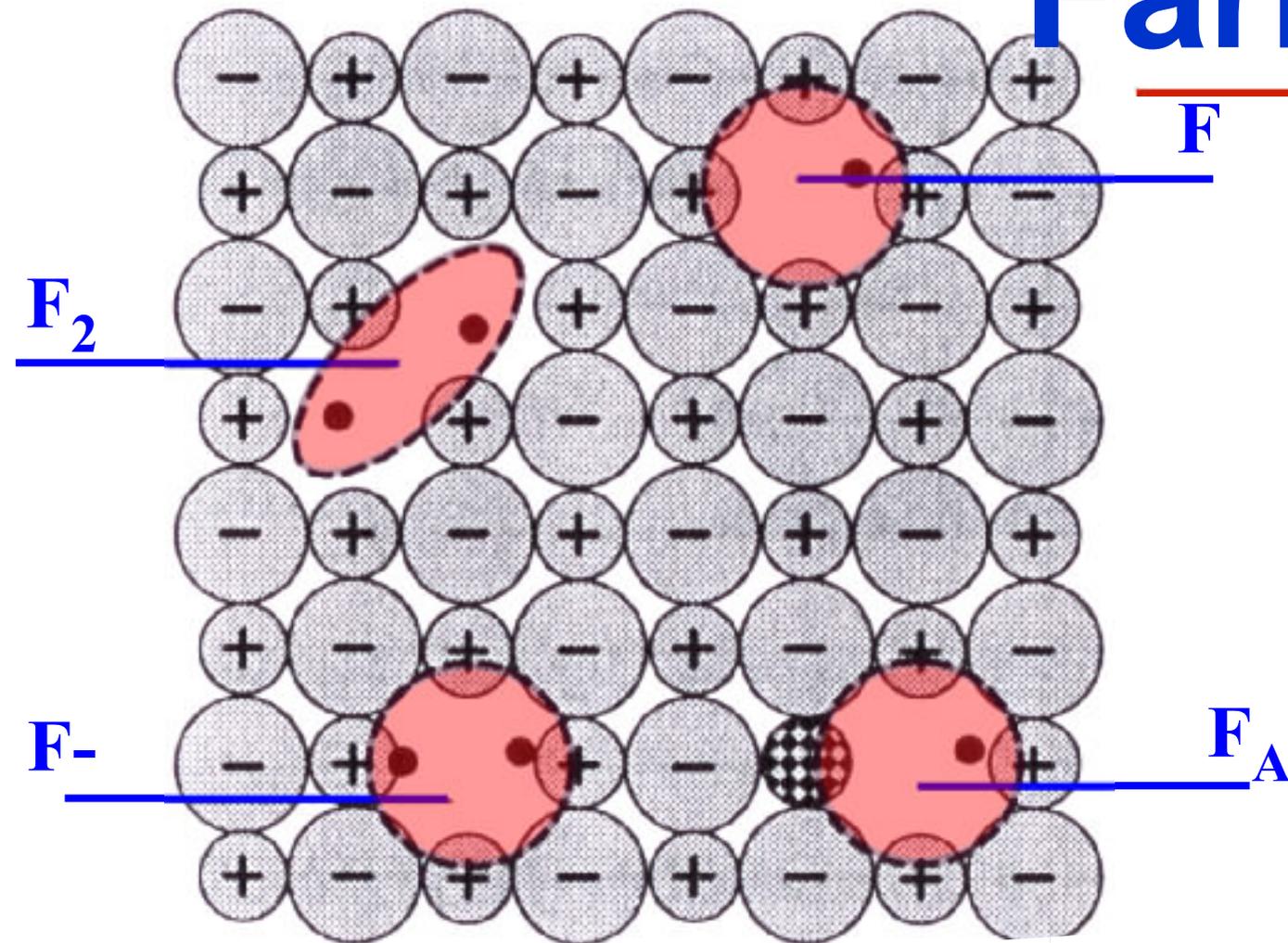


Verstärkungsbandbreiten



Laser-medium	Formel	Abstimmbereich [nm]	Betriebs temperatur	Pumpquelle
Ti:Saphir	$Al_2O_3:Ti^{3+}$	660-986	RT	Ar±Laser
Alexandrit	$BeAl_2O_4:Cr^{3+}$	710-820	22-300°C	Blitzlampe
		720-842	RT	Kr±Laser
	$SrAlF_6:Cr^{3+}$	825-1010	RT	Kr±Laser
	$KzrF_3:Co^{2+}$	1650-2070	77K	cw Nd:Y Laser

