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**INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS**
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**H4.SMR/845-8**

**Second Winter College on Optics**

**20 February - 10 March 1995**

# *Optical Storage*

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Lecture Notes

- 2nd Winter College on Optics (ICO) -

# " Optical Storage "

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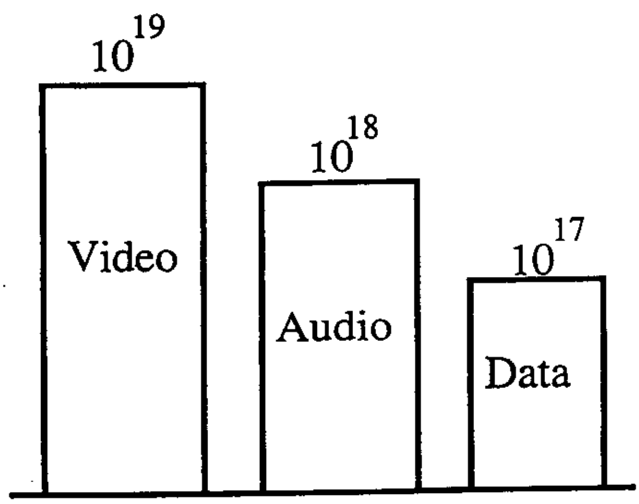
*Trieste, Italy*

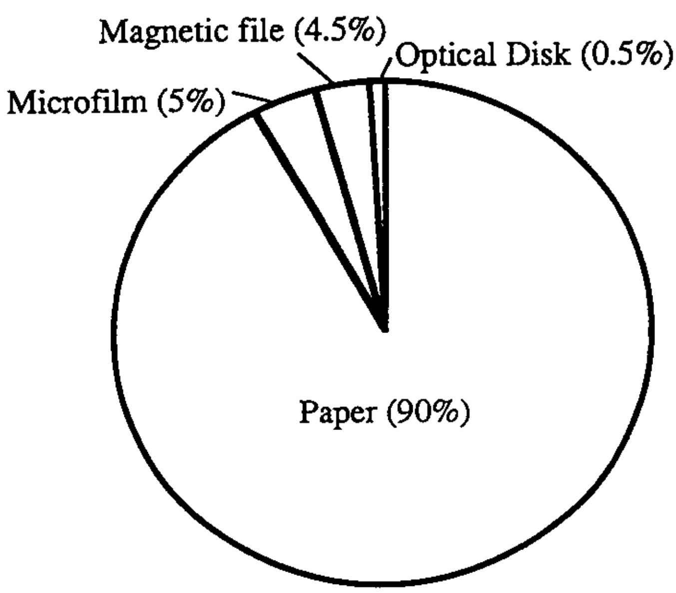
# Contents

# History

| | '60 | '70 | '80 | '90 | '00 |
|---|---|---|---|---|---|
| Phase | Research | Read Only | 1st Generation<br>Erasability | Higher Density | 2nd Generation |
| Optical Disk | Holographic (BTL, Hitachi) | Phase Pit (Philips) | VD Prod. (Pioneer He-Ne)<br>CD Prod. (Philips/Sony)<br>W/O Prod. (Toshiba) | 5"M/O (Hitachi)<br>5" P/C (Matsushita) | DVD (Toshiba,Hitachi Matsushita etc.)<br>3.5" M/O (Hitachi/Sony) |
| LD | Diode Laser (GE) | LD-RT-CW (BTL) | Low Power 780nm<br>High Power 830nm | 780nm | 635nm<br>680nm |

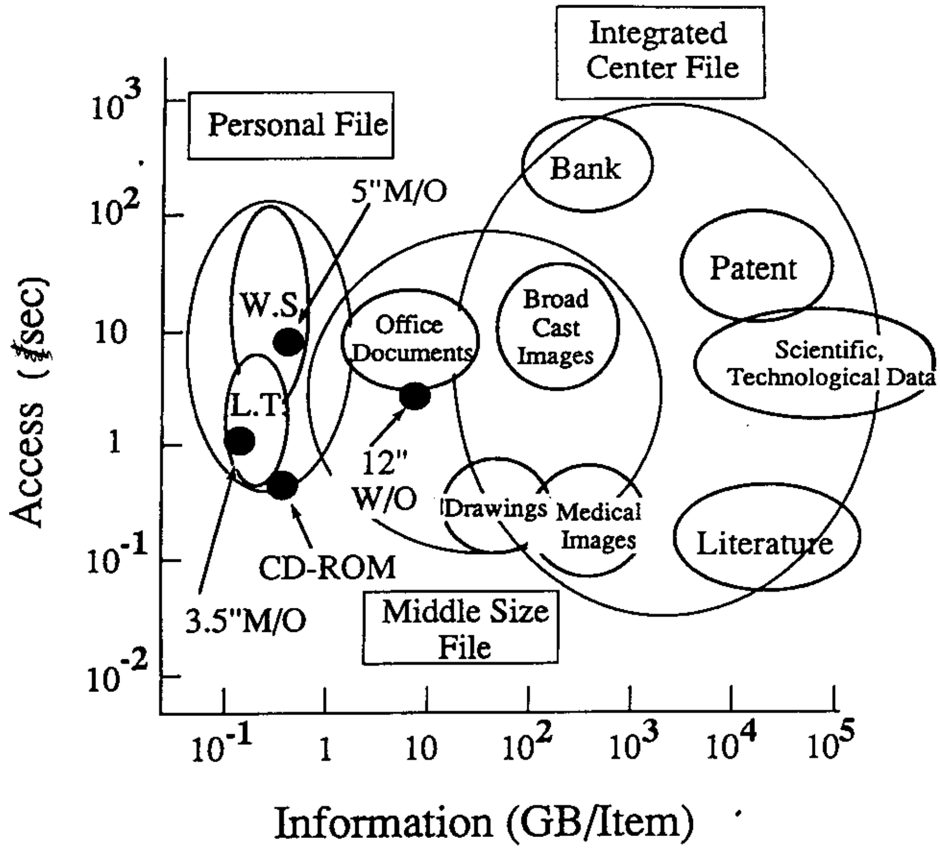



Storage (Byte)




Storage Type

## Optical Disk Market

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## Advanteges of Optical Disks

| | Optical Disk | Magnetic Disk | Floppy | Magnetic Tape |
|---|---|---|---|---|
| Storage Density | ◎ | ○ | △ | ◎ |
| Carrier | ○ | × | ○ | △ |
| Access | △ | ○ | × | × |
| Duplication | ○ (CD, CD-ROM) | × | × | △ |
| Bit Cost | △ | △ | ◎ | ○ |

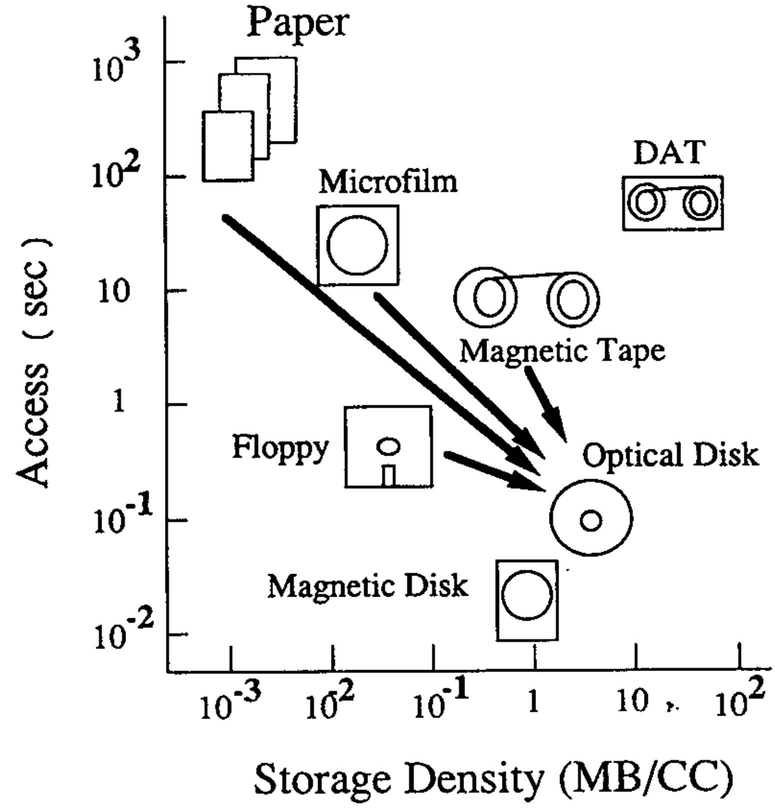
◎ Excelent

○ Good

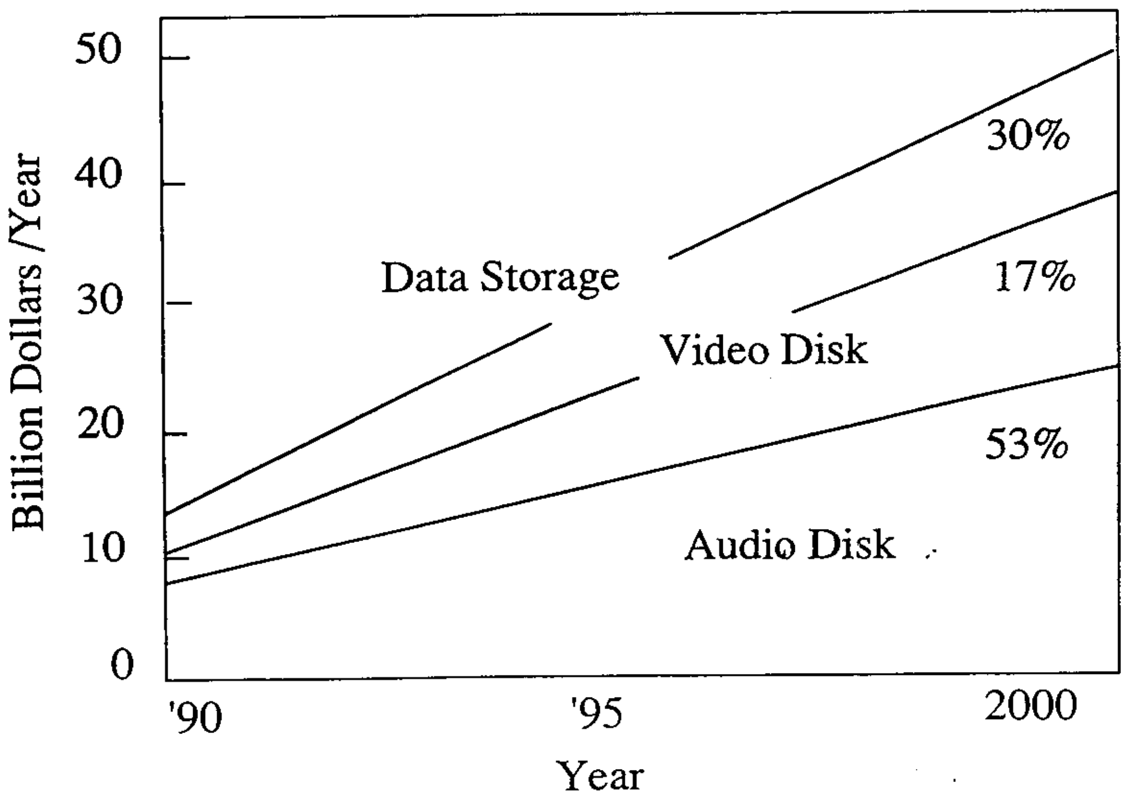
△ Fair

× No Good

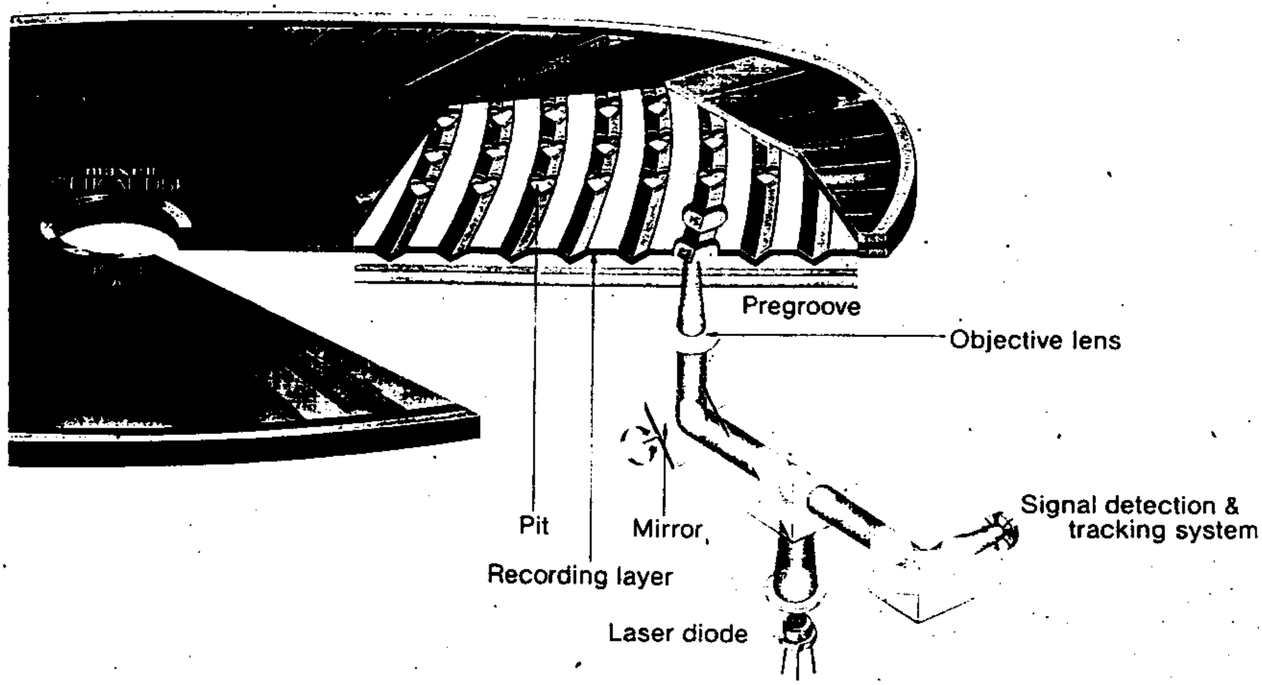
## Optical Disk Replacement




## Optical Disk Market Size



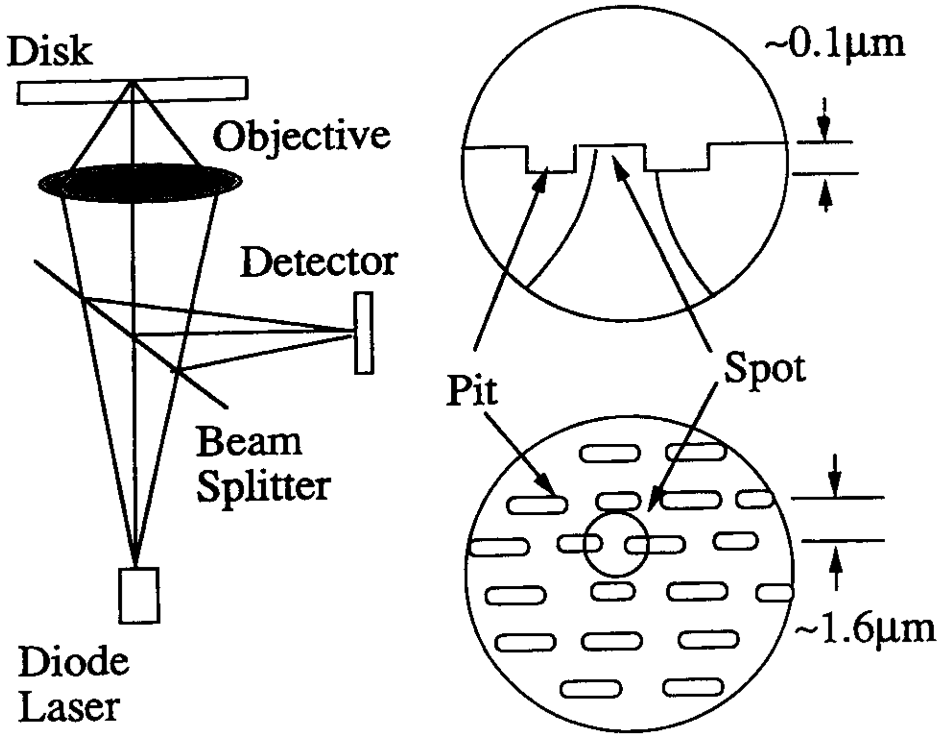
Structure of the optical disk




## Optical Disk Memory Structure

- Disk
- Drive (Player)
  - Optical Head
  - Access Mechanics
  - Rotation Mechanics
  - Controler
  - Signal Processing

# Optical Disk & Pick-Up



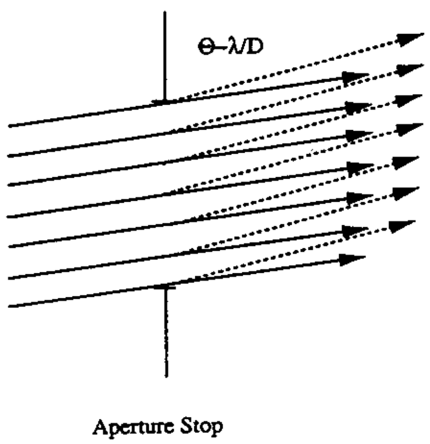

1) Diode laser facet is imaged and a spot is formed on the surface of the disk.

