

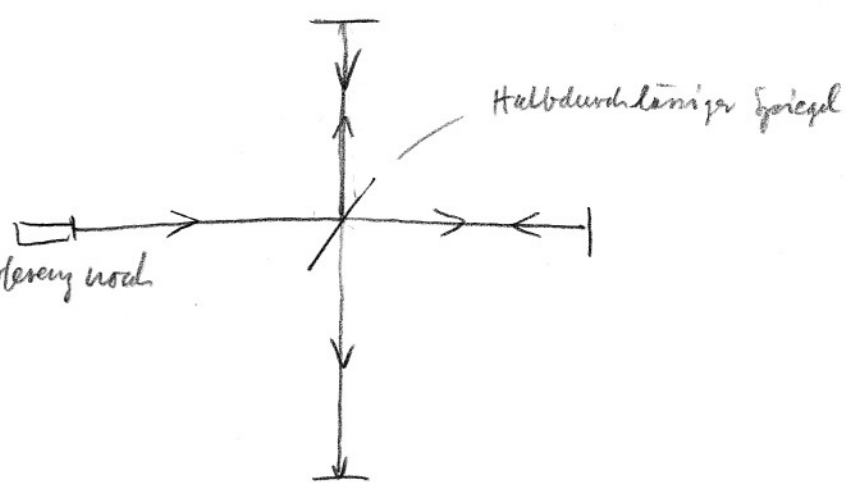
Kohärenz

thermische Quellen: inkohärent
 Laser: kohärent

$I = I_1 + I_2$ Intensitäten addieren
 Phasenunterschied 2 Quellen
 $I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos(2\pi \Delta l / \lambda + \Delta \phi)$
 Interferenz, Amplituden addieren

zeitliche Kohärenz

Michelson-Morley



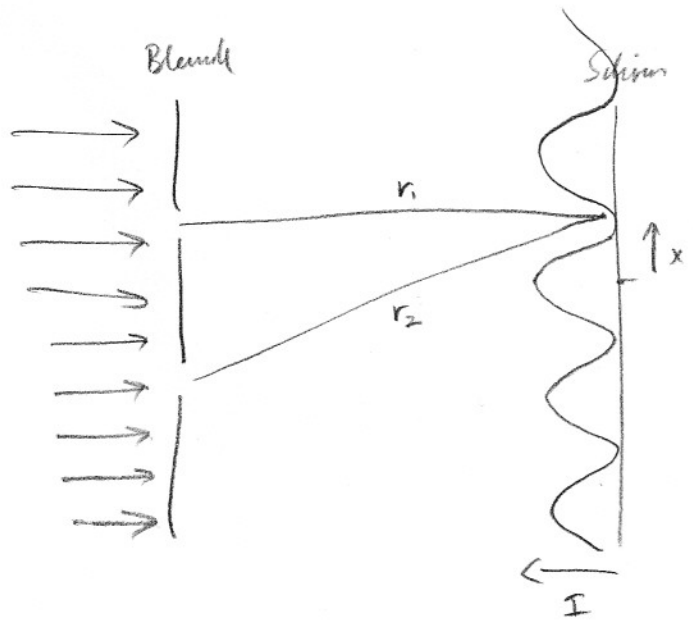
Kohärenzlänge L_c : max sl wo Interferenz noch beobachtbar.

Kohärenzzeit τ_c : $\tau_c = \frac{L_c}{c}$
 $\Delta \nu \cdot \tau_c = \frac{1}{2\pi}$ (Fourier)

spektrale Reinheit

| Drucklampe | λ [nm] | L_c [μm] | τ_c | $\Delta \nu$ |
|--------------------------|----------------|-------------------|---------------------|--------------------|
| Ne | 632.8 | $3 \cdot 10^{-2}$ | 10^{-10} | $3 \cdot 10^{-6}$ |
| Cd | 643.8 | $3 \cdot 10^{-1}$ | 10^{-9} | $3 \cdot 10^{-7}$ |
| Kr | 605.8 | $1 \cdot 10^2$ | $3 \cdot 10^{-7}$ | $1 \cdot 10^{-9}$ |
| He-Ne Laser stabilisiert | 632.8nm | $5 \cdot 10^5$ | $1.6 \cdot 10^{-3}$ | $2 \cdot 10^{-11}$ |