Farbzentren

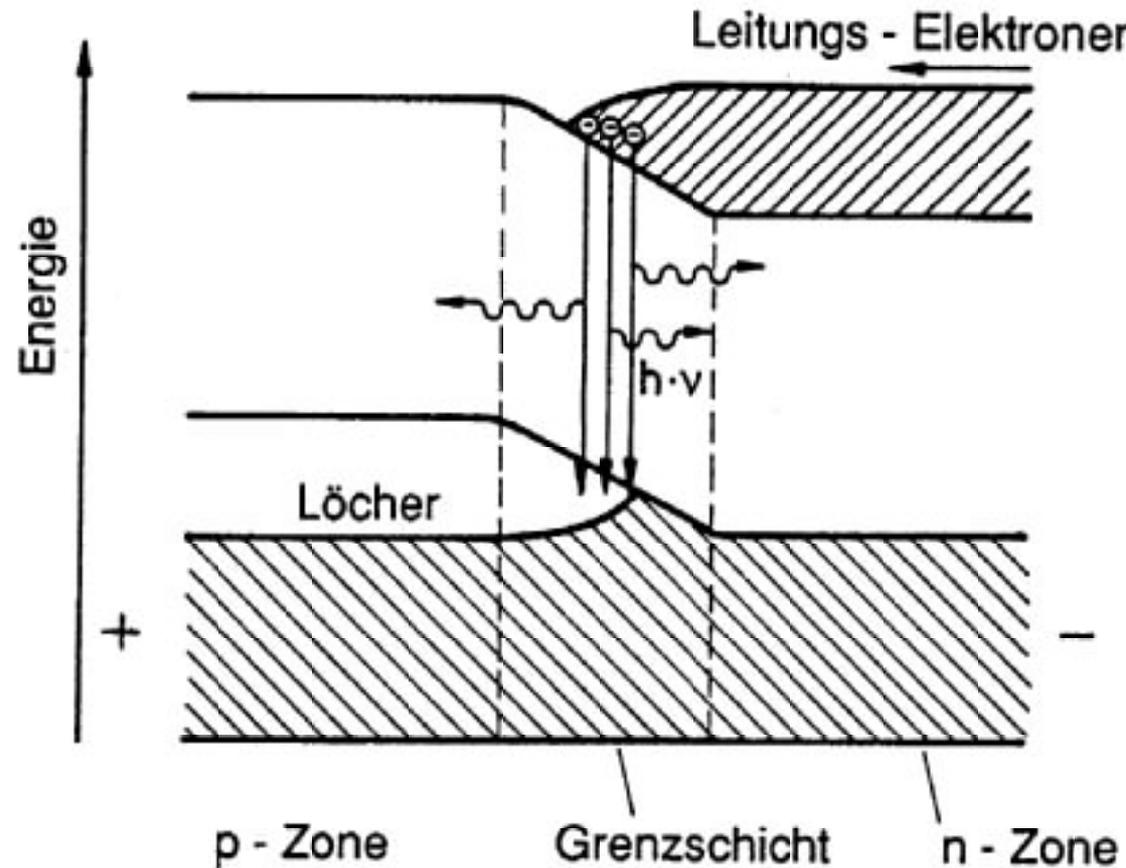
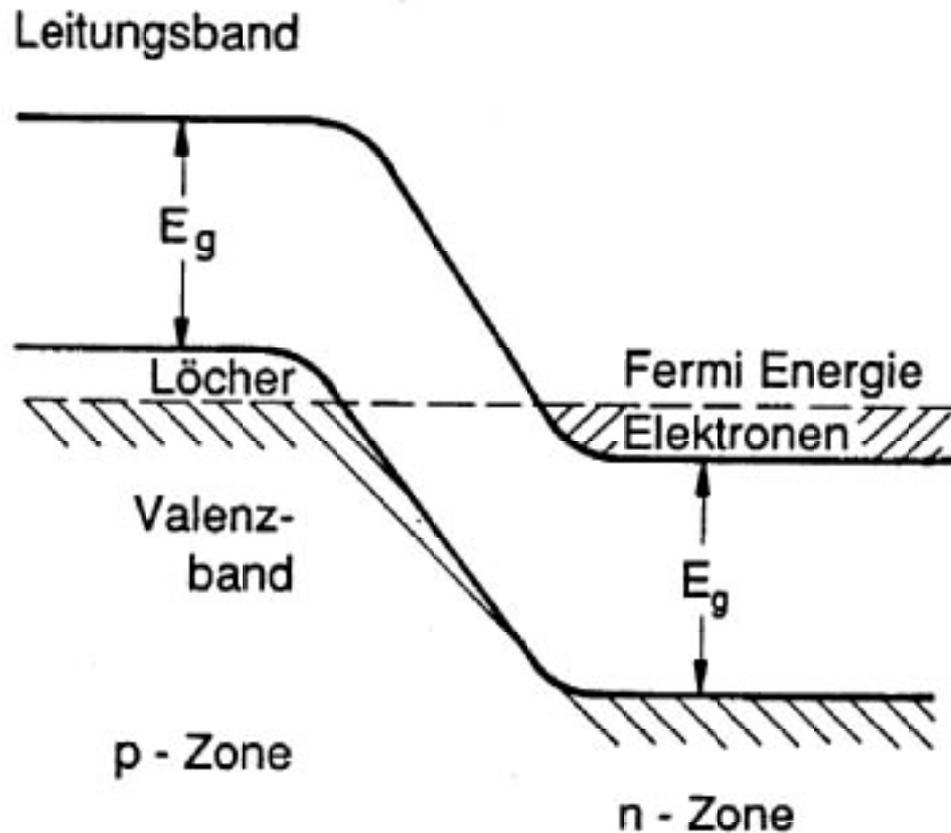


F_2^+	F ⁻ -zentren	NaCl/OH ⁻	1400-1750	77K	cw Nd:YAG-Laser
F_A II	"	RbCl:Li	2,6 - 3,3 μm	77K	Kr ⁺ -Laser
F_2^+ A	"	KI:Li	2,38-3,99 μm	77K	Er:YLF-Laser
F_3^+	"	LiF	500-640nm	77K	Farbstofflaser