2) The spot size is about $\lambda/NA$ and equal to the track pitch.

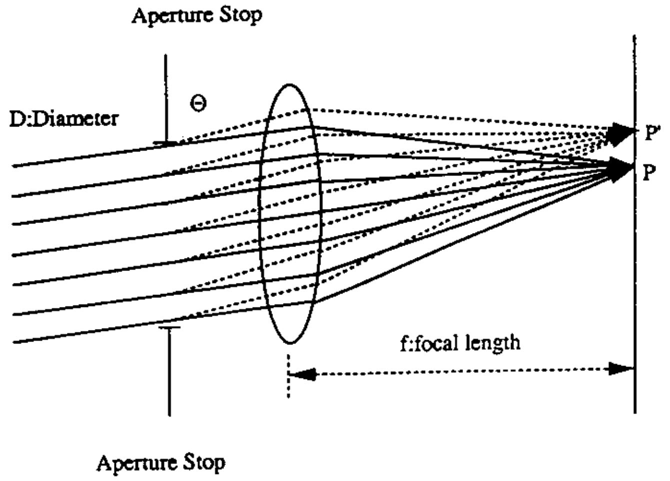
3) The storage density is approximately $(\lambda/NA)^2$.

4) Auto-Focusing and Tracking are essential for the system.

## Spot Profile



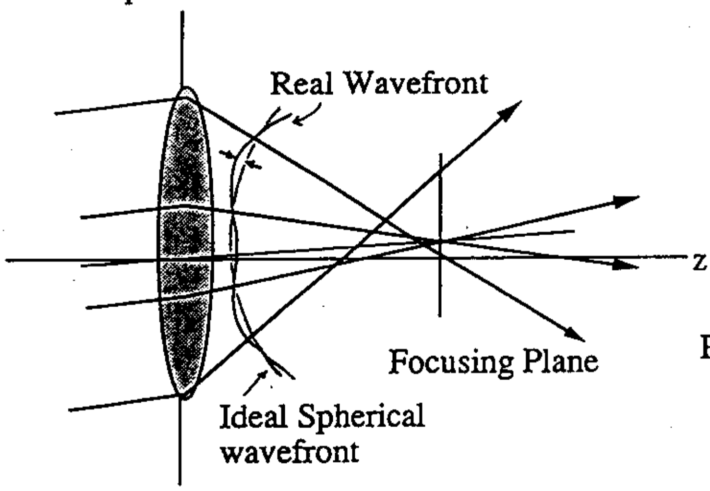

1) Diffraction by an aperture




2) Focusing by an aberration free lens

Spot Size=2.44 f $\lambda/D$

## Spot Profile & Pupil Function




Pupil Function:

$$P(\rho,\theta)=T(\rho,\theta)\exp\left\{2\pi i\Phi(\rho,\theta)\right\}$$

Amplitude :

$$T(\rho,\theta)=\exp\left\{-\sigma\rho^2\right\}$$

Phase of Wavefront =
(Wavefront -Ideal spherical wavefront)

$\Phi(\rho,\theta)$ in units of $\lambda$

Spot Profile = Fourier Transform of a Pupil Function

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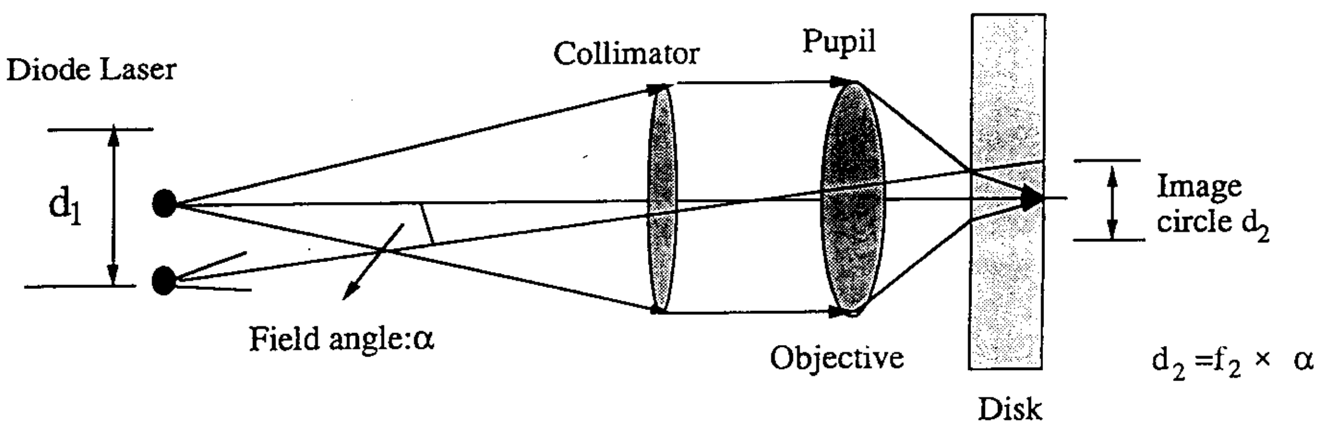
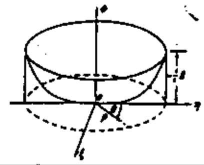
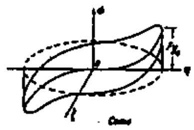
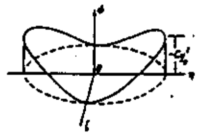
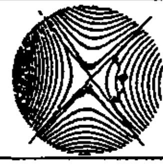
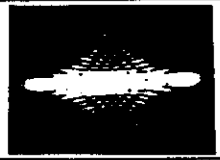
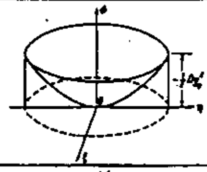
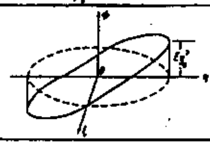
## Imaging Optics for a Diode Laser

Diffraction Limited, aberration free imaging optics
with some field angle is required.




$d_1 = f_1 \times \alpha$

## Third order Wave Aberration

| Type | Expressin | Wavefront | Interference pattern | Image plane |
|---|---|---|---|---|
| Spherical | $A_{40}\ \rho^4$ |  |  |  |
| Coma | $A_{31}\rho^3\ \cos(\theta - \theta_1)$ |  |  |  |
| Astigmatism | $A_{22}\rho^2\ \cos^2(\theta - \theta_2)$ |  |  |  |
| Defocus (Curvature of field) | $A_{20}\rho^2$ :Defocus |  | | |
| Tilt (Distortion) | $A_{11}\rho\ \cos(\theta - \theta_1)$ |  | | |

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## Distribution of the Aberration Margin

$$\sqrt{\iint (\Phi_1 + \Phi_2)^2} = \sqrt{\iint (\Phi_1^2 + \Phi_2^2 + 2\,\Phi_1\Phi_2)}$$

$$= \sqrt{\iint (\Phi_1^2 + \Phi_2^2)}$$

$$\iint \Phi_1\Phi_2\,\rho\,d\rho\,d\theta = 0$$

Orthogonal
(No Correlation)

$$(RMS)_p = (RMS)_d \leq 0.05\ \lambda$$

Aberration Torerance for the Diode Lasers

$$(RMS)_{DL} = (RMS)_{Ob} \leq 0.035\lambda$$



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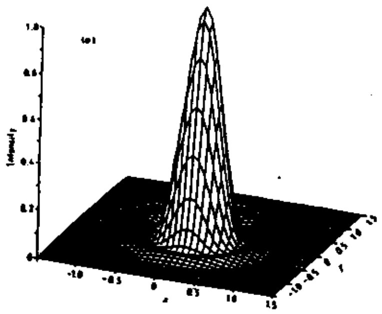
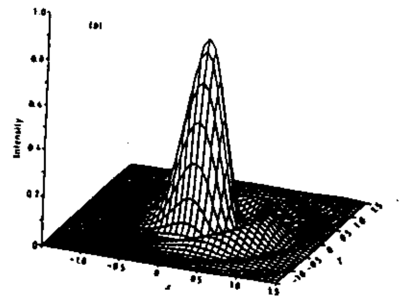
## Marechal Criterion

RMS < 0.07λ





Strehl Intensity

$$I = \frac{1}{\pi^2}\left|\int_0^1 \int_0^{2\pi} e^{ik\Phi}\rho d\rho d\theta\right|^2$$

$$= \frac{1}{\pi^2}\left|\int_0^1 \int_0^{2\pi} \{1 + ik\Phi + \frac{1}{2}(ik\Phi)^2 + \ldots\}\ \rho d\rho d\theta\right|^2$$

$$= 1 - (2\pi/\lambda)^2 (RMS)^2 > 0.8$$

Root Mean Square of the Wave Aberration

$$(RMS)^2 = \frac{\int_0^1 \int_0^{2\pi} \Phi^2(\rho,\ \theta)\ \rho\, d\rho\, d\theta}{\int_0^1 \int_0^{2\pi} \rho\, d\rho\, d\theta}$$

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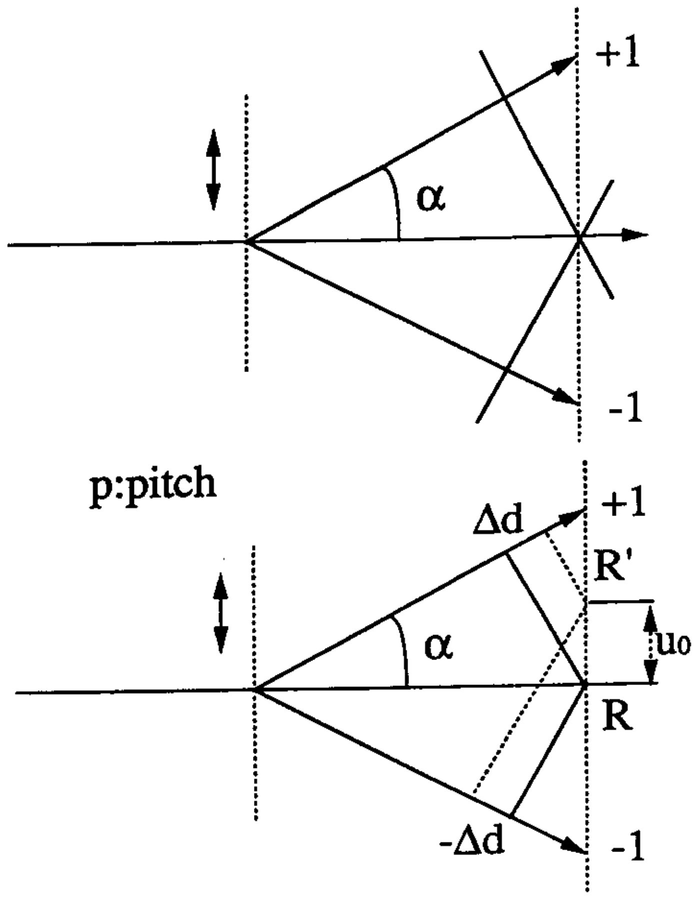
## Aberrations in Optical Disk

| Aberration | Player | Disk |
|---|---|---|
| Spherical | Objective lens | Thickness Err. |
| Coma | Objective, Turn table Tilt | Bending |
| Astigmatism | Diode Laser, Objective | Shrink |
| Defocus | Objective | —— |
| Tolerance | < 0.05λ | < 0.05λ |
| System Tolerance | <0.07λ Marechal Criterion | |

λ → 短
↓
機械精度

## Diffraction Grating




1) Relationship between Diffraction angle $\alpha$ and grating pitch p;

$$\sin\alpha = \lambda / p$$

where $\lambda$ is wavelength.

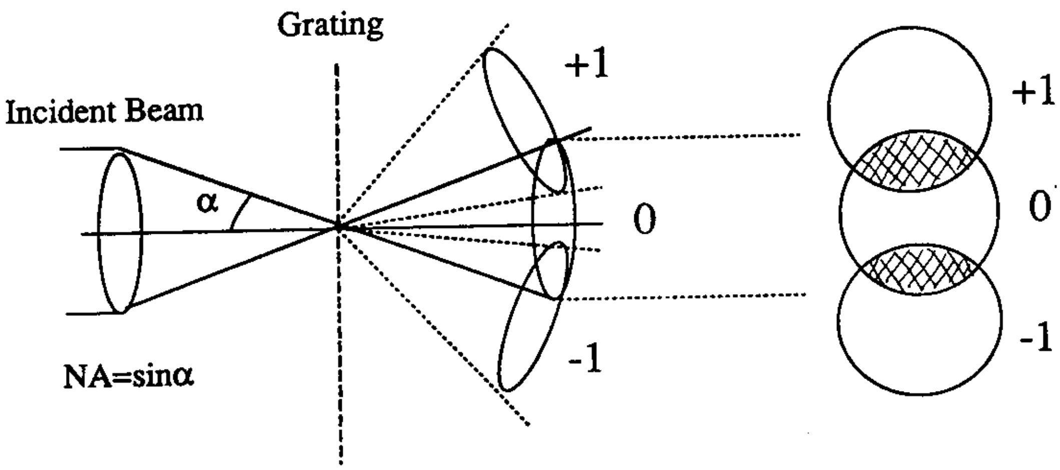
2) Phase difference between zeroth and first order diffracted beam;

$$\Delta\phi = 2\pi\Delta d/\lambda = 2\pi\, u_0 / p$$

where,

$$\Delta d = u_0 \sin\alpha = u_0\, \lambda / p$$

## Interference of Diffracted beams

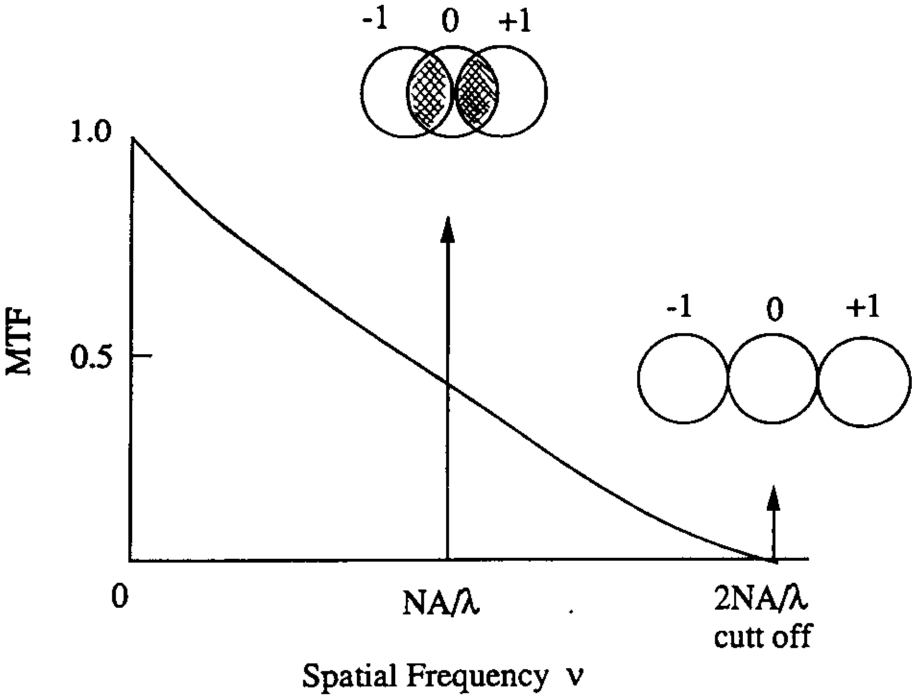


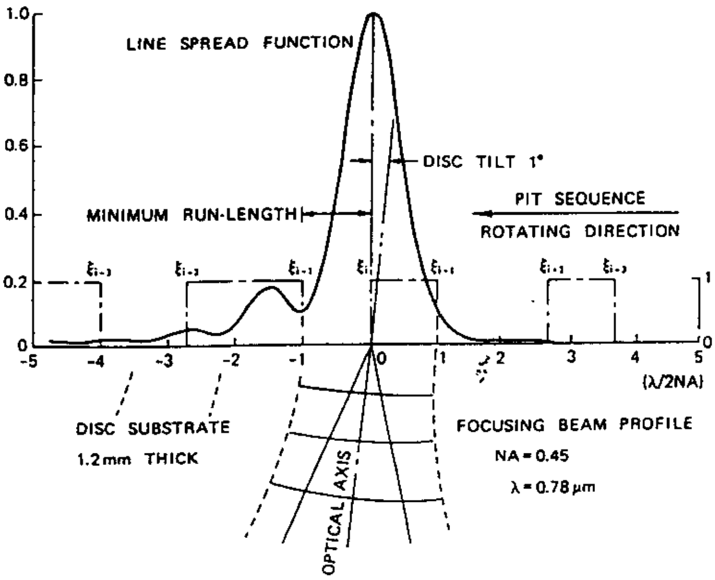

Time dependent Intensity is given by

frequency:
$\nu = s/p$
s:speed(m/s)

$$I(t) = \left| A_0 + A_{+1}\exp(i\Delta\phi_{+1}) + A_{+1}\exp(-i\Delta\phi_{+1}) \right|^2$$
$$\sim A_0^2 \left\{ 1 + \frac{4A_+}{A_0}\cos(2\pi\nu t) \right\}$$