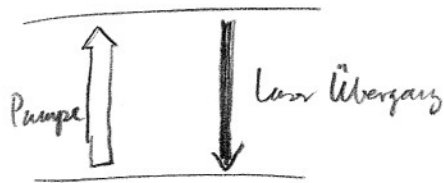
räumliche Kohärenz



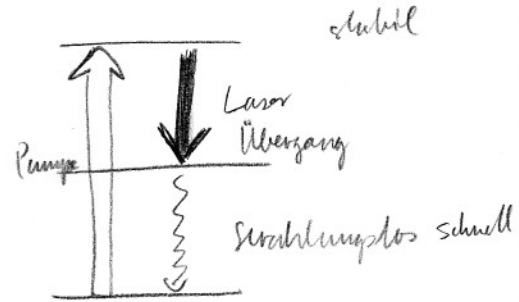
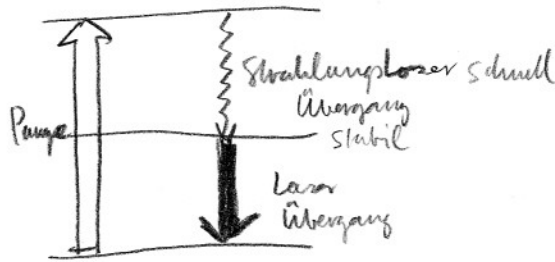
thermische Quelle → kann kohärent gemacht werden:
 zeitliche: schmalbandiges Spektralfilter
 räumliche: Lochbleed

Verschiedene Lasertypen

2- Niveau System



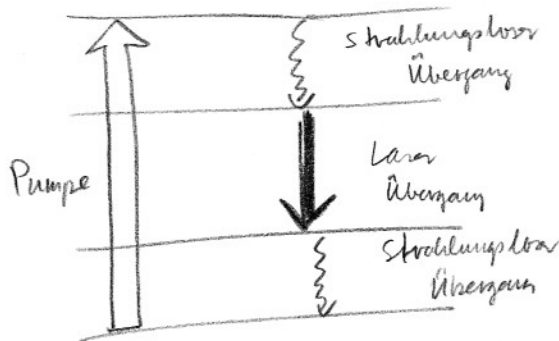
3- Niveau System



Rubin

Problem: GZ kann
besetzt sein

4- Niveau System



Nd: YAG, Nd: Glass, Ti: Saphir

• Festkörper Laser (solid state)