Halbleiterlaser

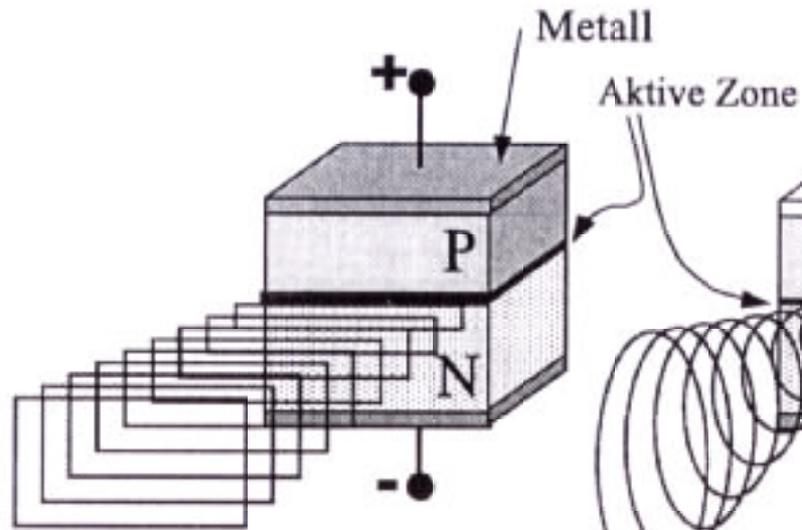
Strom in Durchlassrichtung

ohne äußere Spannung

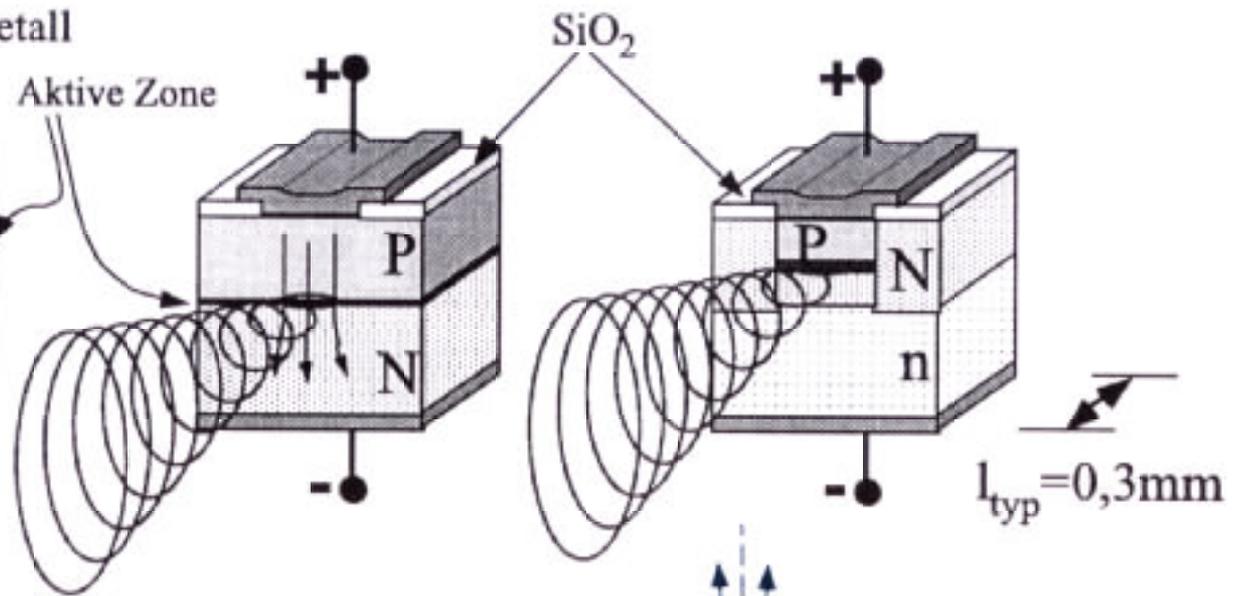


Laserdioden

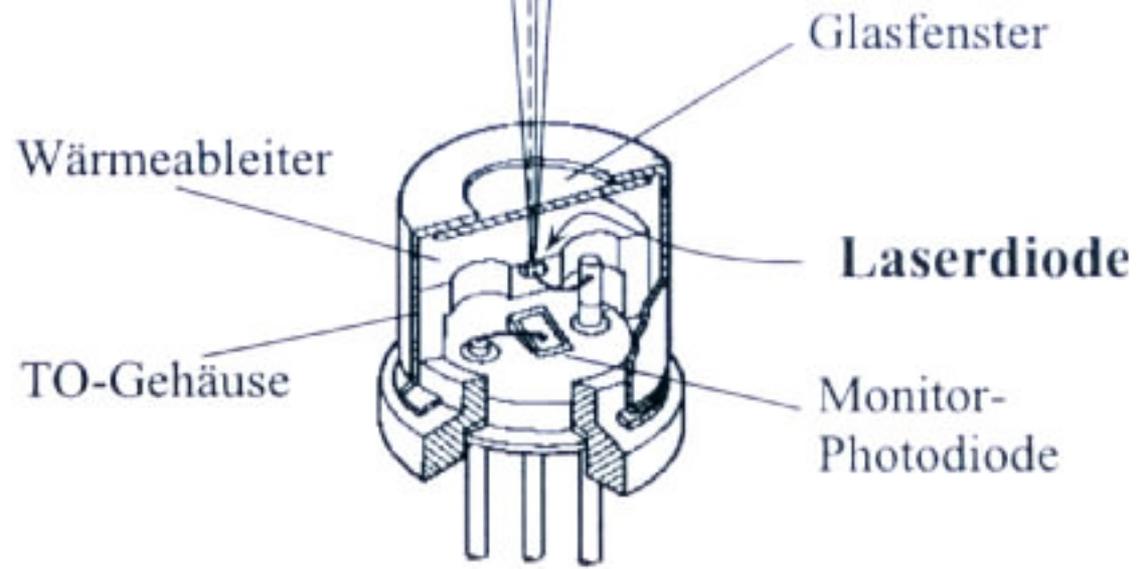