# Modulation Transfer Function




$$g(x)=\begin{cases}1 & \xi_{2i-1}<x<\xi_{2i}\\ 0 & \text{otherwise}\end{cases} \qquad (2)$$

$$f(x)=\int_{-\infty}^{\infty} g(\xi)h(x-\xi)d\xi \qquad (3)$$

$$=\sum_{i=1}^{\infty}\int_{\xi_{2i-1}}^{\xi_{2i}} h(x-\xi)d\xi$$

$$=\sum_{i=1}^{\infty}(-1)^{i-1}H(x-\xi_i) \qquad (4)$$

$$H(x)=\int_{-\infty}^{x} h(\xi)d\xi \qquad (5)$$

$$f(x)=\sum_{i=2m-2r+1}^{2m}(-1)^{i-1}H(x-\xi_i) \qquad (6)$$

$$x=\xi_i,\ (\xi_0<\xi_1<\cdots<\xi_N)$$

$$p_i=\xi_i-\xi_{i-1}$$

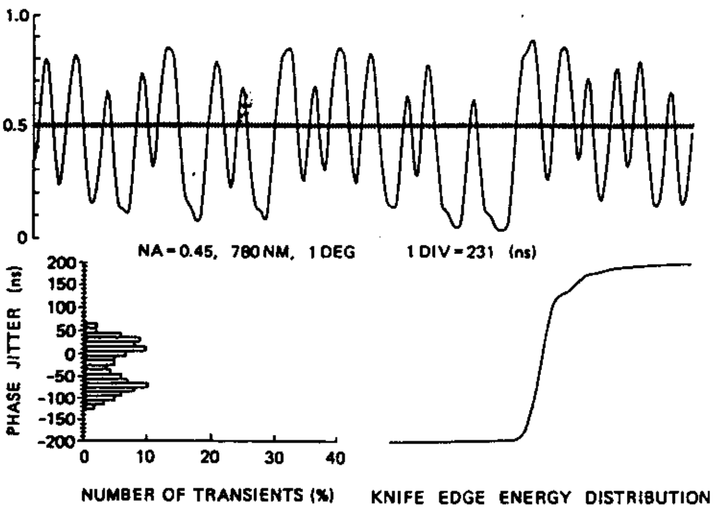



**Fig. 12** Simulated eye diagram, jitter histogram and knife edge energy distribution function when disc tilts 1°.

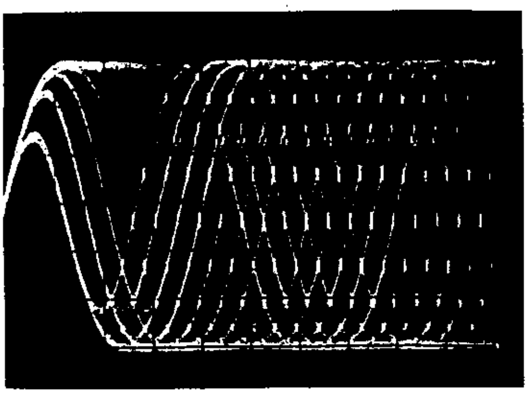


**Fig. 3** Eye diagram when disc tilts 0°. $NA=0.47$, $\theta=0°$, $\lambda=0.78\ \mu m$

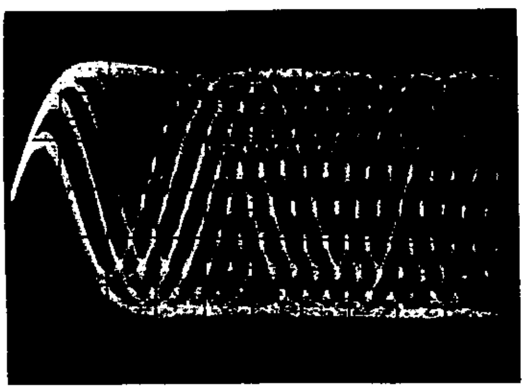


**Fig. 5** Eye diagram when disc tilts 1°.

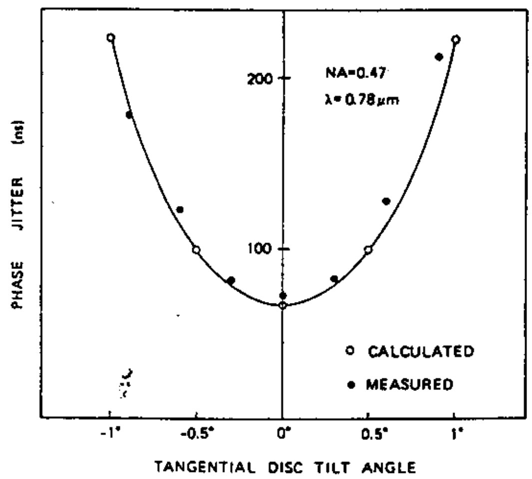
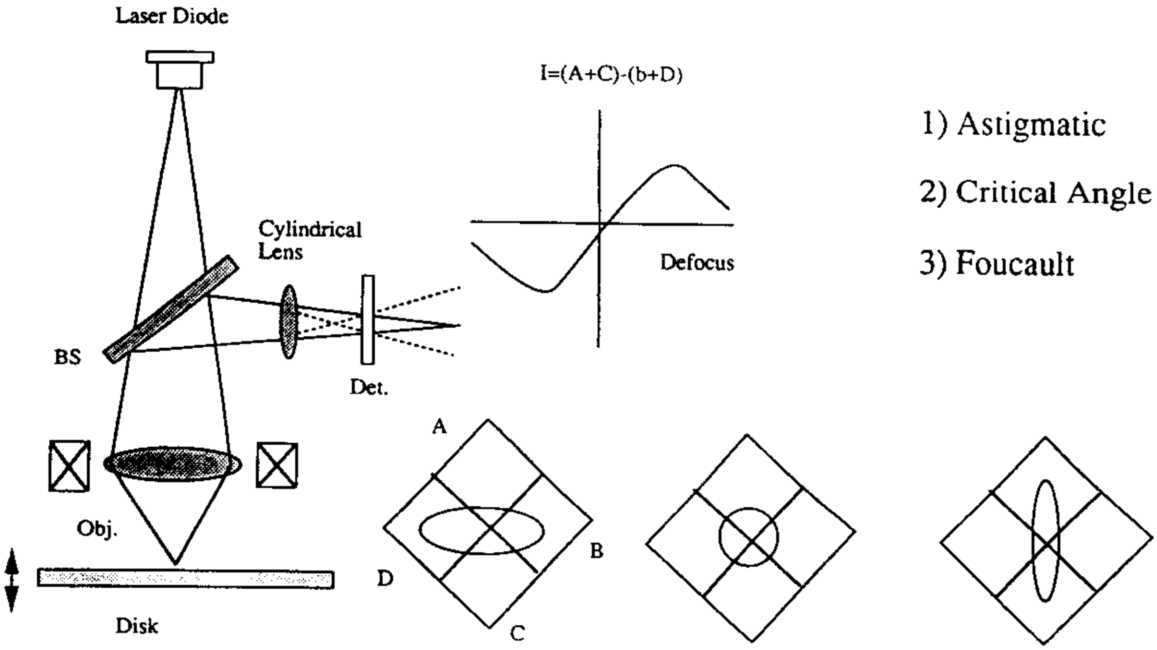



**Fig. 13** Peak-to-Peak phase jitter vs. disc tilt angle in the scanning direction ; Calculated and measured values are shown.

## Auto-Focusing

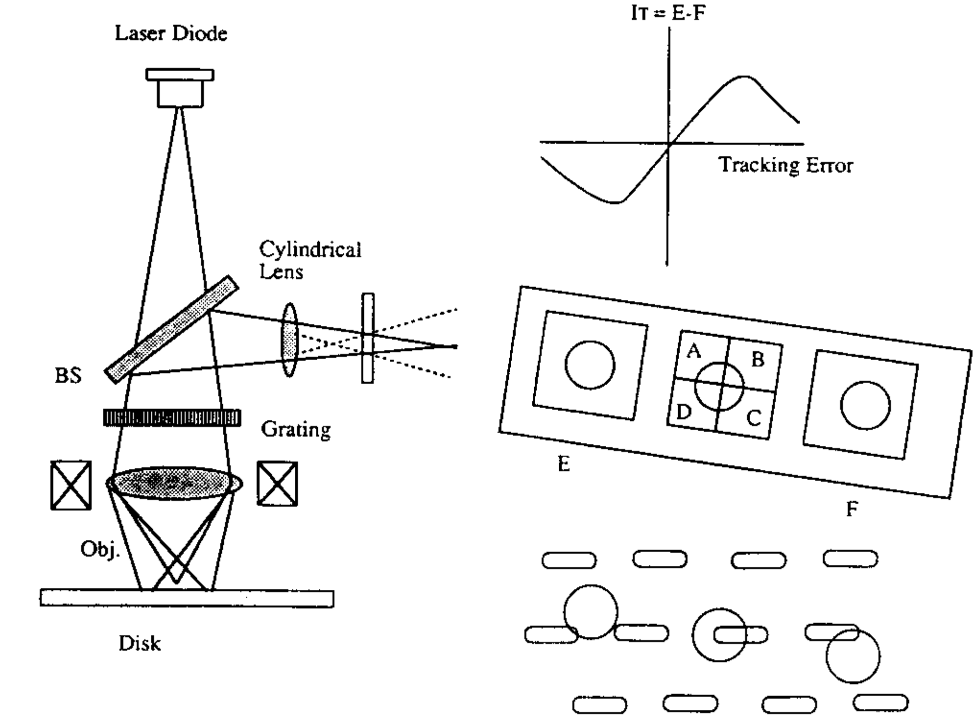



1) Astigmatic

2) Critical Angle

3) Foucault

## Auto-Tracking

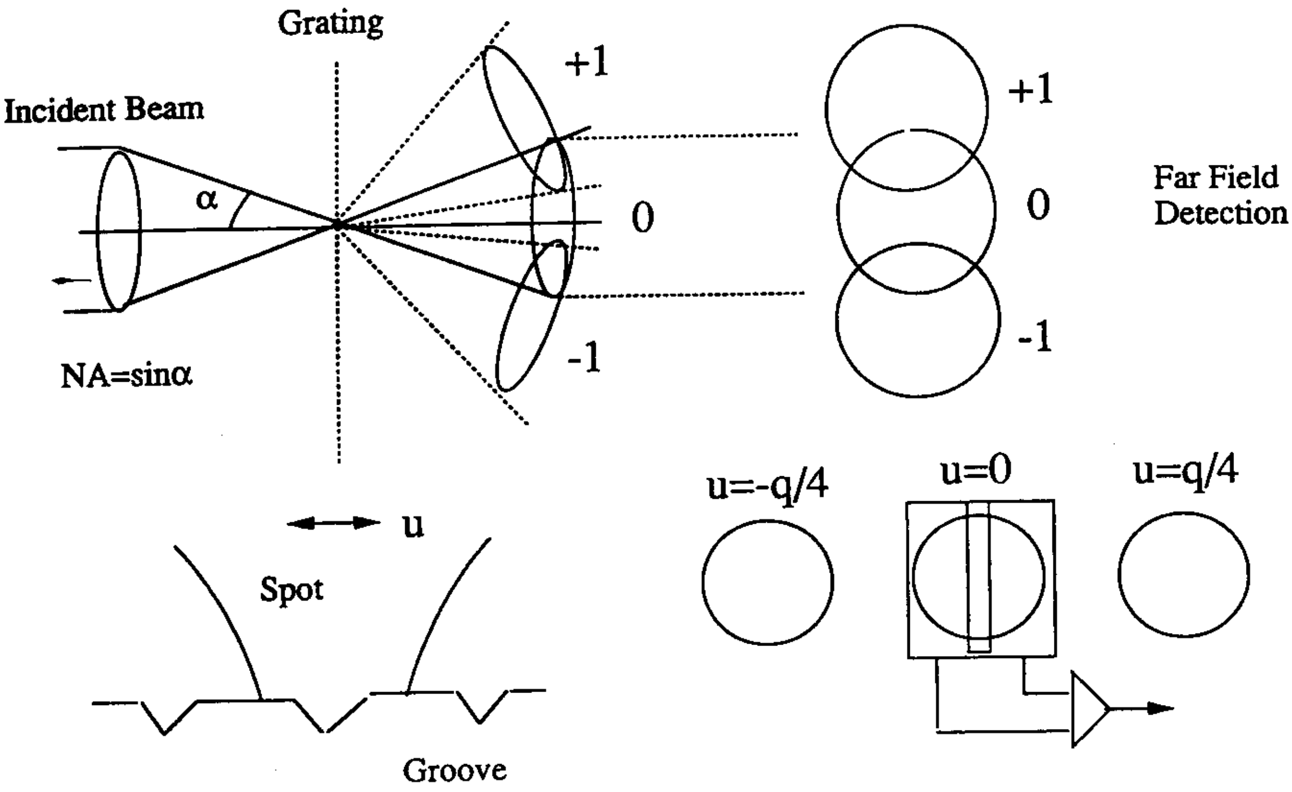



1) 3-Spot

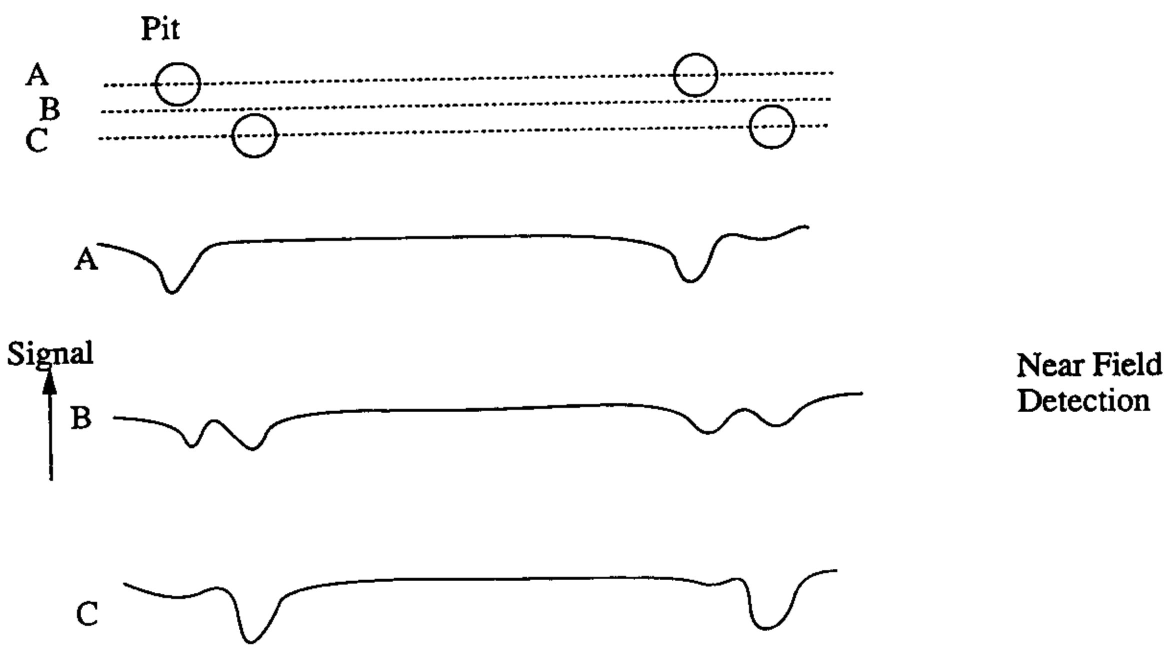
2) Far Field

3)Sampling

## Tracking- Push-Pull

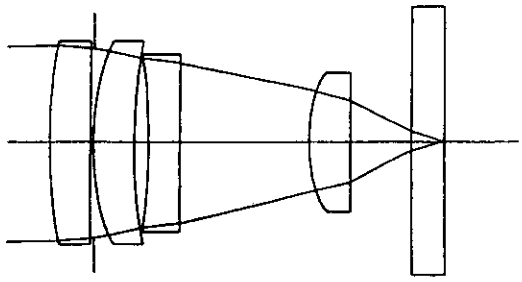



## Tracking-Sampled Servo



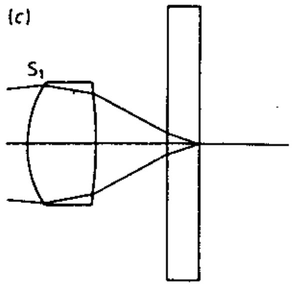
Objective Lens    Abbe's Sine Condition

conventional



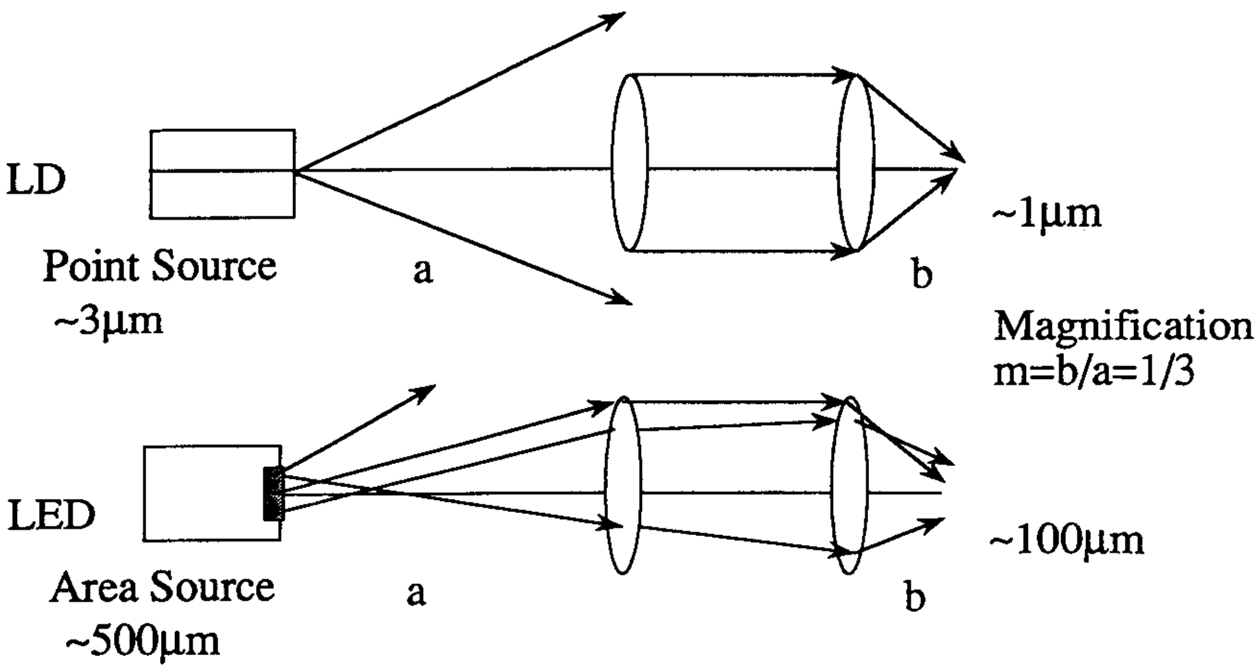
| | |
|---|---|
| Focal Distance | 8mm |
| NA | 0.45 |
| Field Diameter | 1.0mm |
| Field curvture | 6µm at the rim |
| Diameter | 7.5mm |
| Length | 11mm |
| Weight | <2g (mount included) |