- Rubin
- Neodym Glas / YAG / YLF
- Ti: Saphir

• Gas Laser

- HeNe
- Ar Ionen
- Excimer Laser
- CO₂

• Farbstoff Laser

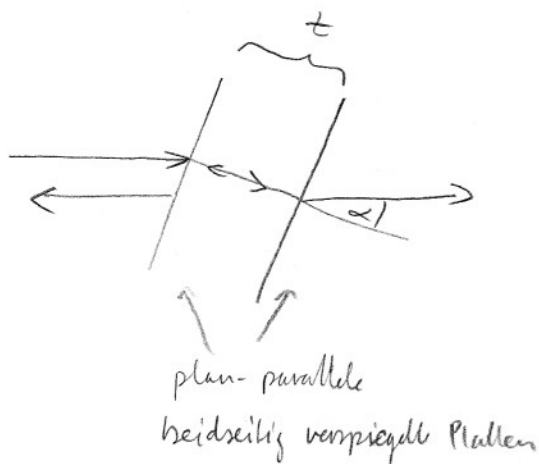
• Halbleiter

• Free Electron Laser

8.3 Einmodenlaser

Nur eine Frequenz \rightarrow Spektralfilter

z.B. Fabry-Perot Etalon



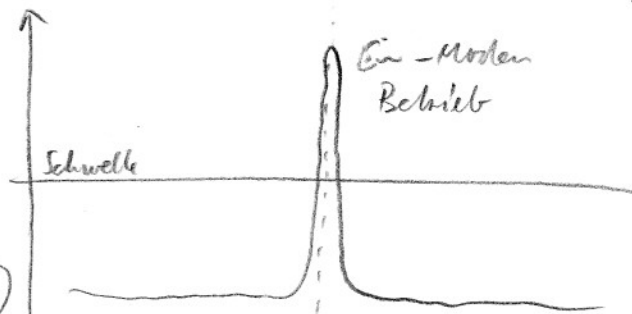
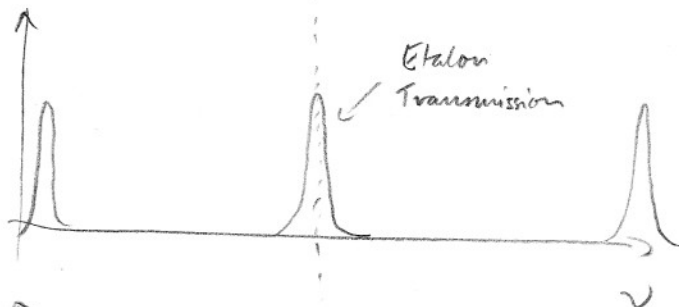
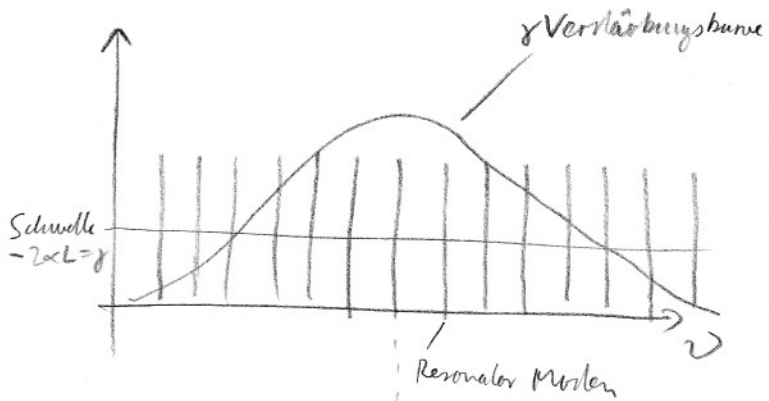
$$T = \frac{1}{1 + F \sin^2(\delta/2)} \quad \text{Transmission}$$

$$F = \frac{4R}{(1-R)^2} \quad \text{Fineness}$$

δ = Phasenverschiebung (optische Wegdifferenz Δs)

$$\delta = 2\pi \Delta s / \lambda$$

$$\Delta s = \text{opt. Wegdifferenz} = 2t \cdot \sqrt{n^2 - \sin^2 \alpha}$$



Stabilität / Linienbreite:

- Schwankungen Resonator (ΔL) (\sim MHz)
- " Brechungsindex via DP (Druck etc.) (\sim 100 MHz)

\rightarrow feedback mit Piezo-positionierung zur Längenstabilisation $\rightarrow \Delta \nu < 1$ Hz

Photonen Statistik

Strahlungseinheit und deren Schwankungen → Photonen Statistik
unterhalb Laserschwelle

$\langle n \rangle =$ mittlere Photonanzahl in Lasermode $= \frac{1}{e^{h\nu/kT} - 1}$ Bose-Einstein Verb.

wie Planck Hohlraumstrahlung bei Temp T, wobei $T \rightarrow \infty$ bei Annäherung an Schwelle

Schwankungen: $\frac{\langle \Delta n^2 \rangle}{\langle n \rangle^2} = \frac{\langle n \rangle + 1}{\langle n \rangle}$ ($\langle \Delta n^2 \rangle = \langle n \rangle (\langle n \rangle + 1)$)

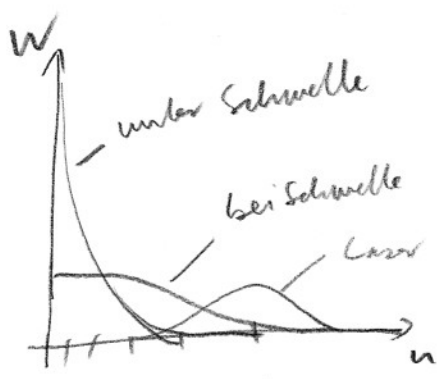
d.h. für große $\langle n \rangle$: Schwankungen \approx Mittelwert

Oszillation des Lasers

Wahrscheinlichkeit W bei $\langle n \rangle$ gerade n Photonen zu finden:

$W(n) = \frac{\langle n \rangle^n}{n!} e^{-\langle n \rangle}$ Poisson-Verteilung