Einfache Diodenstruktur



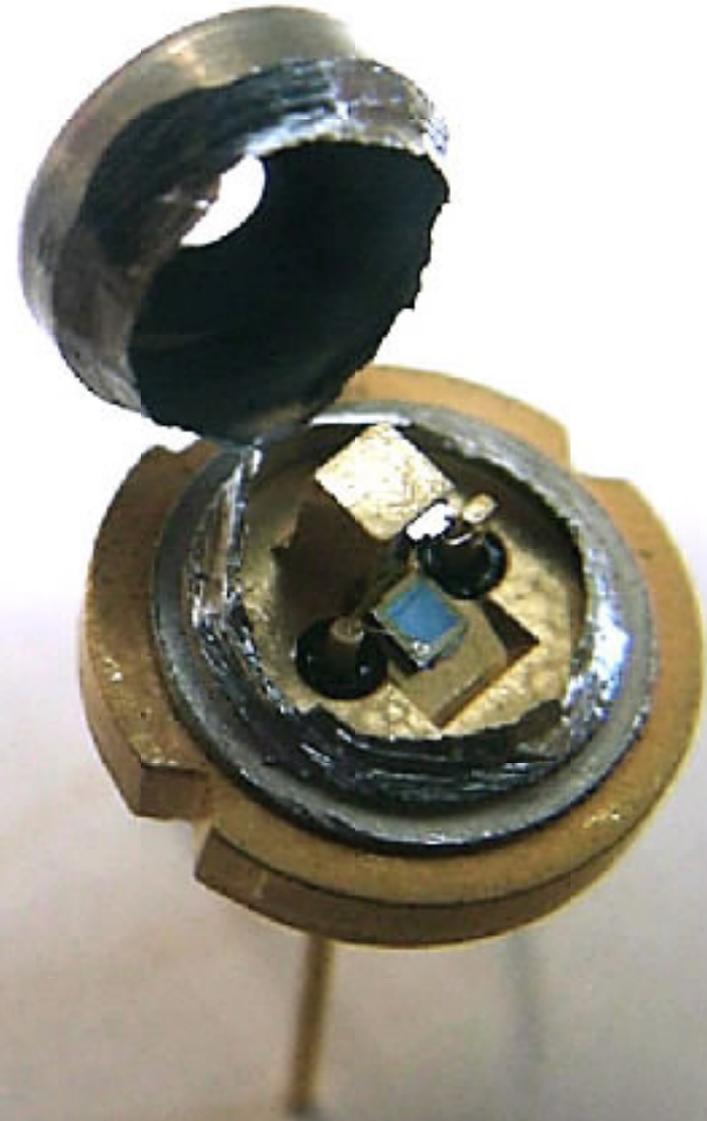
Heterostrukturen



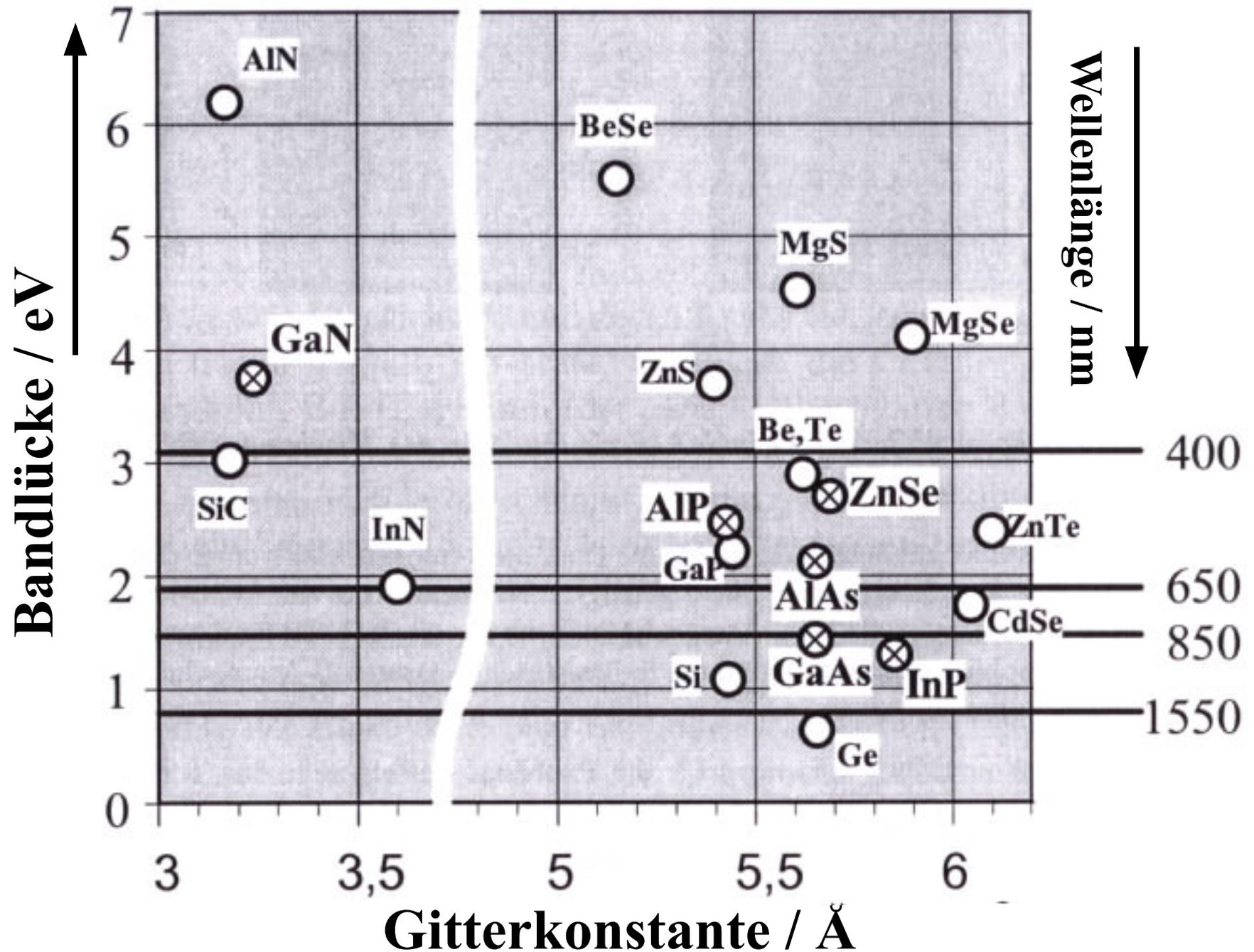
Laserdiode im Gehäuse



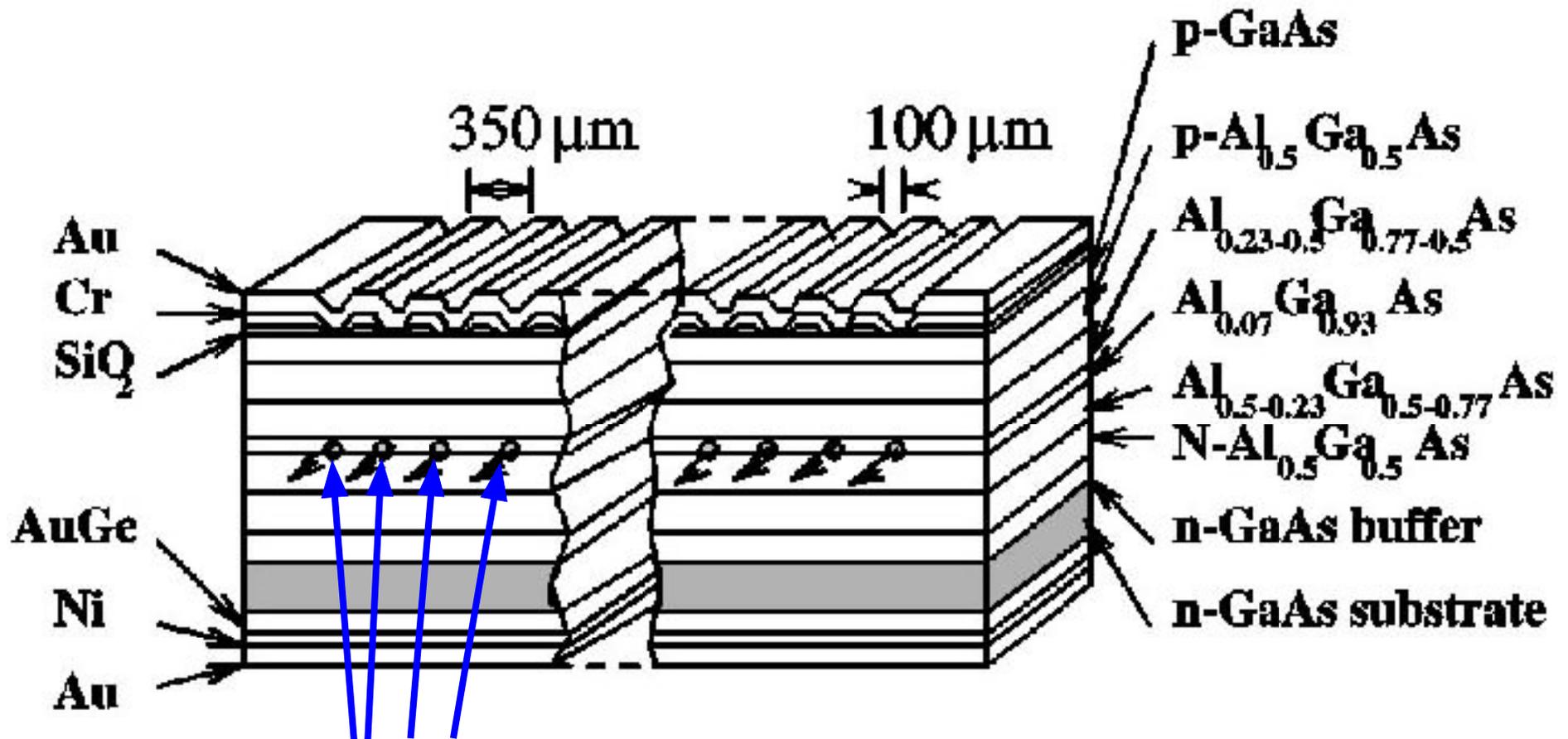
Laserdioden