Aspheric

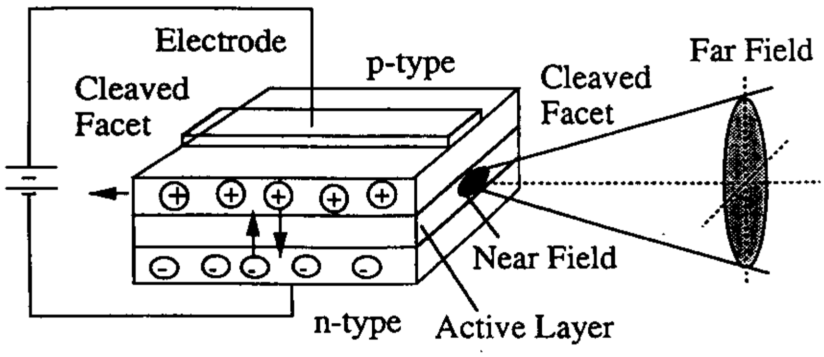



| | |
|---|---|
| Focal Distance | 3.7mm |
| NA(object side) | 0.10 |
| NA(image side) | 0.45 |
| Field Diameter | 1.0mm |
| Field curvture | 2 µm at the rim |
| Asphericity | 11 µm(respect to the best fit sphere) |
| Diameter | 4.1mm |
| Thickness | 3.2mm |
| Weight | <0.25g (mount included) |

## Why Laser?



# Diode Laser Structure




1) Small size:400*100*100μm

2) Highly Efficient
ex. He-Ne<0.1%

3) High Frequency Direct Modulation~GHz

4) Wide Wavelength Region

5) Long Life time

6) Mass Production, Low Cost

Electron- Hole Recombination-----$\lambda$(nm)=1.240/Eg

Carrier Density>$1*10^{18}$---------Population Inversion(Gain)

1) Astigmatism

2) Feed-back Noise

3. Optical Characteristics

There are two types of LD chips presently produced by Hitachi, Ltd.: the HLP-1000 and the HLP-2000. Both of these chips are made of DH-structure AlGaAs material, but differ in operating current, output power level and certain other characteristics as shown in Table I. Several types of packages, the HLP-1000 series and the HLP-2000 series, are available from Hitachi, Ltd., as explained in 5.

Table I. Optical and electrical characteristics ($T_{hs}$ = 25°C)

HLP-1000

| Item | Symbol | Test Condition | min. | typ. | max. | Unit |
|---|---|---|---|---|---|---|
| Threshold Current | $I_{th}$ | | | 70 | 100 | mA |
| Output Power | $P_o$ | $I_f = I_{th} + 25mA$ | 4 | 5 | | mw |
| Forward Voltage Drop | $V_f$ | $I_f = 100mA$ | | 1.8 | | V |
| Wavelength | $\lambda_p$ | | 800 | 830 | 850 | nm |
| Beam Divergence | | | | 10X30 | | deg. |
| Rise and Fall Time | $\tau_r, \tau_f$ | | | | 0.5 | ns |

HLP-2000

| Item | Symbol | Test Condition | min. | typ. | max. | Unit |
|---|---|---|---|---|---|---|
| Threshold Current | $I_{th}$ | | | 20 | 35 | mA |
| Output Power | $P_o$ | $I_{th} + 5mA$ | 0.75 | 1 | | mw |
| Forward Voltage Drop | $V_f$ | $I_f = 25mA$ | | 1.8 | | V |
| Wavelength | $\lambda_p$ | | 800 | 830 | 850 | nm |
| Beam Divergence | | | | 35X40 | | deg. |
| Rise and Fall Time | $\tau_r, \tau_f$ | | | | 0.5 | ns |

$I_{th} \propto I_0 e^{T/T_0}$

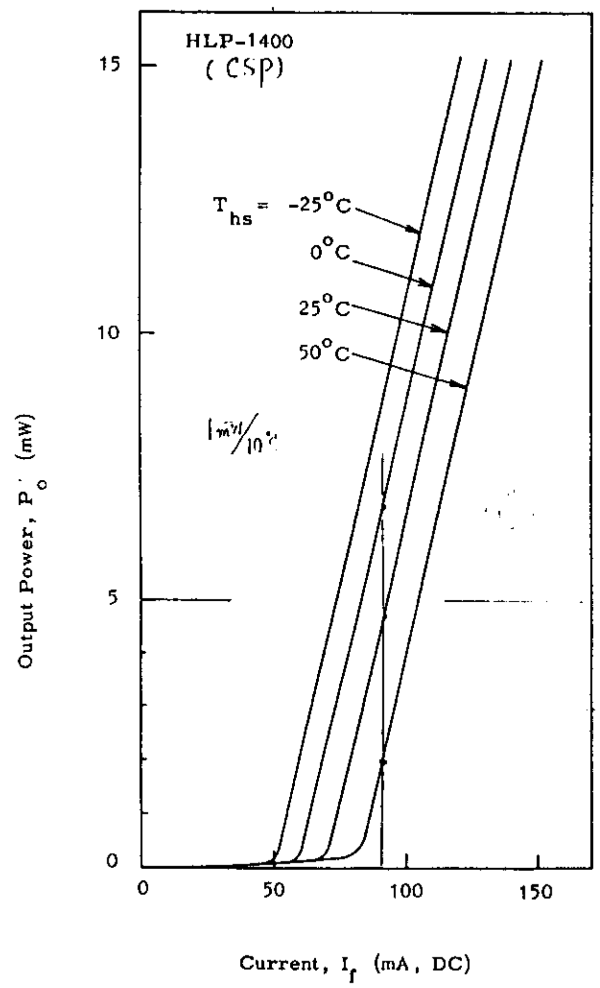



Fig. 2 Typical light vs current characteristics of HLP-1000 diodes.



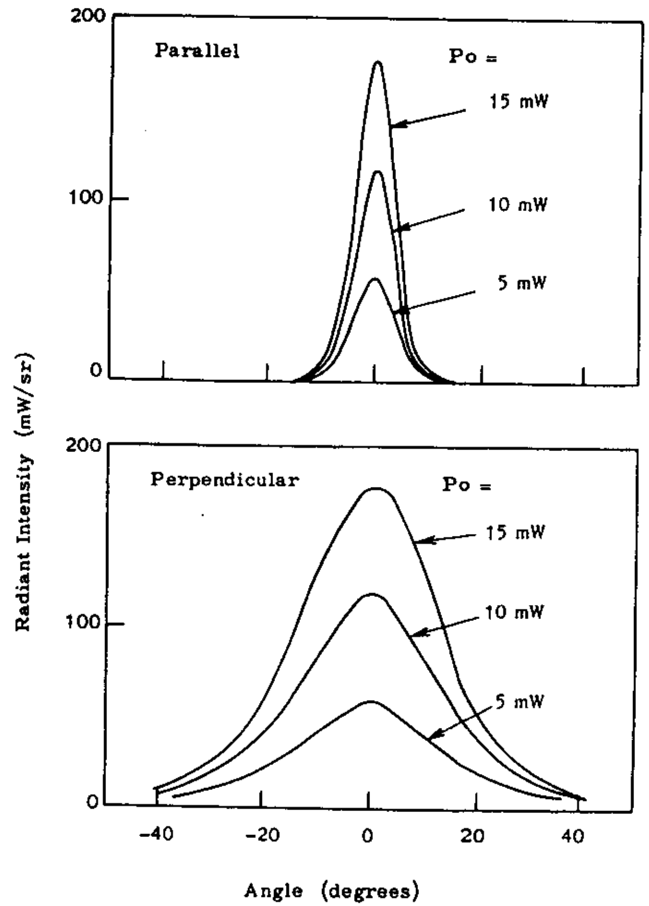



Fig. 6 Typical far-field patterns of HLP-1000 diodes parallel and perpendicular to the junction plane.

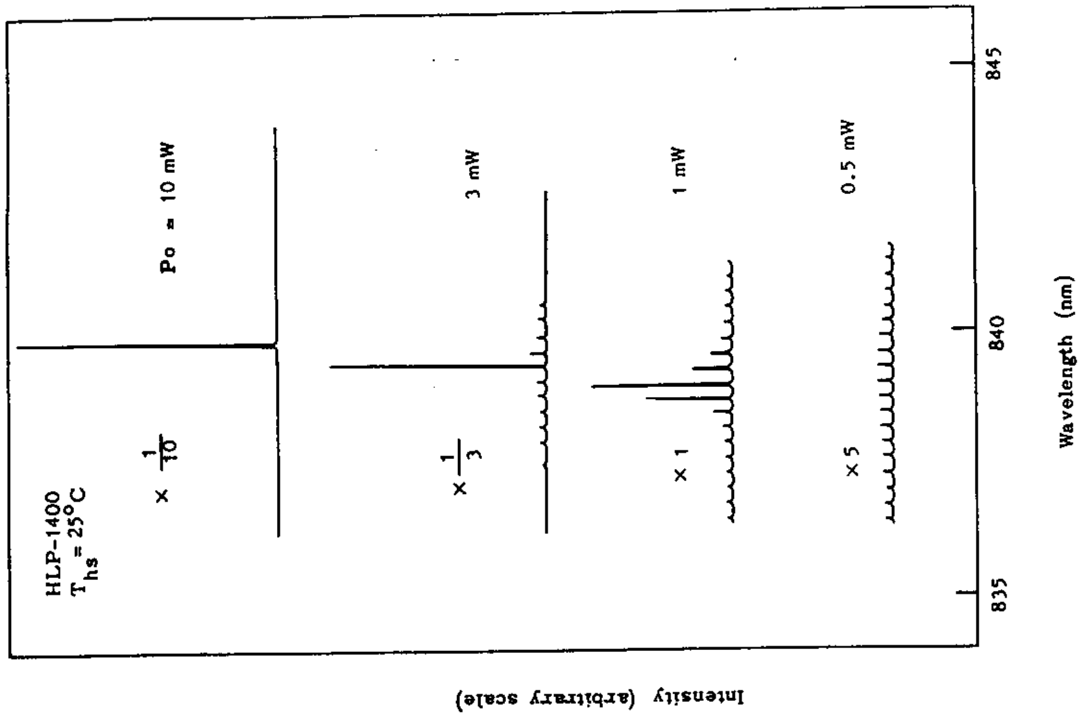



Fig. 8 Typical emission spectra of HLP-1000 diodes at various output power levels.



## Laser Specifications for Optical Disks

| | | Specifications |
|---|---|---|
| Output Power | Read | 3-5 mW |
| | Record | >30 mW |
| | | Modulation |
| Lateral Mode | | Fundamental Single |
| Aberration | | 0.03λ rms |
| Noise | | < -120dB/Hz |
| Size | | < (10 φ ~30mm ) |
| Temperature | | 0----50°C |

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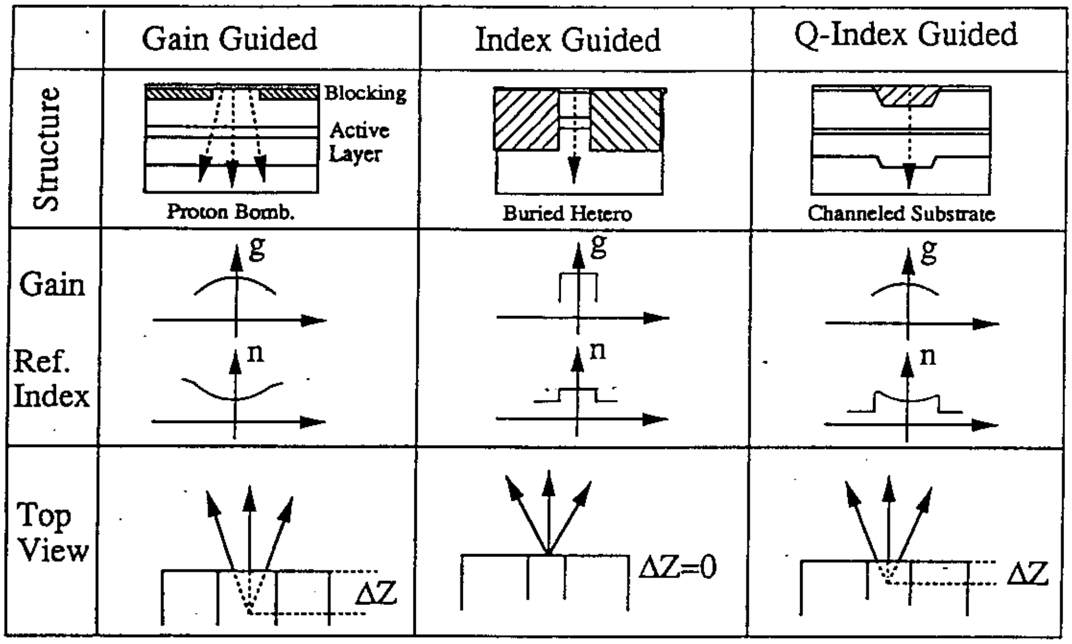
# Diode Laser Astigmatism




ΔZ : Asdtigmatic Distance

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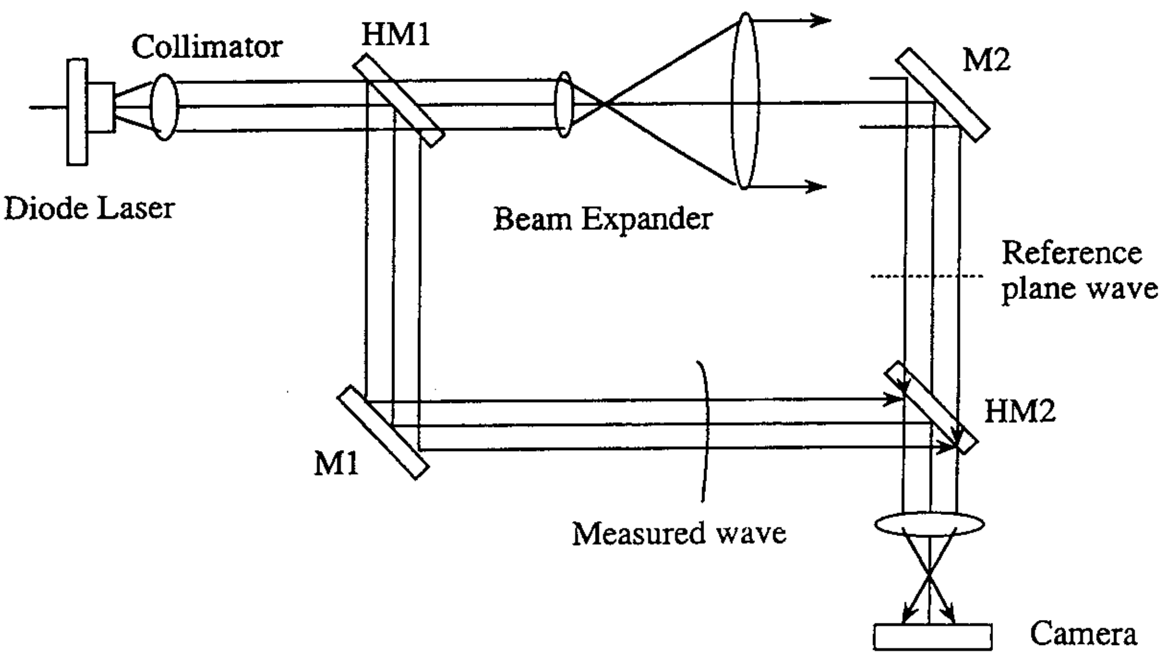
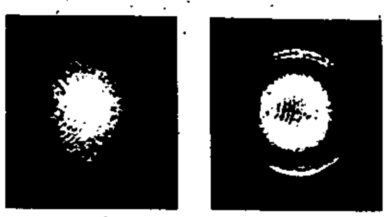
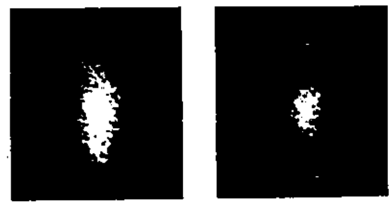
# Interferometric Measurement