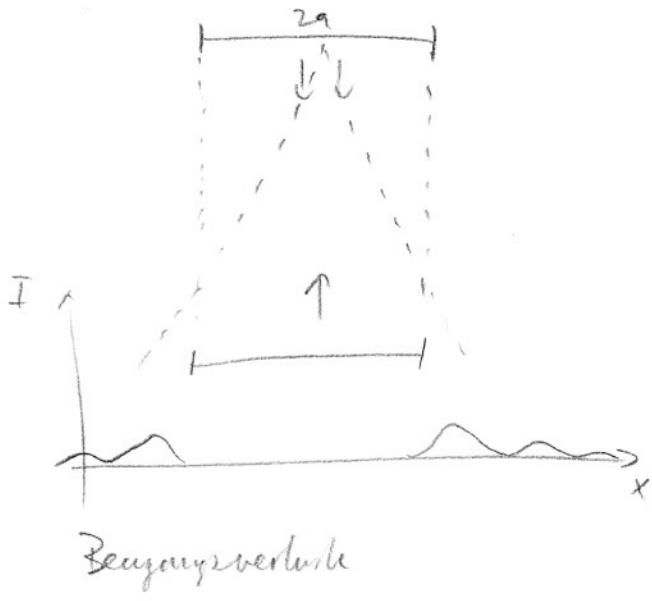
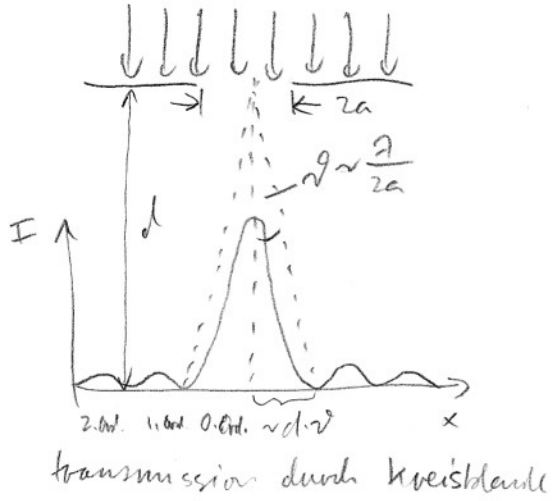
$\langle \Delta n^2 \rangle = \langle n \rangle$ or $\frac{\langle \Delta n^2 \rangle}{\langle n \rangle^2} = \frac{1}{\langle n \rangle}$



8.2.1. Offene optische Resonatoren

Beugungsverluste:

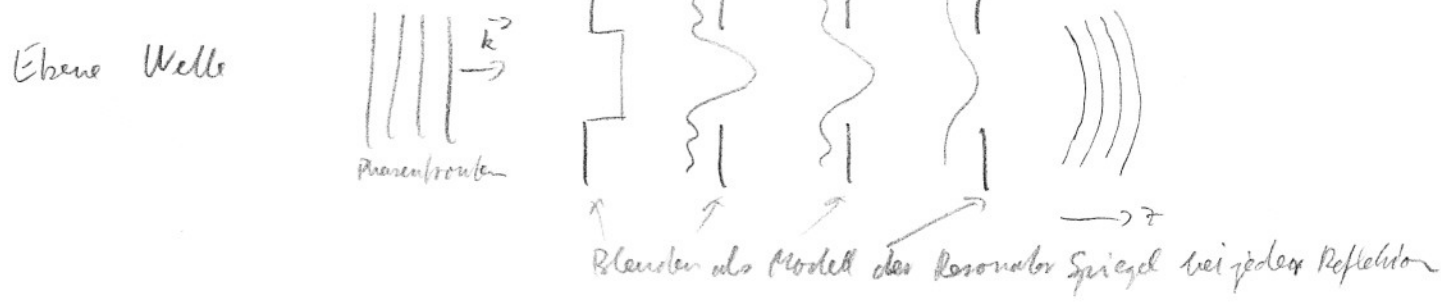
analog: Resonator



Um gesamte 0. Ordnung Beugungspore zu reflektieren: $d \cdot \vartheta \approx a$

Munkbaum zeigen, dass Verluste ca. $\gamma \sim 1/N$ sind $\frac{d\mathcal{L}}{2a} \rightarrow \frac{a^2}{\lambda d} \approx 1$
 ($I = I_0 e^{-\gamma}$)
 Fresnelzahl