Halbleiterlaser

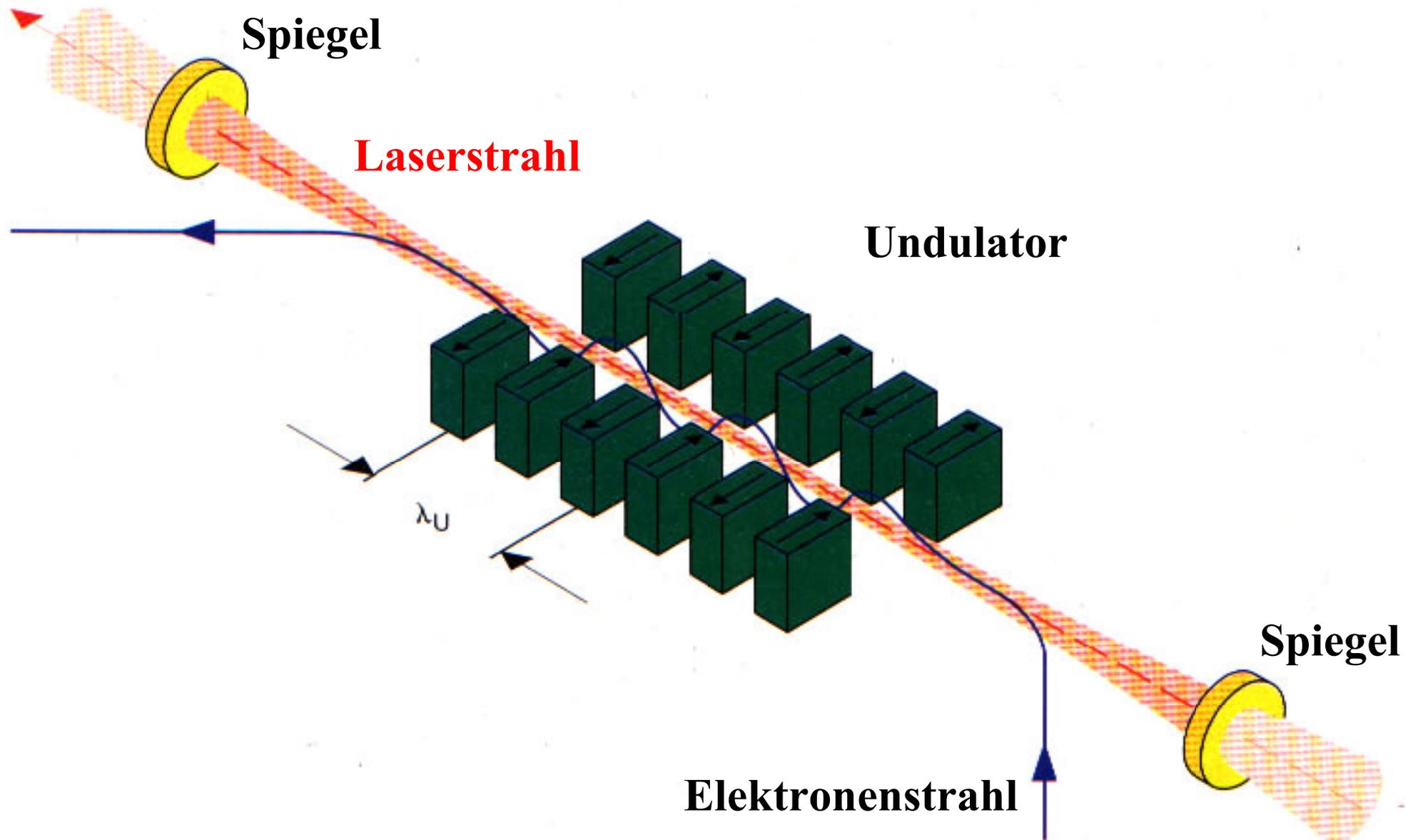


Laserdioden Arrays



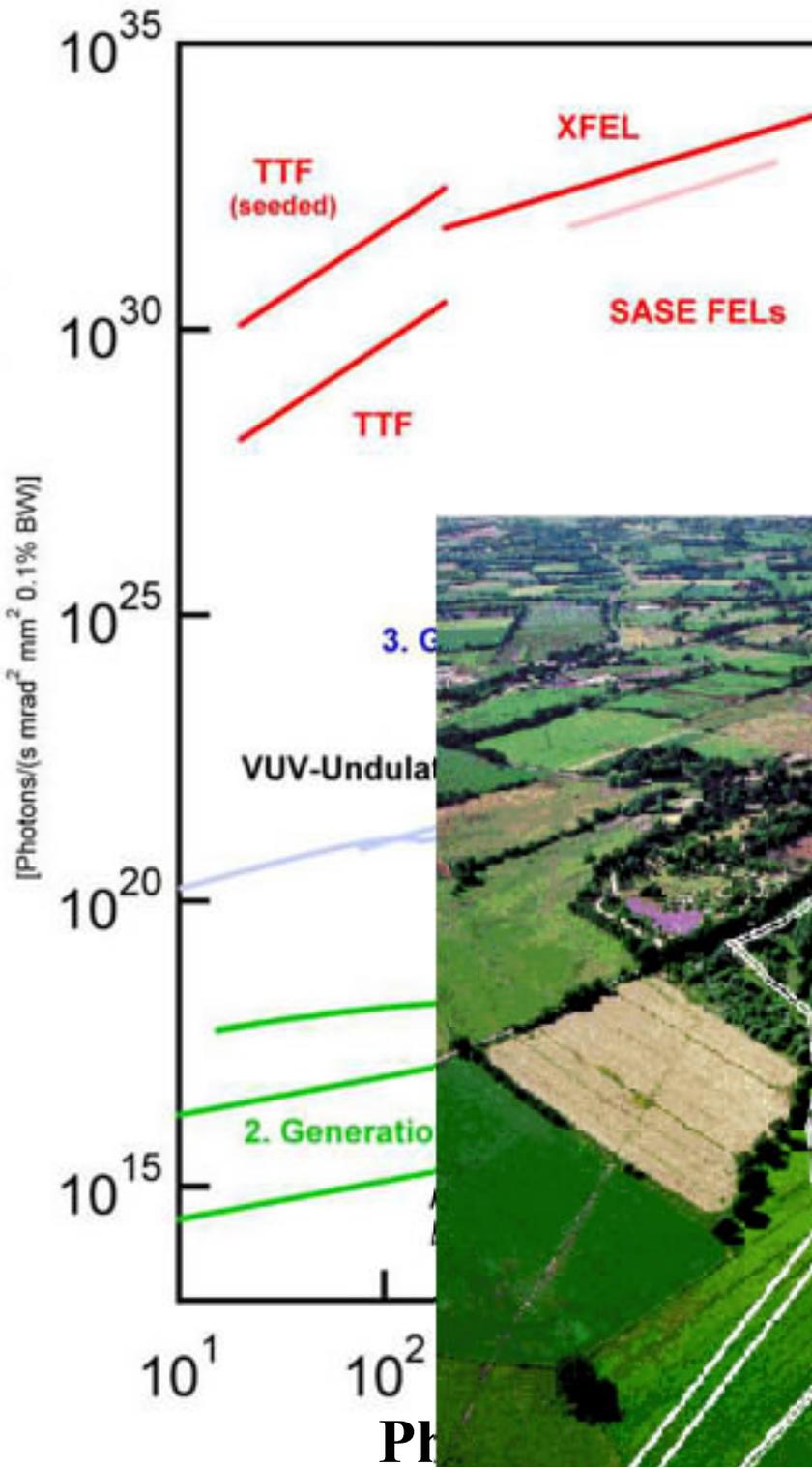
Einzelne Dioden

Freie Elektronen Laser



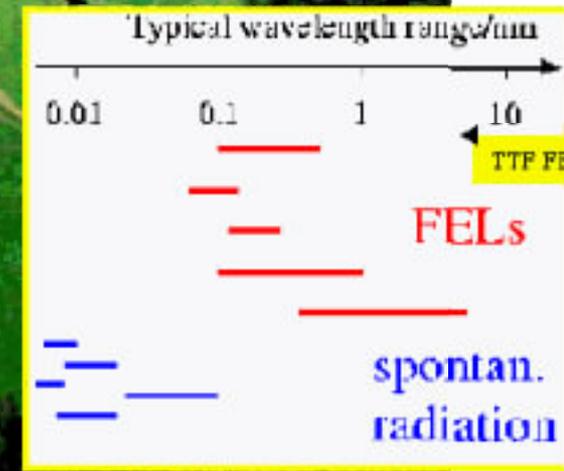