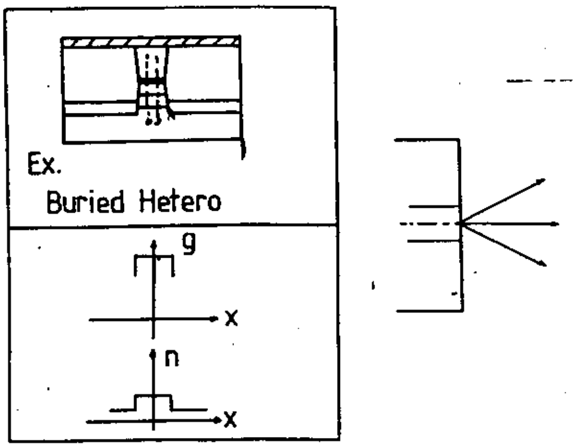




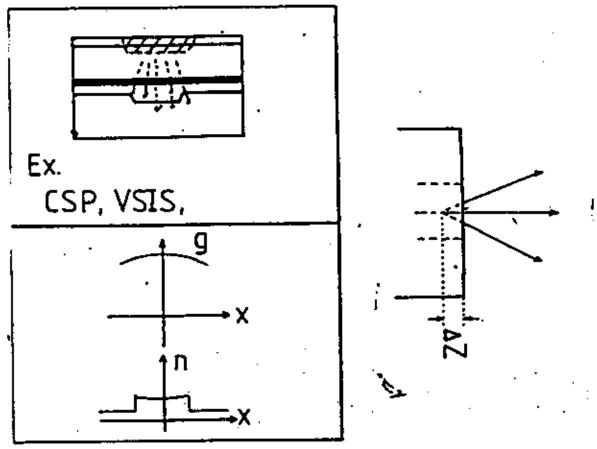
(a) (b)
BH(830nm)



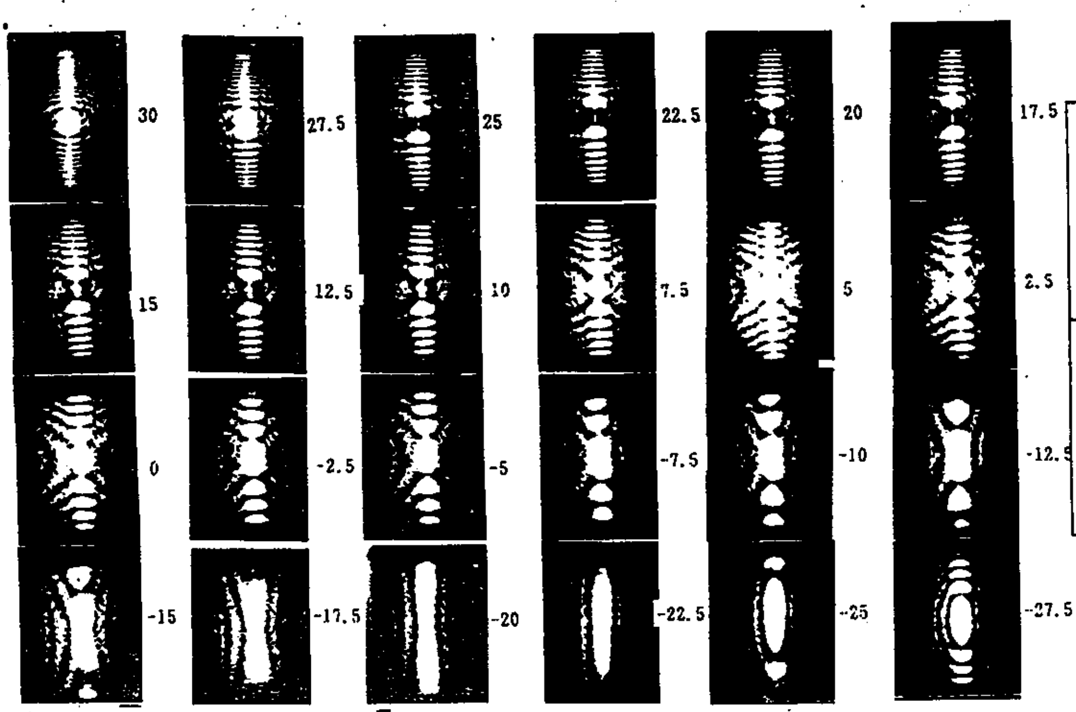
(a) (b)
CSP(750nm)

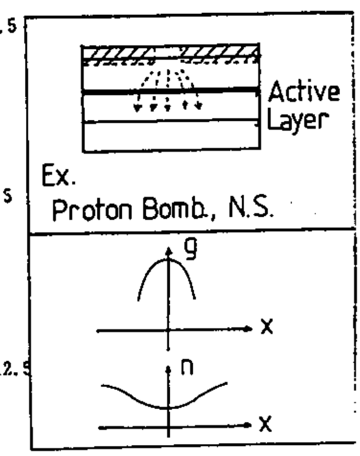



Index Guide




Quasi-index Guide



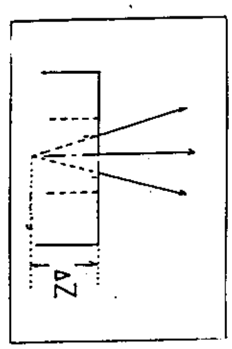
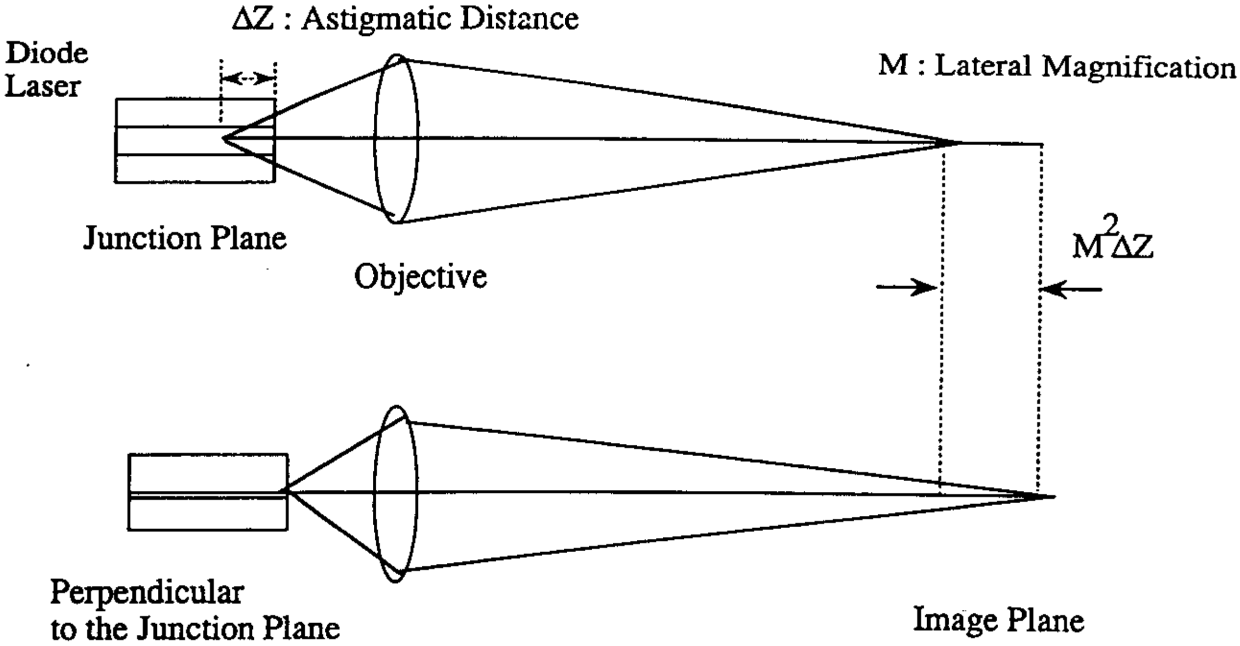




図３－１０　利得ガイド型レーザの干渉縞（１）数字はコリメータレンズの送り、Δａ（ｍｍ）を示す。

## Near Field Measurement

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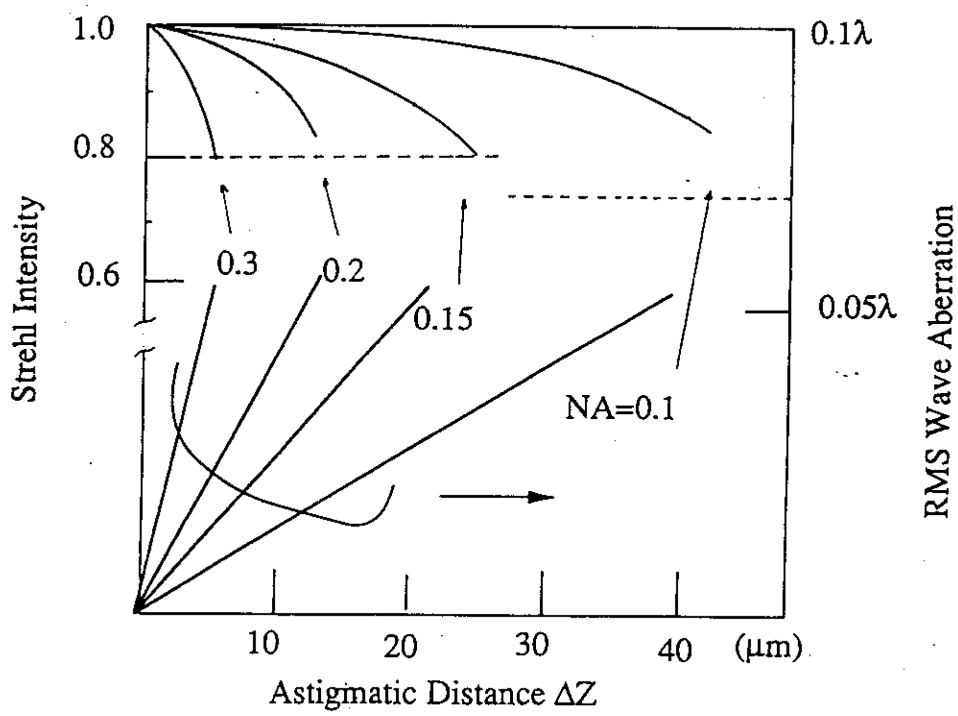
## Astigmatism Tolerance for the Diode Lasers

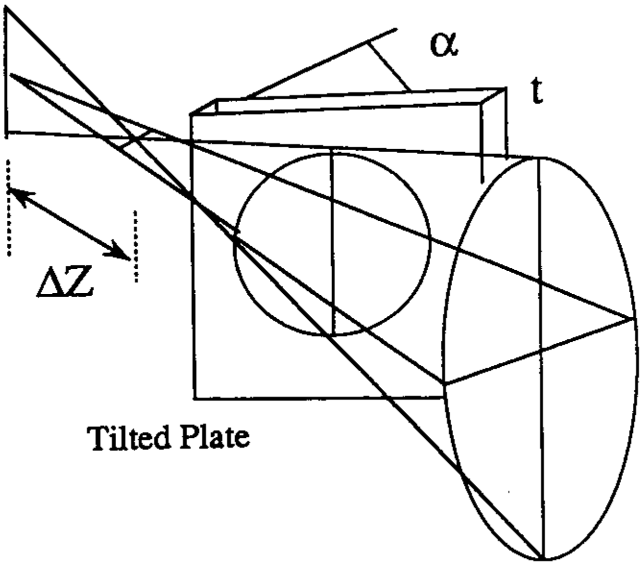
Astigmatism:

$$\Phi(\rho,\theta) = A^{z}_{22}\rho^{2}\cos 2\theta$$

$$A^{z}_{22} = \Delta Z \, NA^{2}/4$$



## Astigmatism Correction




$$\Delta Z = \frac{t\,(n^2-1)\alpha^2}{n^3}$$

ΔZ : Astigmatic distance

t : Thickness of plate

n : Refractive index of plate

α : Tilted angle

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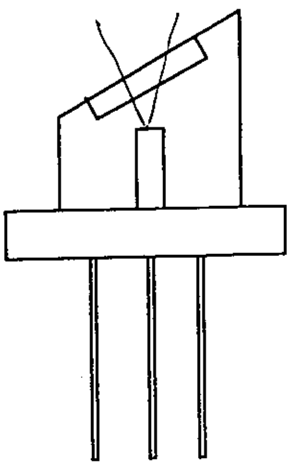
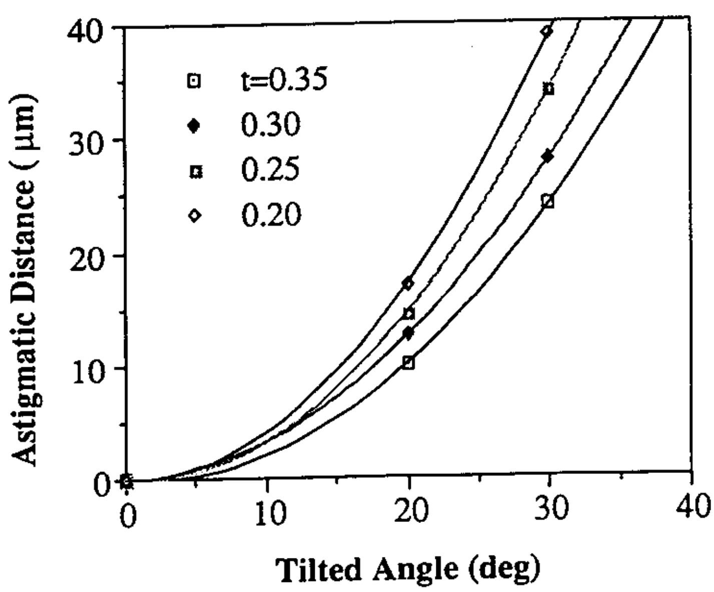
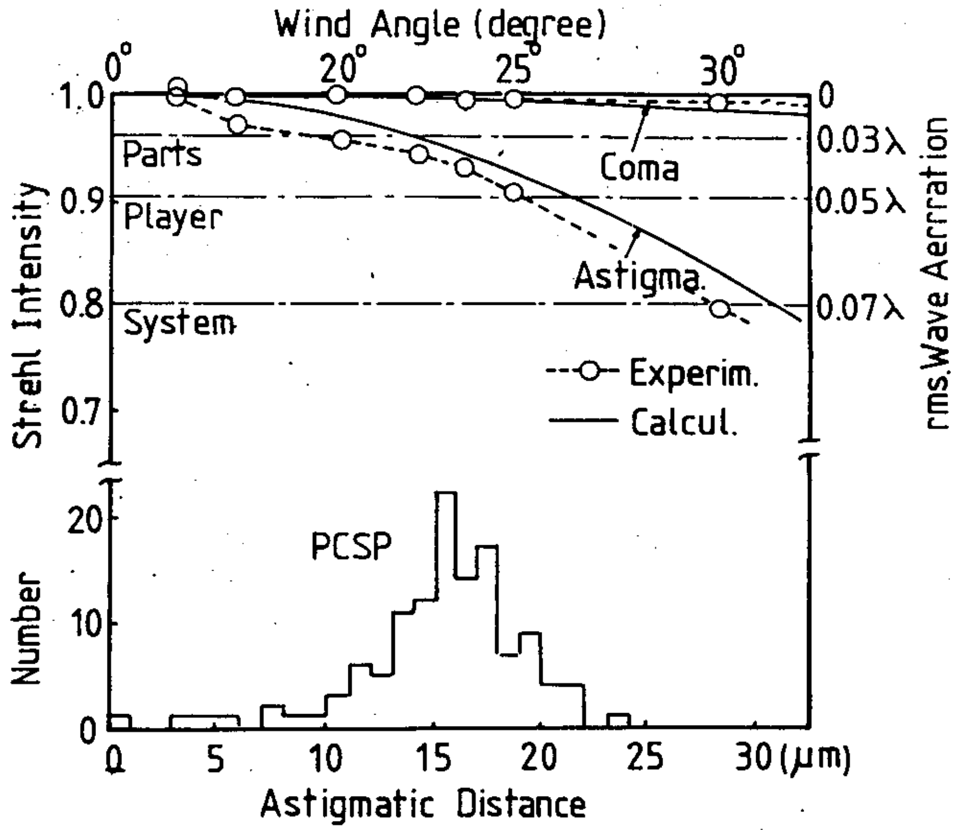
## Tilted Window Diode Laser