Moden des offenen Resonators

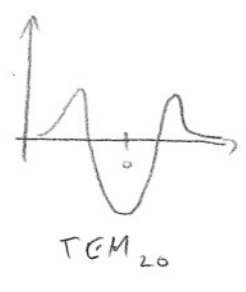
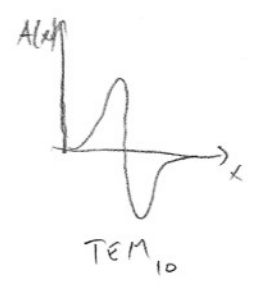
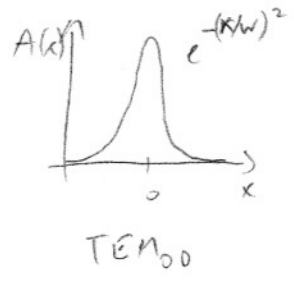


$A(x,y)$: Amplitudenverteilung in x,y Ebene $\perp z$ Ausbreitungsrichtung

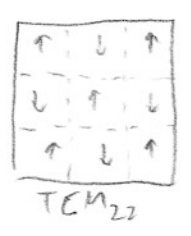
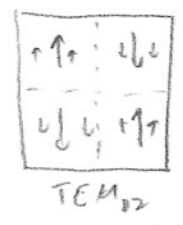
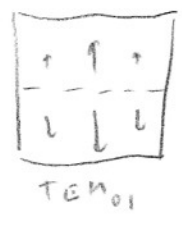
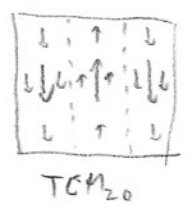
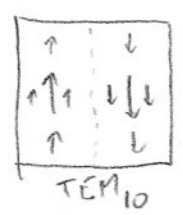
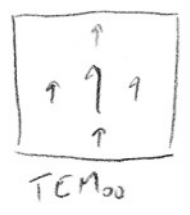
stationärer Zustand: $A_n(x,y) = C \cdot A_{n-1}(x,y)$ $|C| < 1$, unabh. von x,y

Man kann $A(x,y)$ im stationären Zustand beschreiben (Kirchhoff'sche Beugungstheorie)

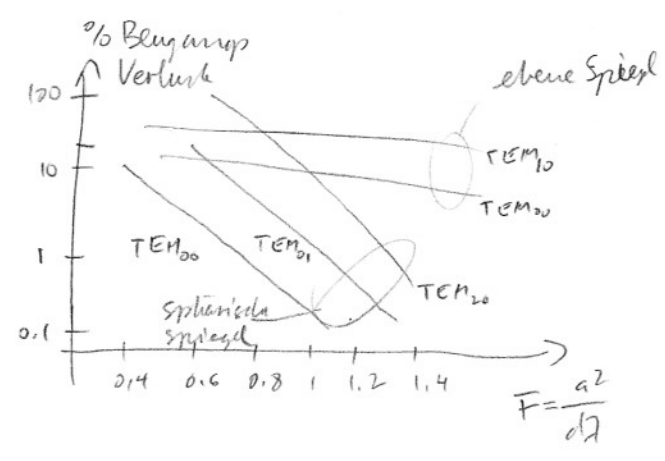
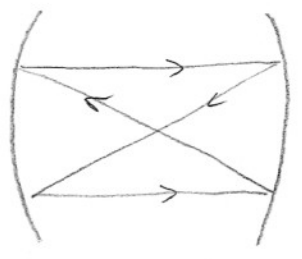
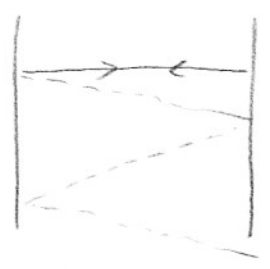
\rightarrow Lösungen für A , verschiedene Moden: transversal-elektromagnetische Moden TEM_{nmq}
 in z -Richtung durch die Anzahl Knoten n,m in x,y Richtung und q in z -Richtung



$$q = \frac{d}{\lambda/2} \gg 1$$



ebene vs. sphärische Spiegel



Frequenzspektrum

$$\nu_r \sim \frac{c}{2d} \left\{ q + \frac{1}{2}(m+n+1) \right\}$$

vgl. mit $\nu_r = q \frac{c}{2d}$