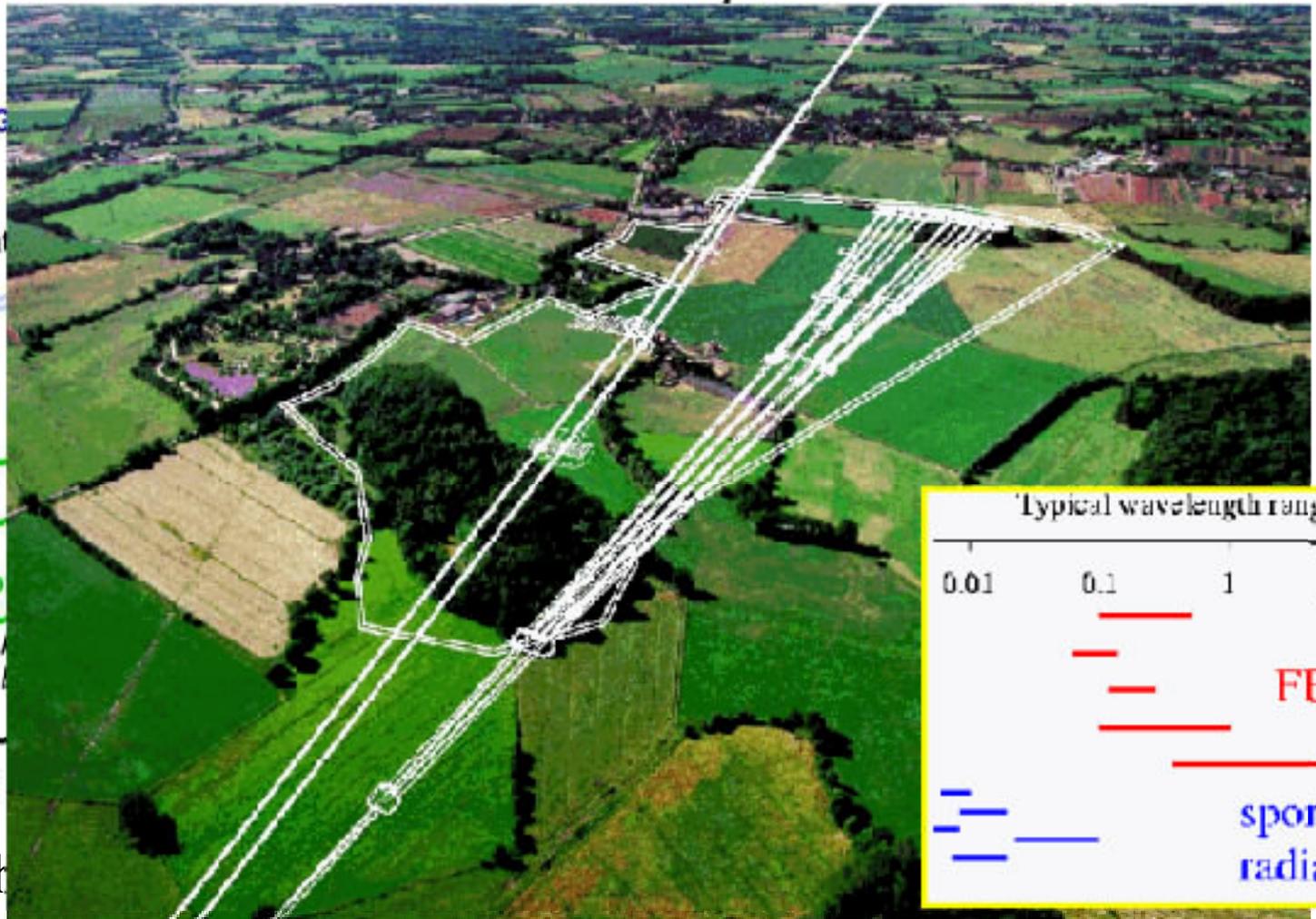
SASE FEL

Brillanz (Spitzenleistung)

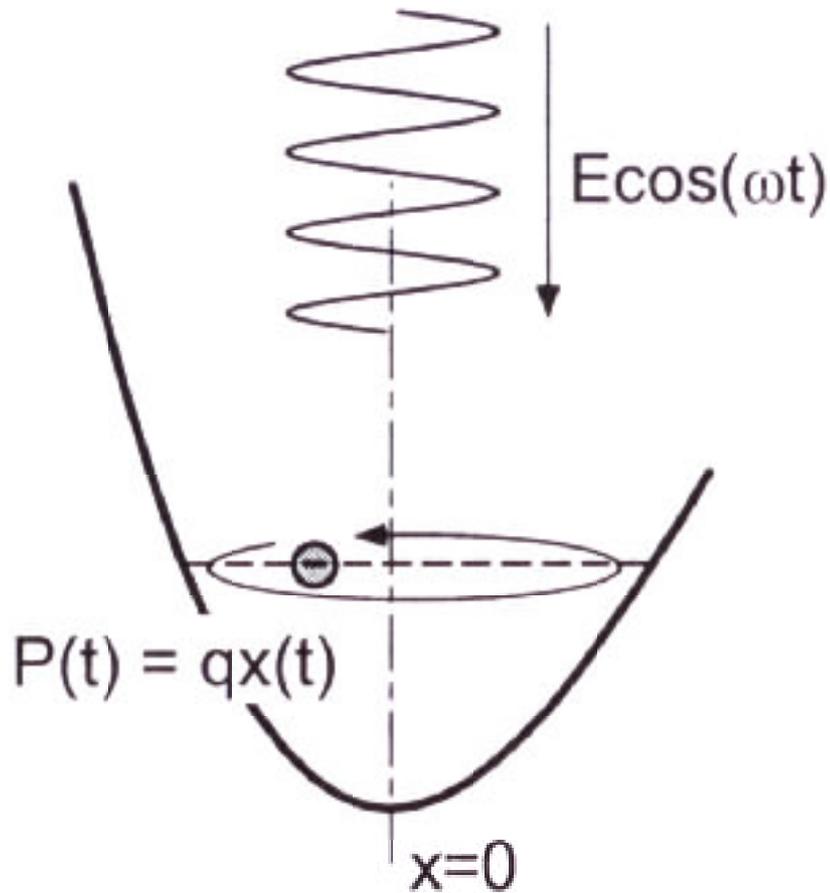


Projektierte Leistung

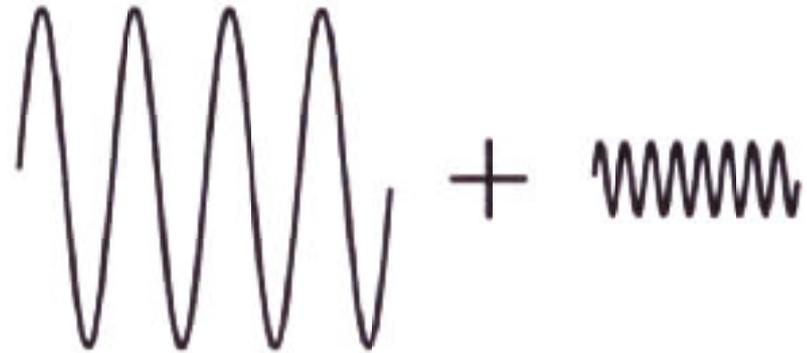
Geplanter XFEL bei Hamburg (DESY)