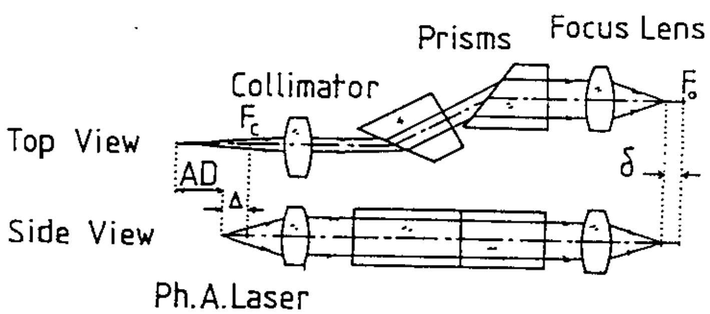
Side View




55 millions/year

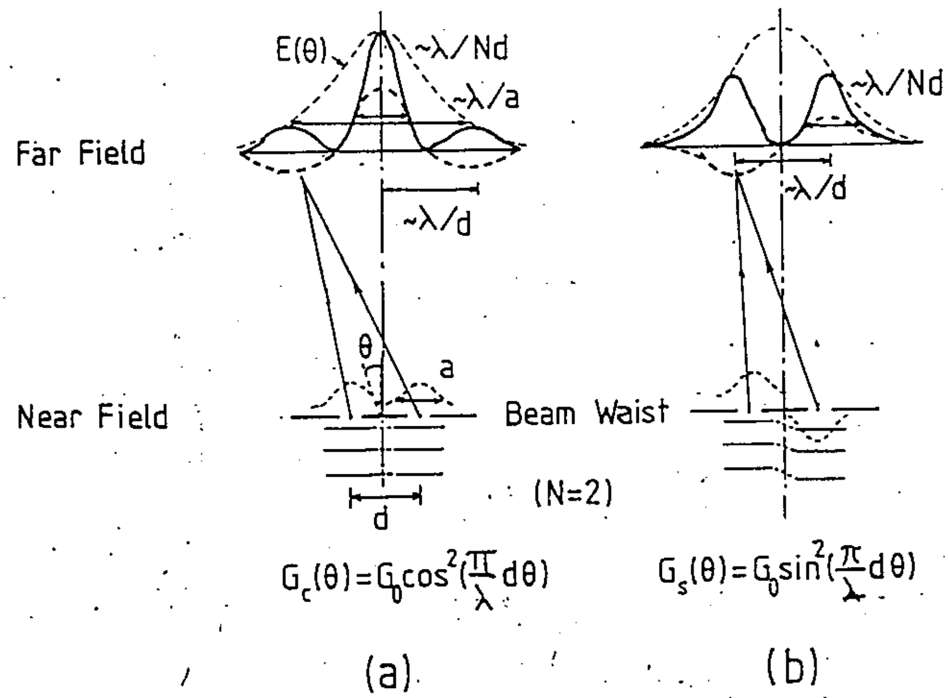



## Astigmatism correction with prisms




$$AD + \Delta = M_T^2 \delta_T$$
$$\Delta = M_S \delta_S$$
$$\delta = \delta_T = \delta_S$$
$$AD = (M^2 - 1)\Delta \quad , \quad M = M_S / M_T$$

## Far field pattern of phase coupled array lasers

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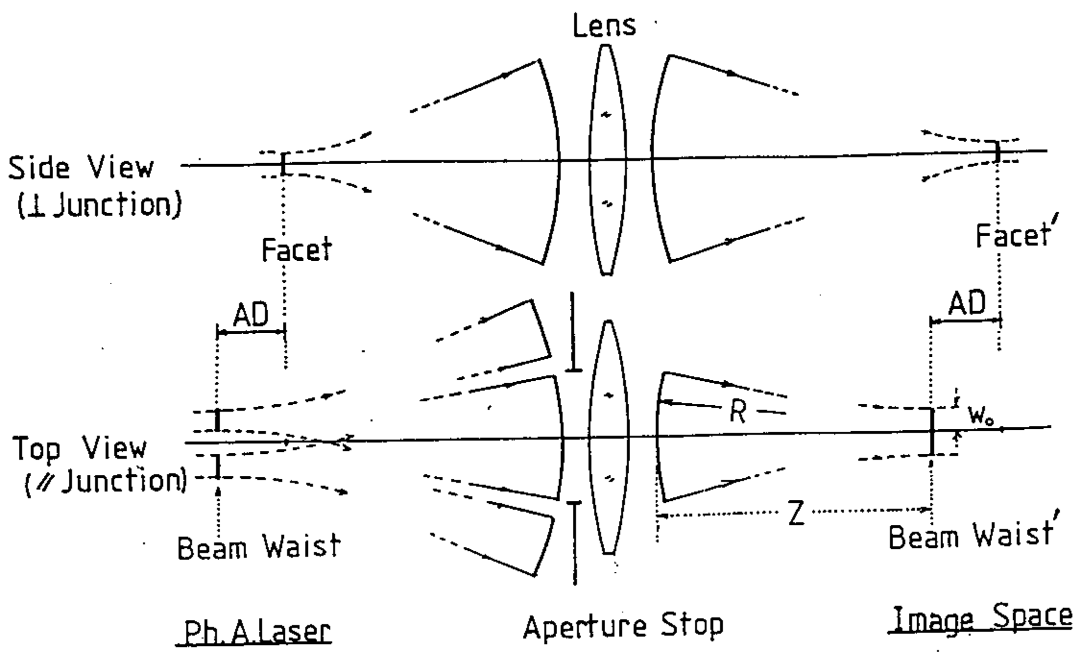
## Optical Path Analysis for the Phase Coupled Array Lasers

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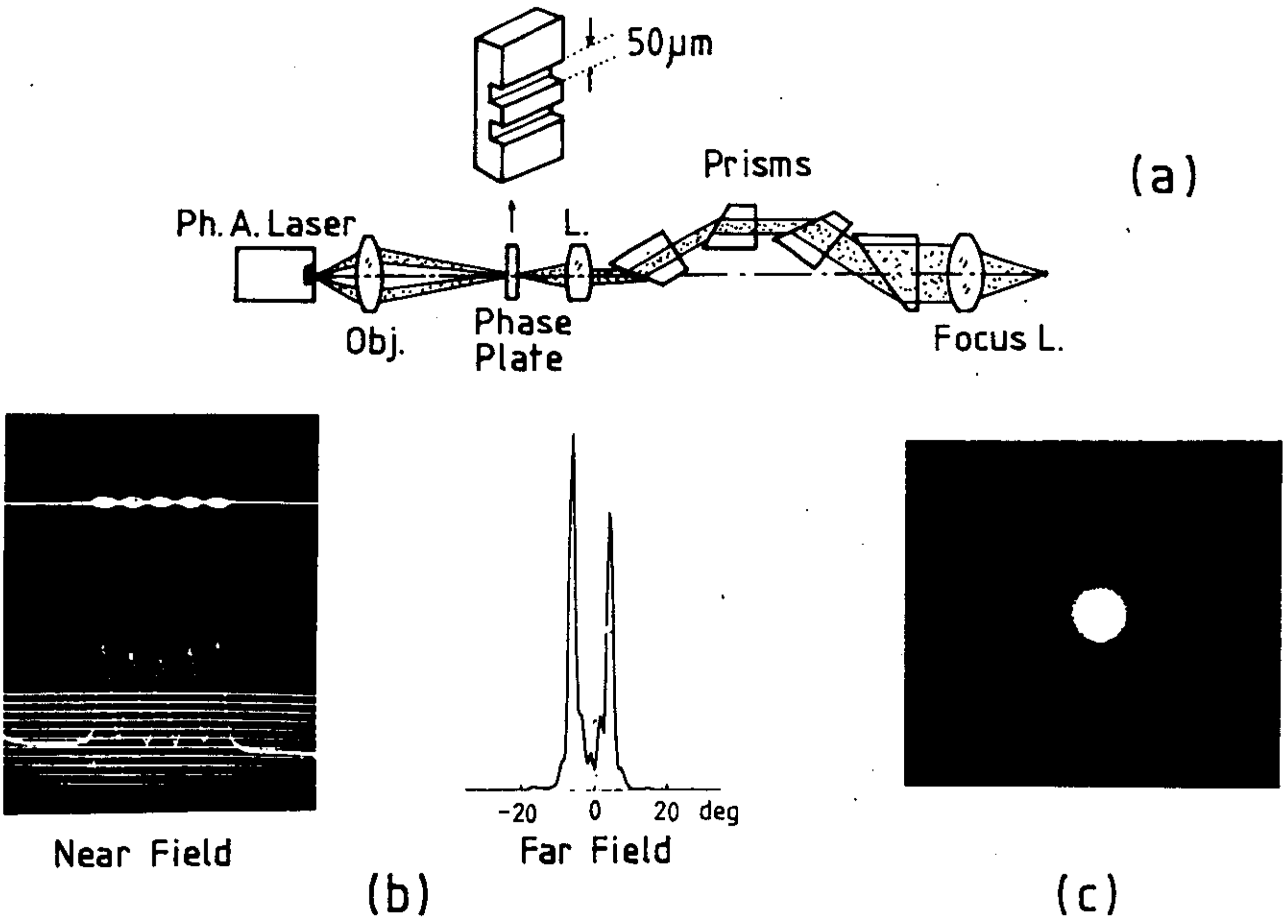
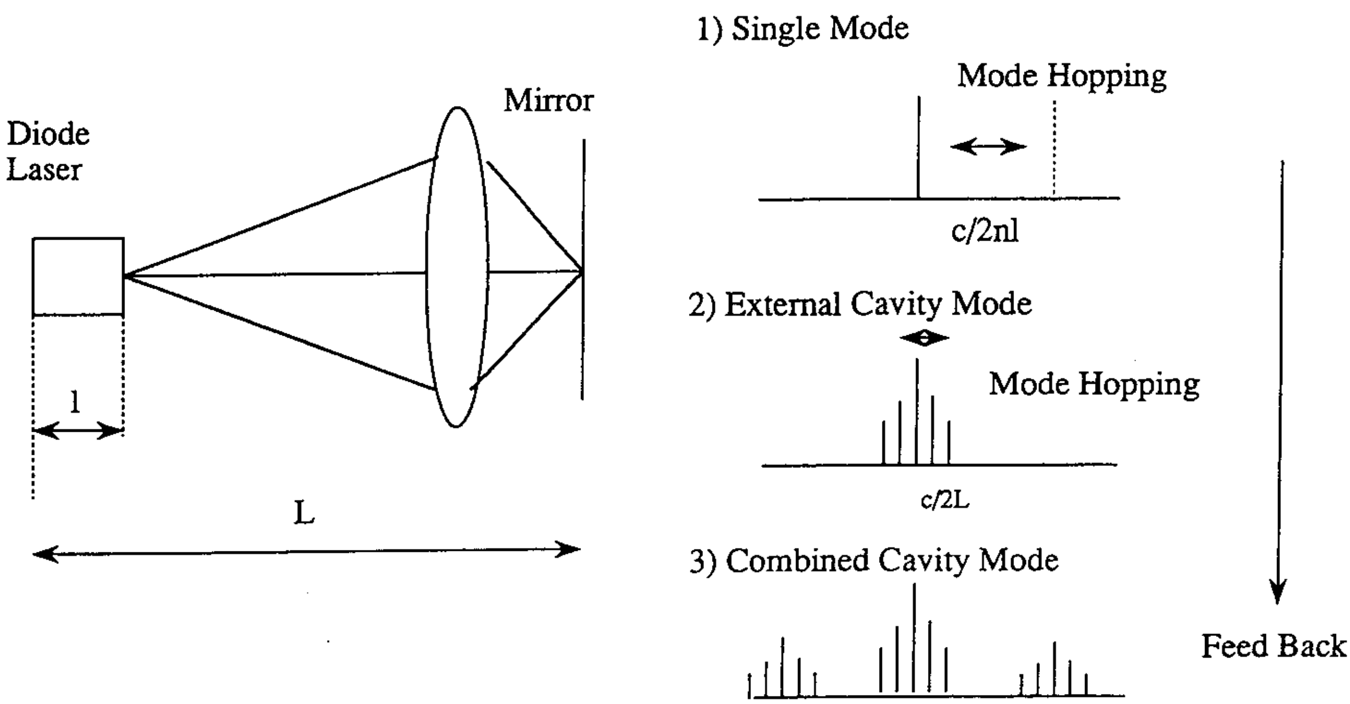
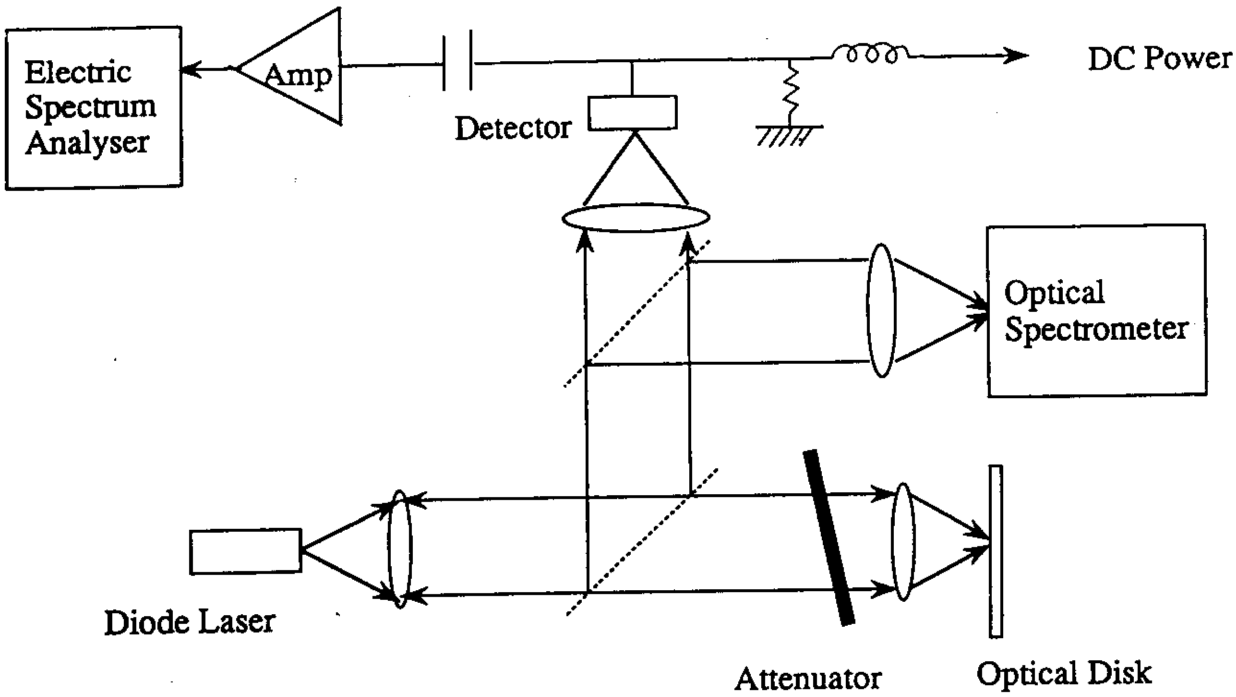



## Cavity Modes & Diode Laser noise



## Noise Measurement Set-up

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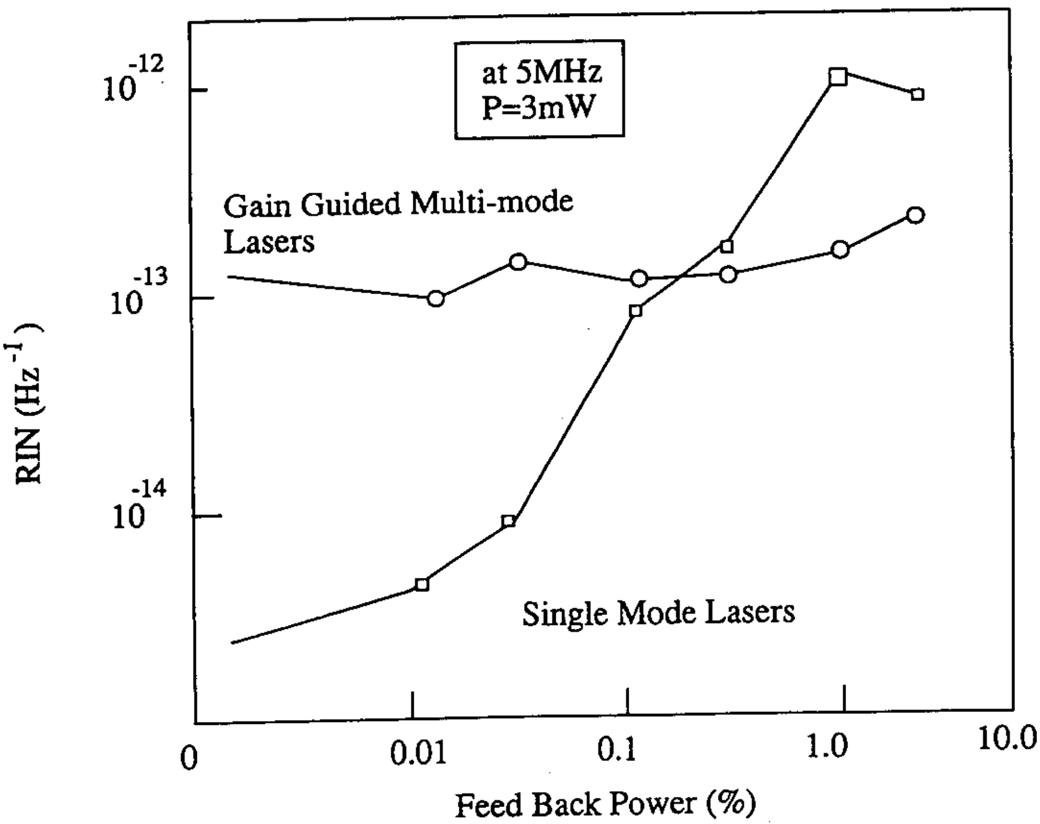
## Diode Lasers noise