Nichtlineare Optik



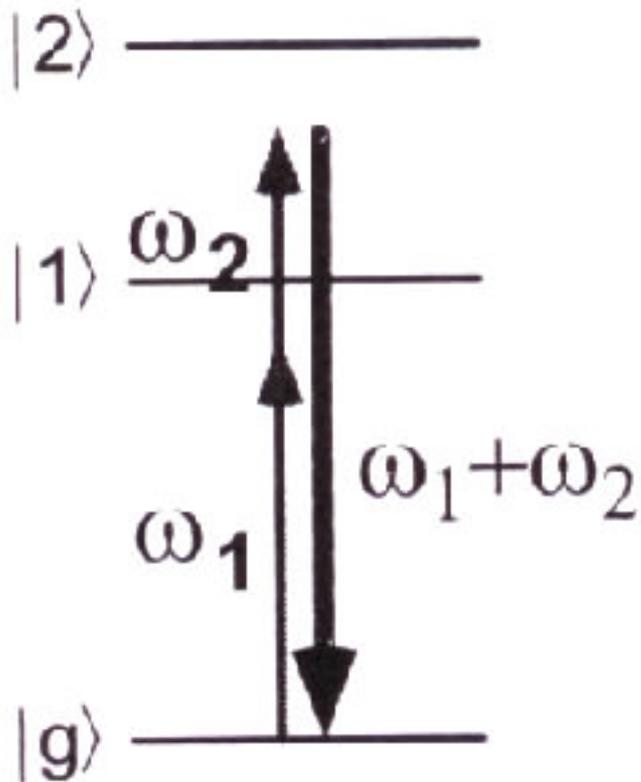
$$P(t) = P_{lin} \cos(\omega t) + P_{nl} \cos(2\omega t) + \dots$$



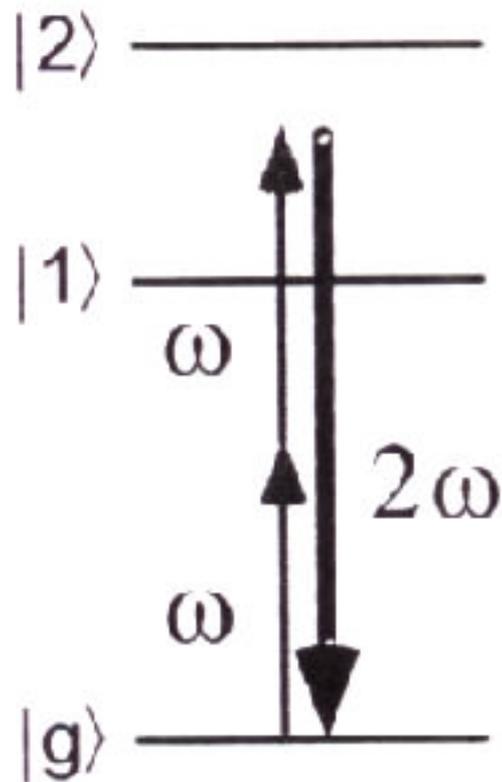
Nichtlineare Optik

3-Wellenmischung

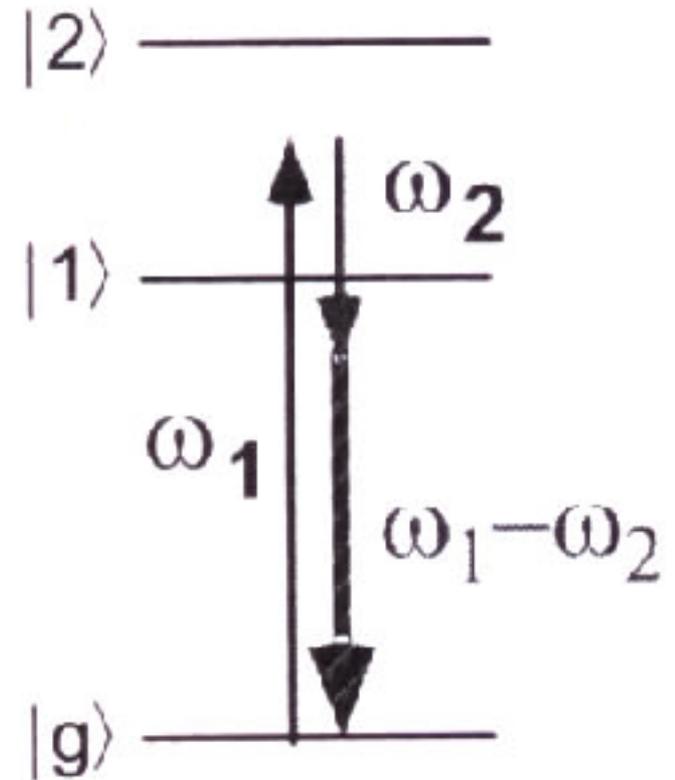
Summenfrequenz- erzeugung



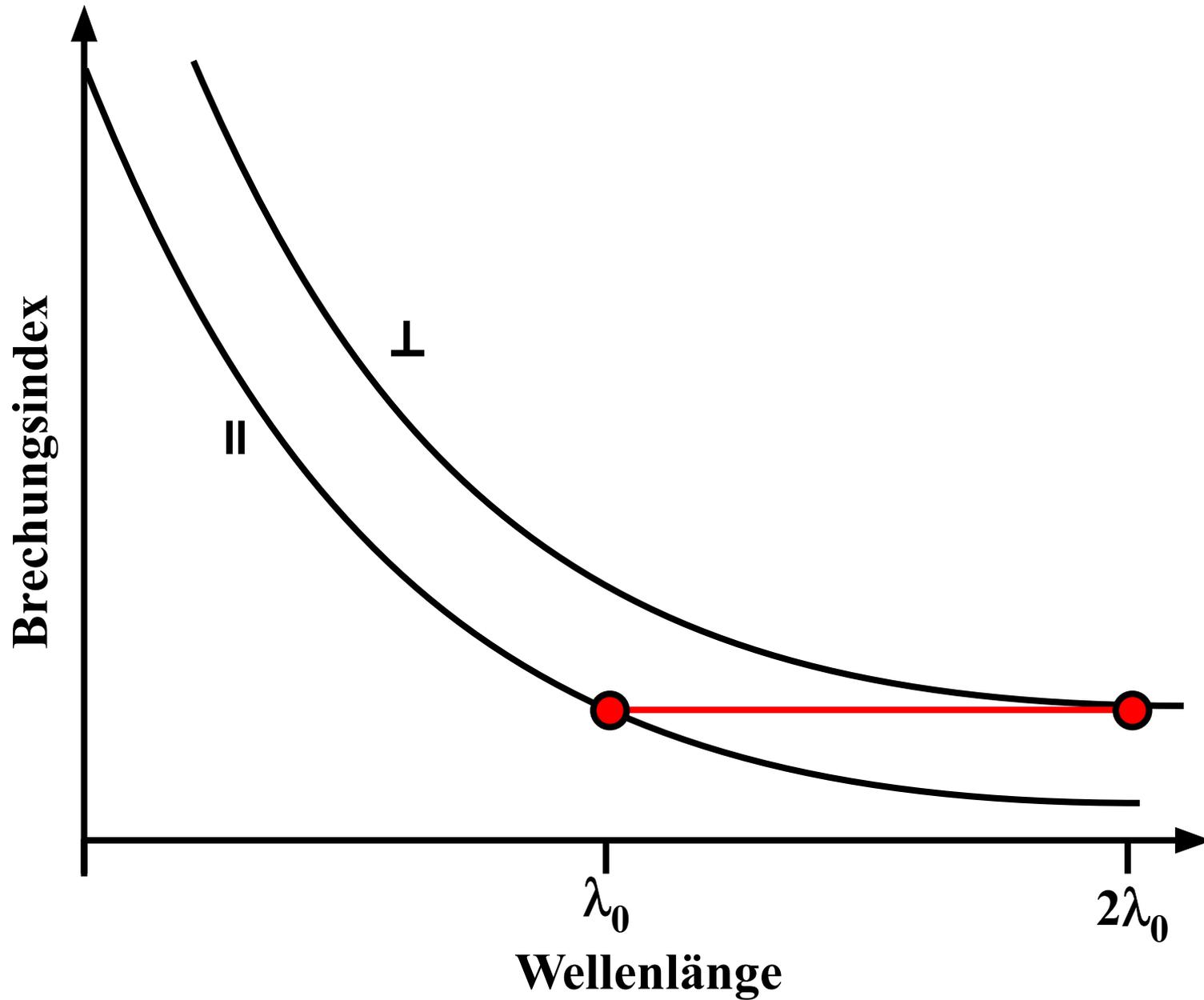
2te Harmonische



Differenzfrequenz- erzeugung

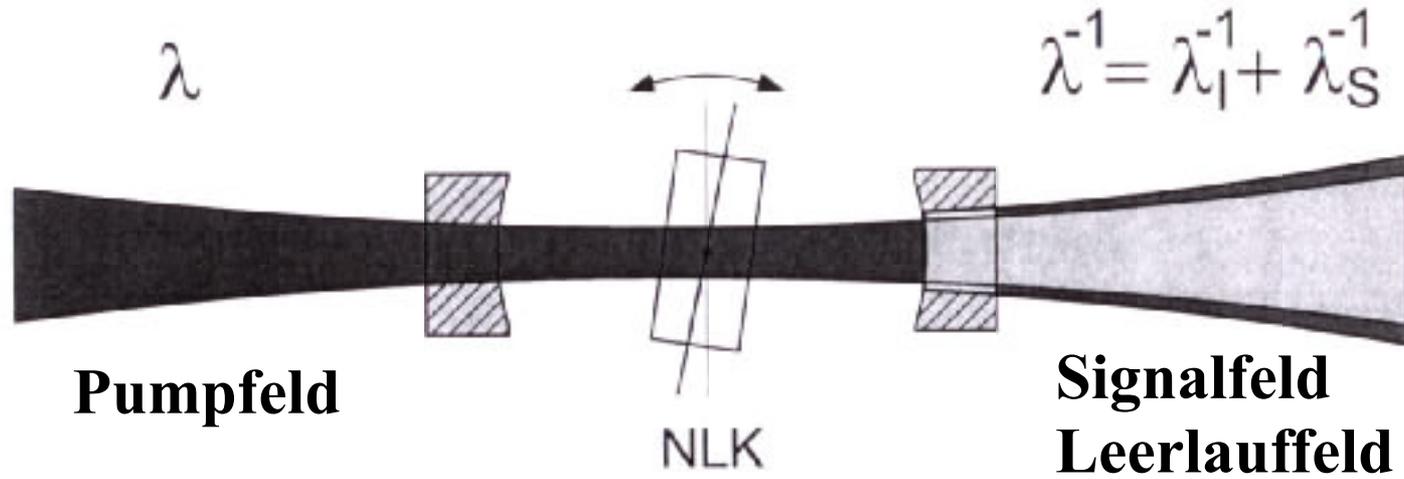


Phasen Anpassung

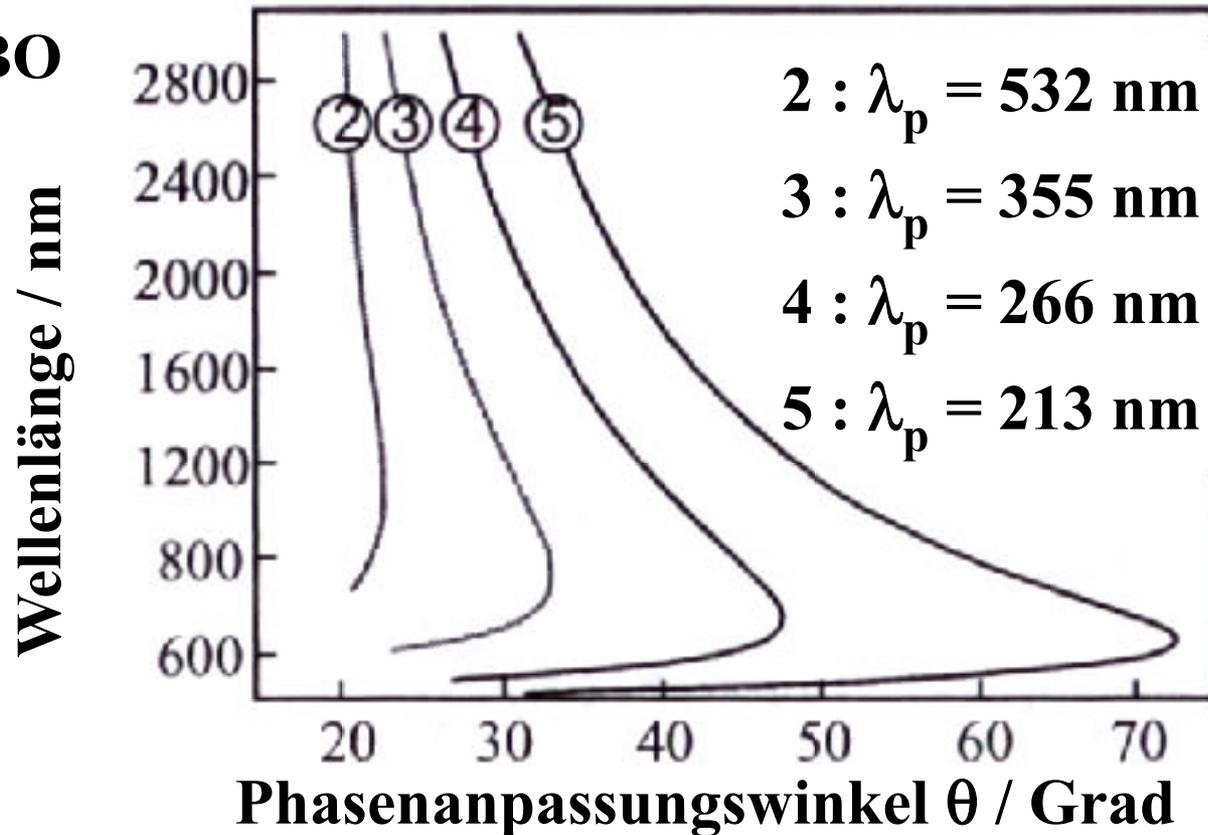


Optischer parametrischer Oszillator

Aufbau



BBO



LBO