# Relative Intensity Noise

$$RIN = \frac{\Delta P^2}{P^2 \Delta f} \qquad (1)$$

$$V = k\,P, \quad \Delta V = k\,\Delta P \qquad (2)$$

| |
|---|
| $\Delta P$ : Noise Power |
| $P$ : DC Power |
| $\Delta f$ : Measurement Band Width |
| $V$ : detecting Voltage |
| $k$ : Conversion ratio |

Noise power indicated on a Spectrum Analyser with 50Ω impedance is given by $\Delta V^2/50 \times 10^3$ (mW). And it is expressed as *x dBm* . Therefore,

$$\begin{aligned} x &= 10 \log (\Delta V^2/50 \times 10^3) \\ &= 20 \log \Delta P + 10 \log (k^2/50 \times 10^3) \qquad (3) \end{aligned}$$

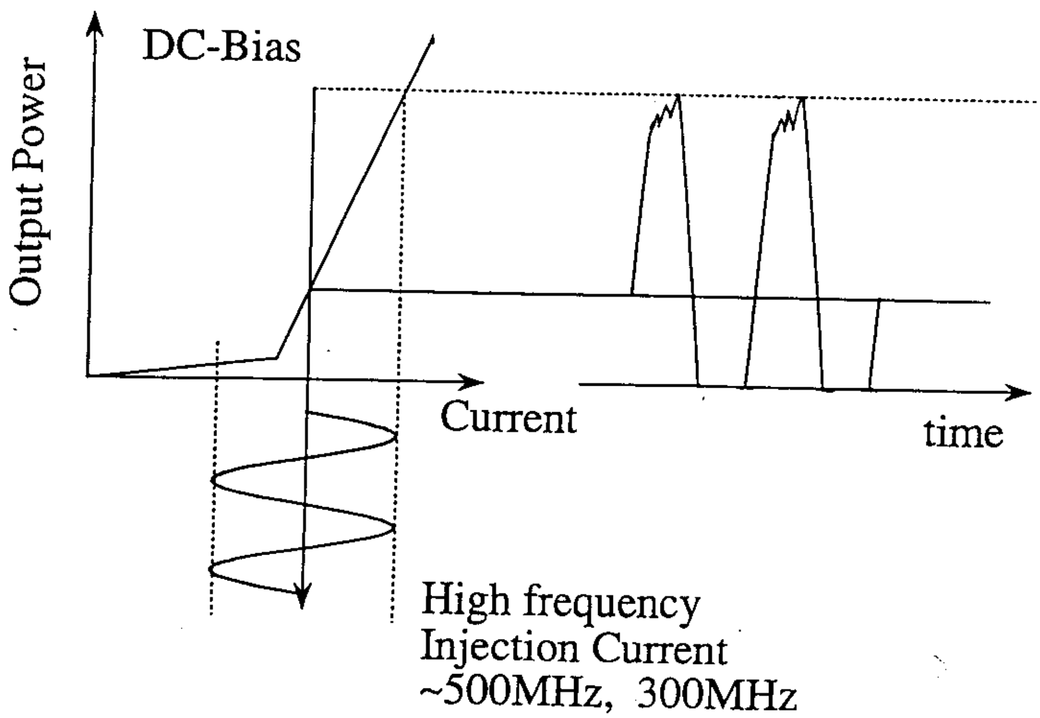
Equations (1), (2) and (3) gives

$$\boxed{10 \log RIN = x - 20 \log(V) - 10 \log (\Delta f) - 13} \qquad (4)$$

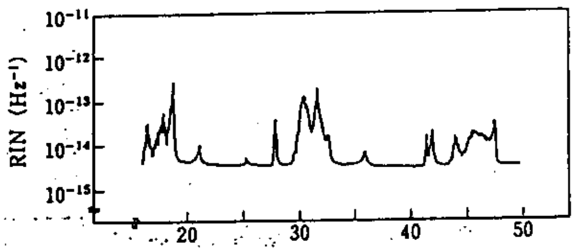
Ex. RIN= -122dB, when x=-90dBm, V=0.05V, and Δf=30kHz



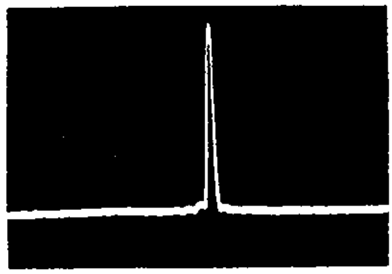
# Noise Reduction with High Frequency Superimposing



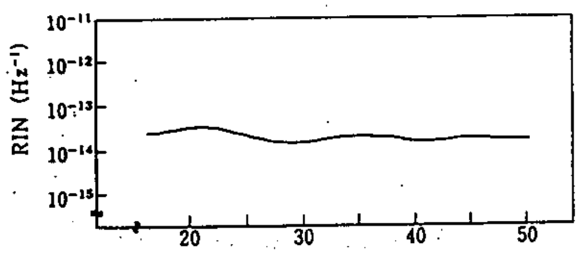
# Noise Reduction with High Frequency Superimposing-Results-



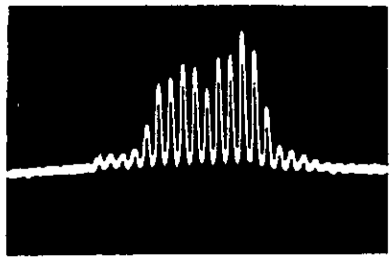

Temperature ( C)



Longitudinal mode




Temperature ( C)



Longitudinal mode

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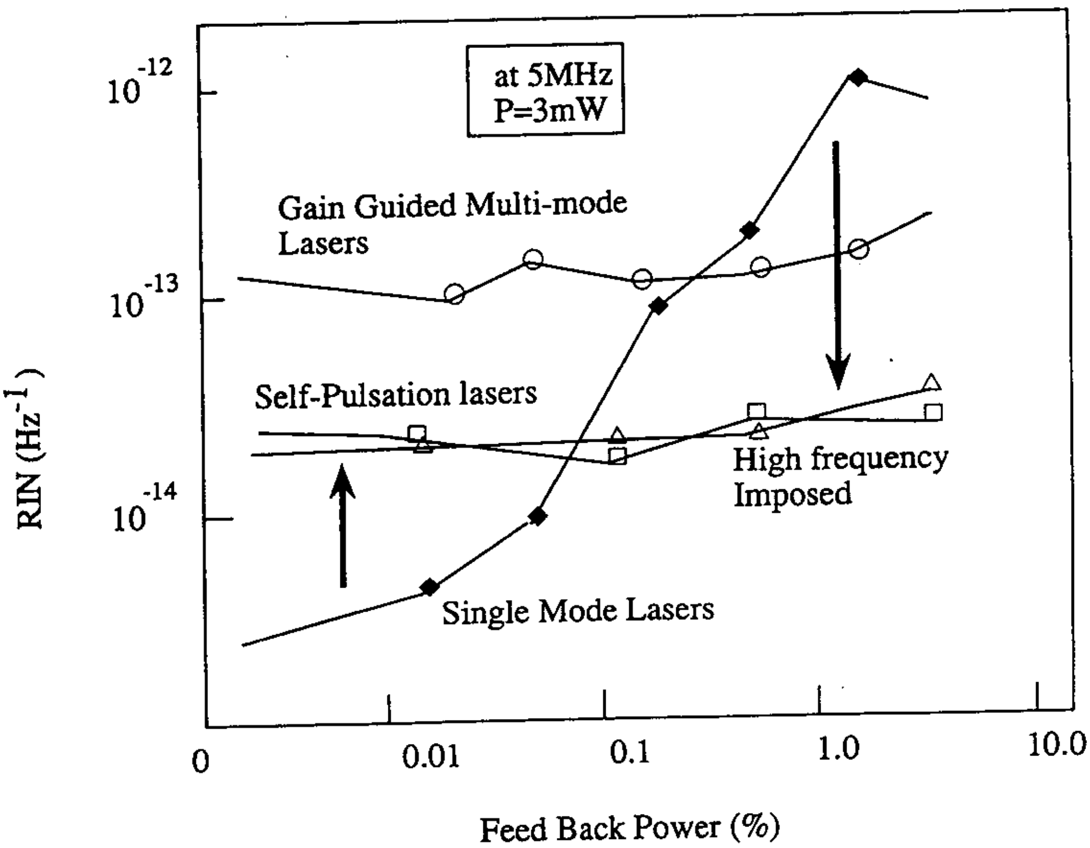




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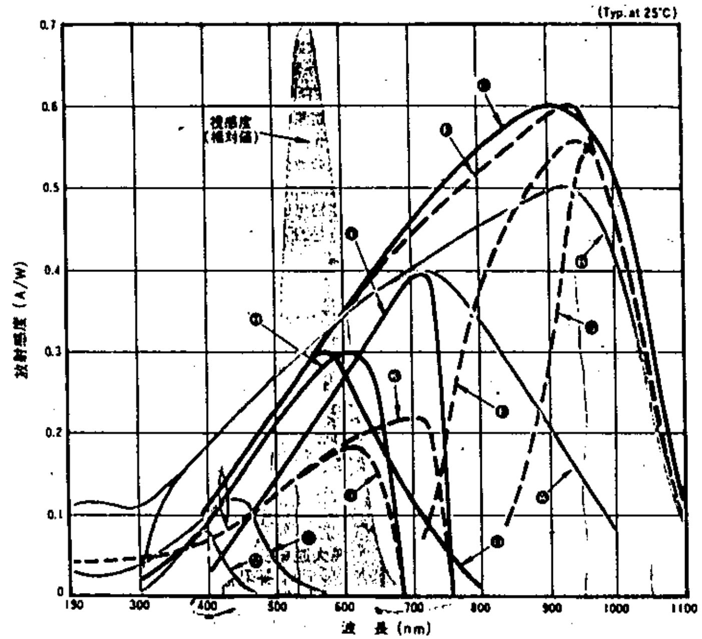
# セレクションガイド

●フォトダイオードの分光感度特性(代表例)




| 種 類 | 特 長 | 分光感度特性 波長範囲(nm) | ピーク波長(nm) | 記号 | 型 名 | 掲載ページ |
|---|---|---|---|---|---|---|
| シリコンフォトダイオード | 紫外～可視域精密測光用 | 190～1000 | 720 | [illegible] | S1226, S1227シリーズ | 12・13 |
| | 紫外～赤外域精密測光用 | 190～1100 | 920 | [illegible] | S1336, S1337シリーズ | 14・15 |
| | 可視～赤外域精密測光用 | 400～1100 | 900 | [illegible] | S2386, S2387シリーズ | 16・17 |
| | 可視域一般測光用, カメラ用 | 320～730 | 560 | [illegible] | S1087, S1133, S2832 etc. | 18・19 |
| | 可視～赤外一般測光用 | 300～1100 | 900 | — | S1087-01, S1133-01 etc. | |
| PINシリコンフォトダイオード | 高速応答 | 400～1000 | 800 | — | S2839, S2840 | 20～23 |
| | | 400～1060 | 900 | — | S1188, S2216, S1721 etc. | |
| | | 400～1100 | 920 | — | S1190, S1223 etc. | |
| [redacted] | | | | | | |
| | 可視カット型 | 700～1100 | 950 | [illegible] | S2506 | |
| | | 840～1100 | 980 | [illegible] | S2506-01 | |
| | 大型受光面, 高紫外感度 | 190～1060 | 920 | — | S1723-05 etc. | |
| GaAsPフォトダイオード (拡散型) | 可視域用, カメラ用 | 300～680 | 610 | [illegible] | G1115, G1116, G1117 etc. | 24・25 |
| | 赤感度延長型 | 400～760 | 710 | [illegible] | G1735, G1736, G1737 etc. | |
| GaAsPフォトダイオード (ショットキ型) | 紫外～可視域用 | 190～680 | 610 | [illegible] | G1125-02, G1126-02 etc. | 26・27 |
| | 赤感度延長型 | 190～760 | 710 | [illegible] | G1745, G1746, G1747 | |
| GaPフォトダイオード | 紫外～緑色光専用 | 190～520 | 440 | [illegible] | G1961, G1962, G1963 | 28・29 |
| | 紫外専用 | 280～410 | 380 | [illegible] | G1961-01, G1962-01 | |
| シリコンアバランシェフォトダイオード | 高速応答, 高ゲイン | 350～1050 | 830 | — | S2381, S2382, S2383 S2384, S2385 | 30・31 |



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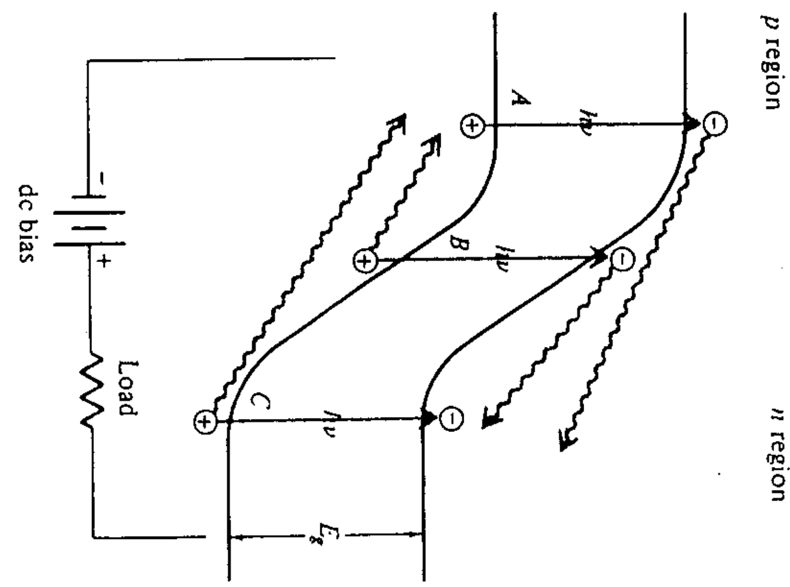
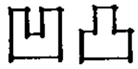
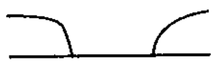
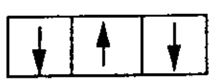


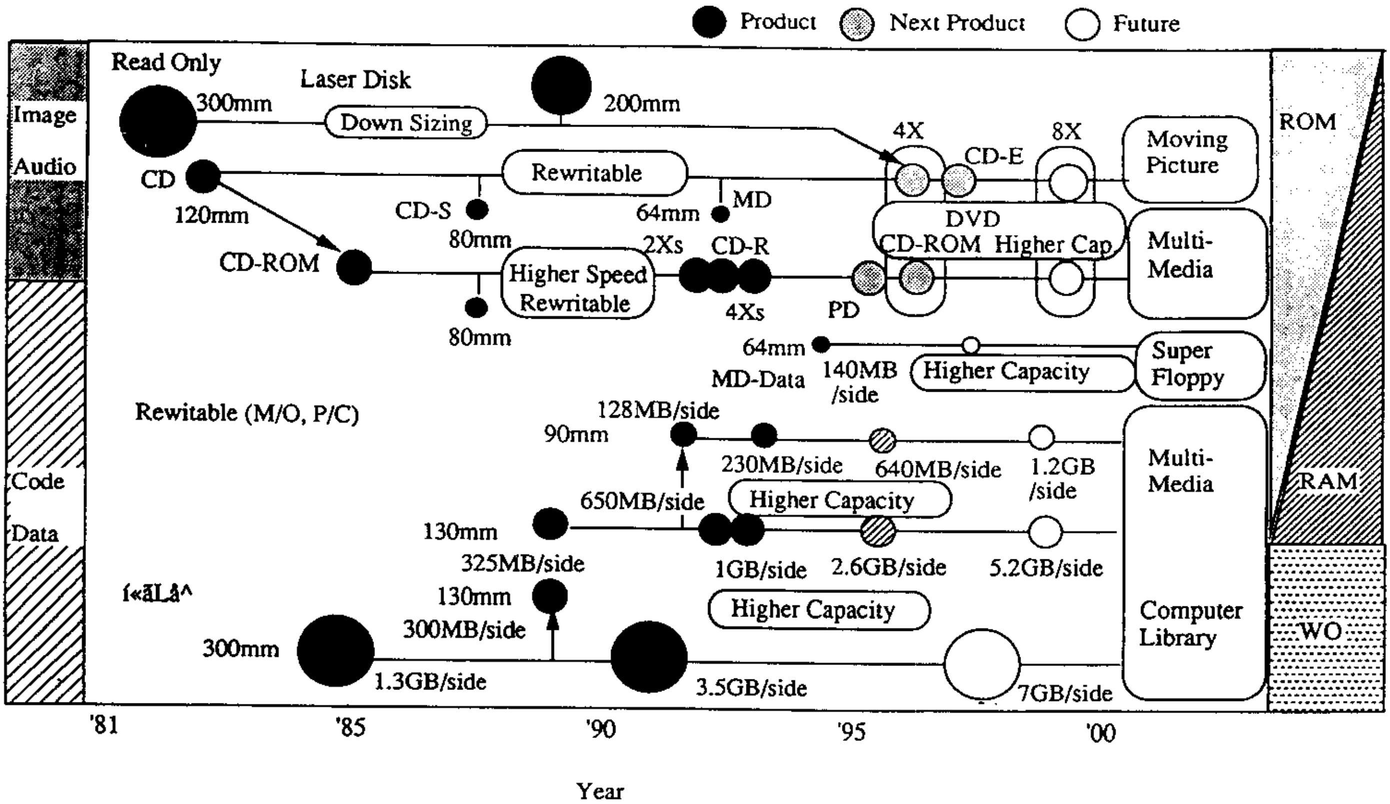
# Optical Disk Types

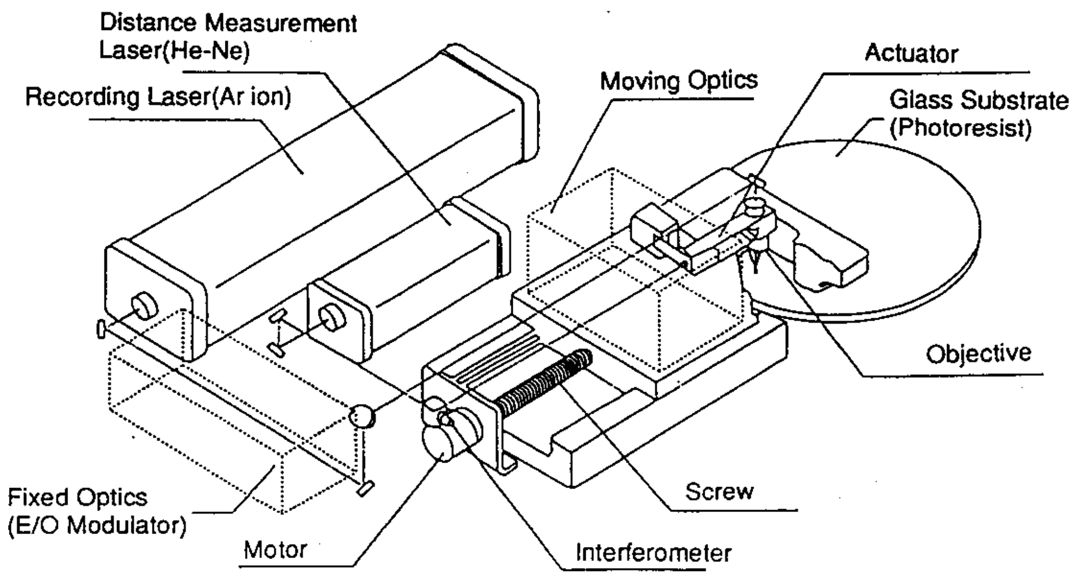
| | |
|---|---|
| Read Only |  Pits |
| Write Once | Hole Making<br>Phase Change<br>Organic Dye |
| Rewritable | Magneto-optic<br>Phase Change |

Optical Disks

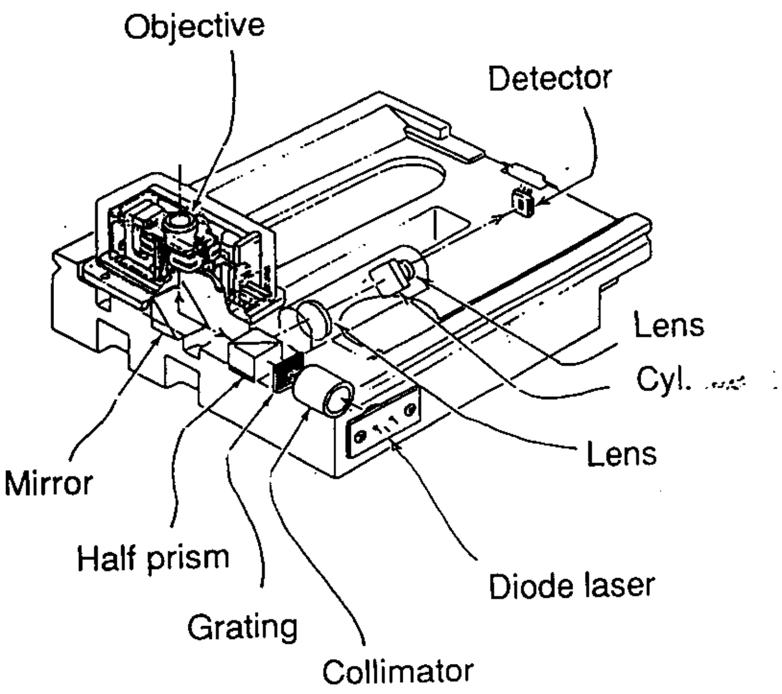
| Type | | Pit | Applications |
|---|---|---|---|
| Read only | | Depression  | CD<br>CD-ROM<br>Video Disc |
| Write once | | Hole making  | Document Filing<br>Computer File<br>Video File |
| Rewritable | Magneto-optical | Magnetization  | Computer File<br>CD-E, MD<br>Digital Video |
| | Phase Change | Crystal/Amorphas  | Video-File<br>CD-R, E<br>Video File |

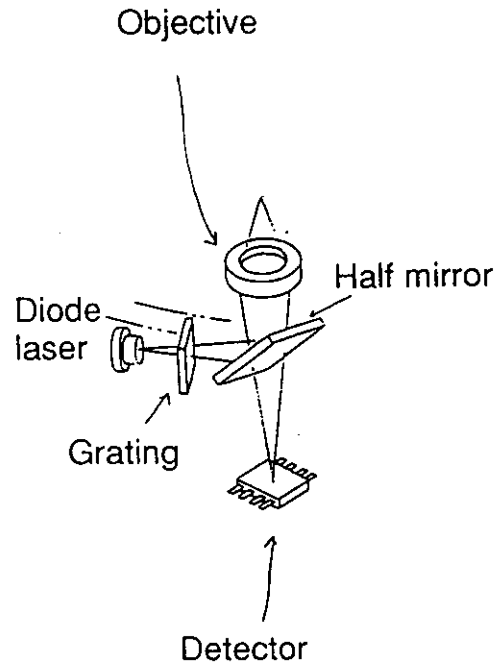
# Optical Disk Map



| I | IV |
|---|---|




## Hitachi Pick-up for CD-Player

| Generation | | I | II | III | IV |
|---|---|---|---|---|---|
| Obj. | Opt. | Infnity | ← | ← | Conj. |
| | Type | Triplet | ← | Aspheric Plastic | ← |
| Col. | NAc | 0.118 | ← | 0.113 | 0.09 |
| | Eff. (%) | 27 | 27.4 | 15.7 | 18.6 |
| Fd Bck(%) | | 1.5 | 1.6 | 0.9 | 1.1 |
| Beam Spl. | | Half Prism | ← | Half Mirror | ← |
| Path Length (mm) | | 80 | 44 | 48 | 25 |
| No. of Opt. Comp. | | 8 | 6 | 6 | 3 |
| Year | | 1982 | 1983 | 1985 | 1988 |

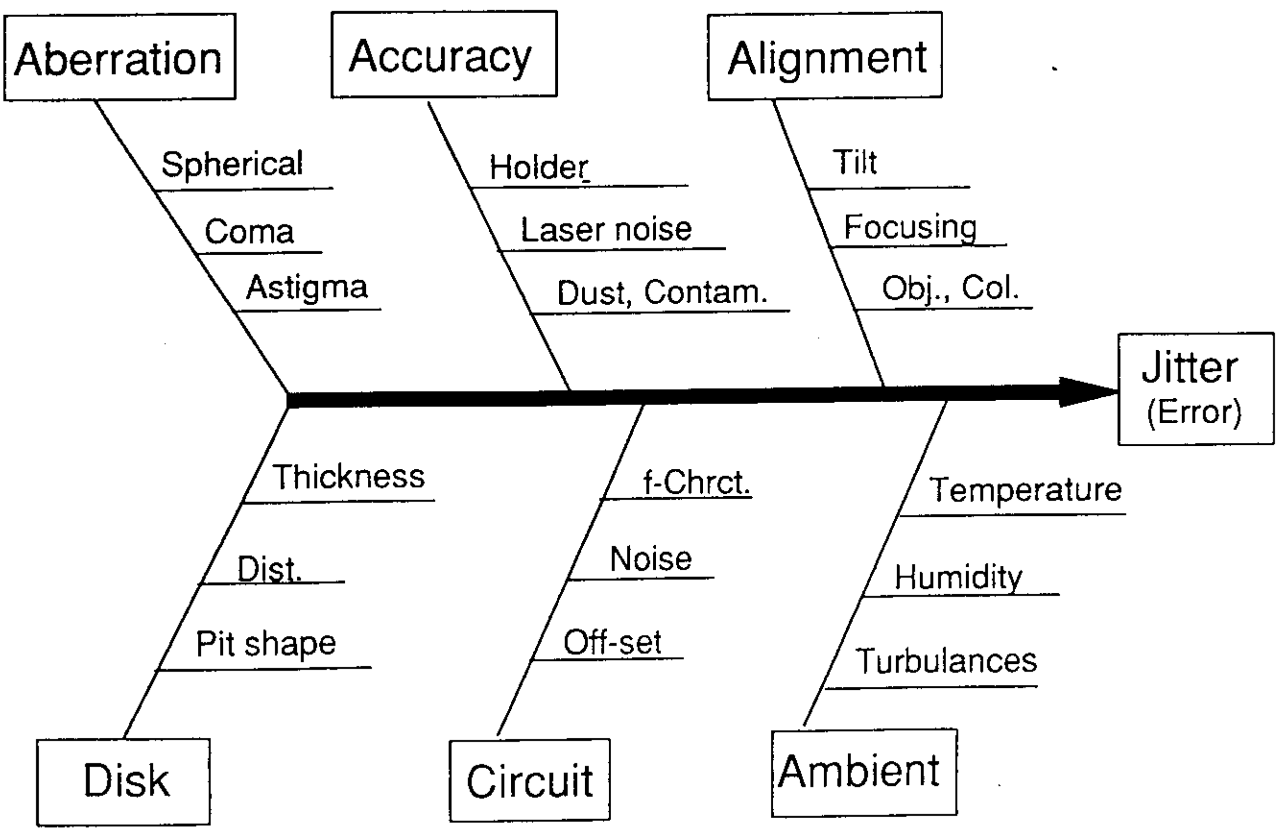
Auto-focus: Astigmatic, Tracking: 3-spots

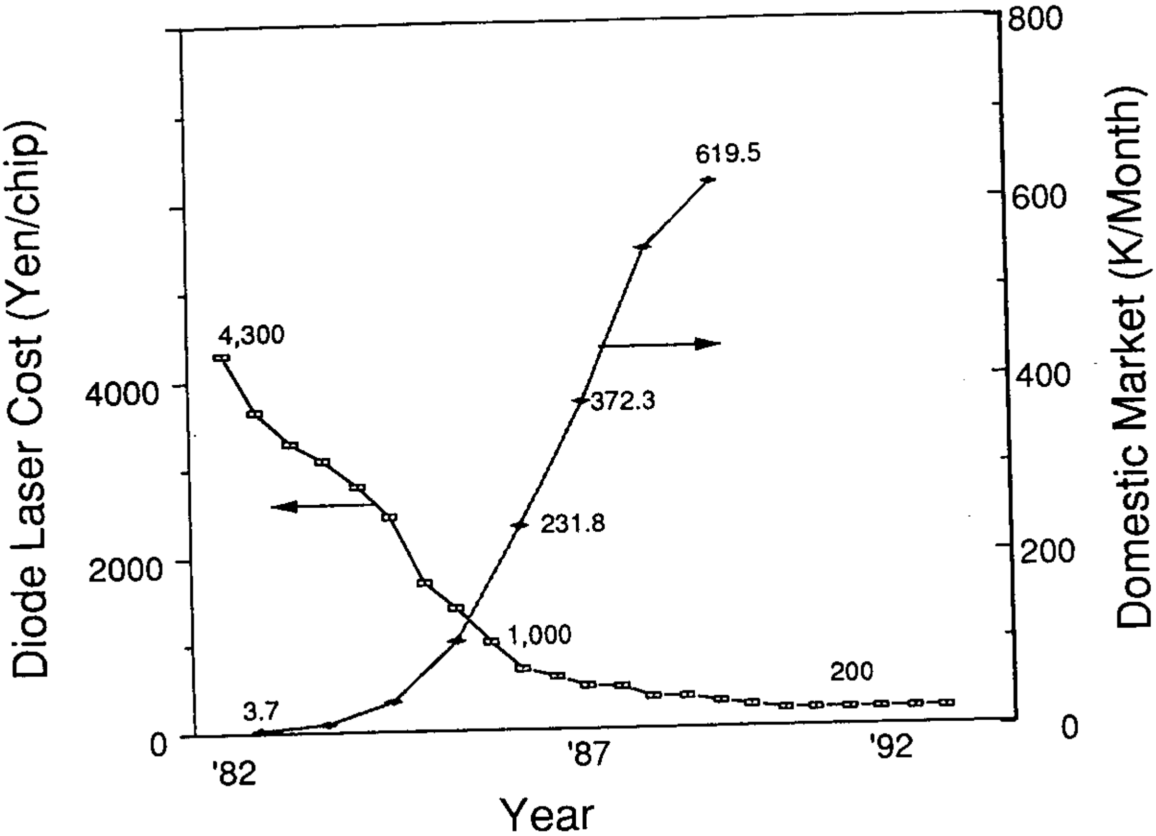
## Diode Lasers for Hitachi Pick-ups

| Generation / Year | | I 1982 | II 1983 | III 1985 | IV 1988 |
|---|---|---|---|---|---|
| Type | | Single mode | Pulsation | Gainguided | Pulsation |
| $I_{th}$ (mA) | | 50 | 50 | 60 | 35 |
| Q.Eff | | 0.25 | ← | 0.3 | |
| Op. Curr.(mA) | | | 65 | 70 | 45 |
| Op. Vol.(V) | | | 1.75 | 1.9 | ← |
| Beam Div. (deg.) | H. | 14 | 11 | 19 | 11 |
| | V. | 27 | 33 | 38 | 37 |
| Ast. Dis. (μm) | | < 5 | < 10 | < 40 Tilted Wndw | <10 |
| Noise Red. | | Mult. Fd Bck | Self Pulsation | Multi. | Self Pulsation |

Po=5mW(APC), Wavelength= 780~7 85nm

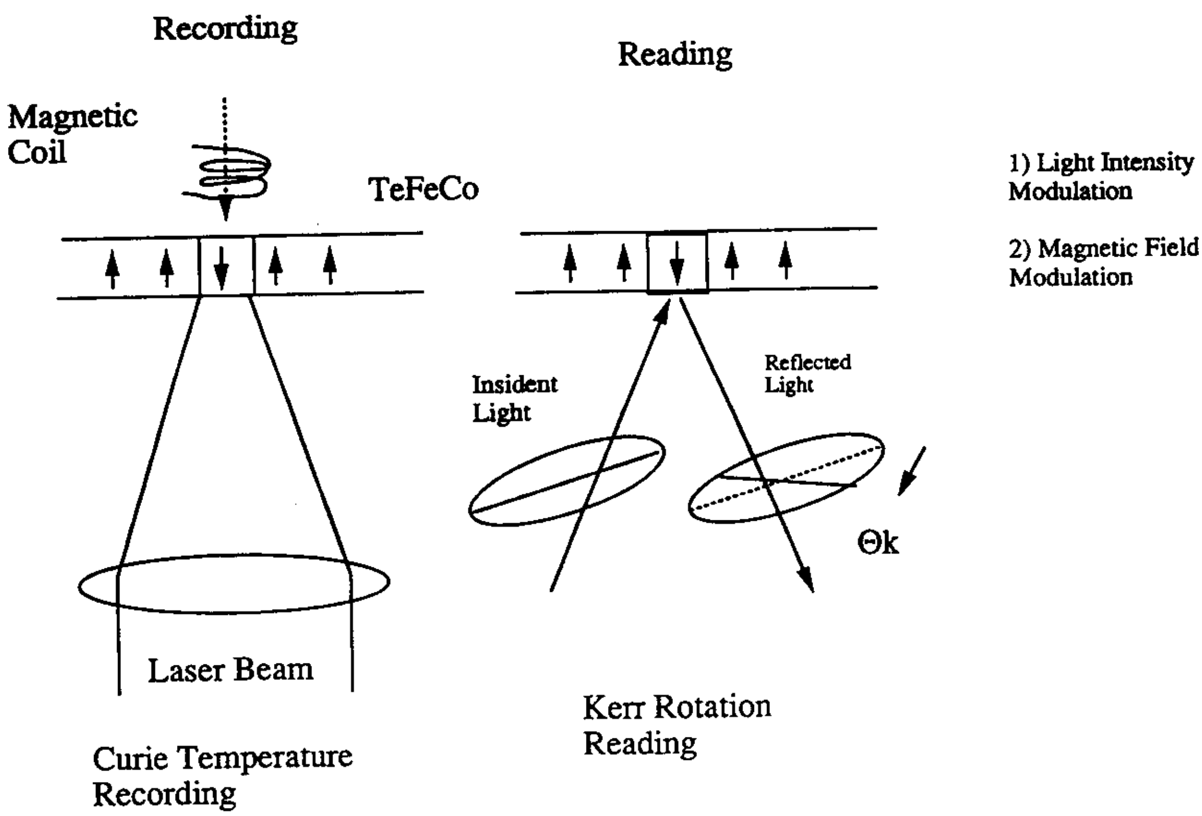
## Jitter Analysis



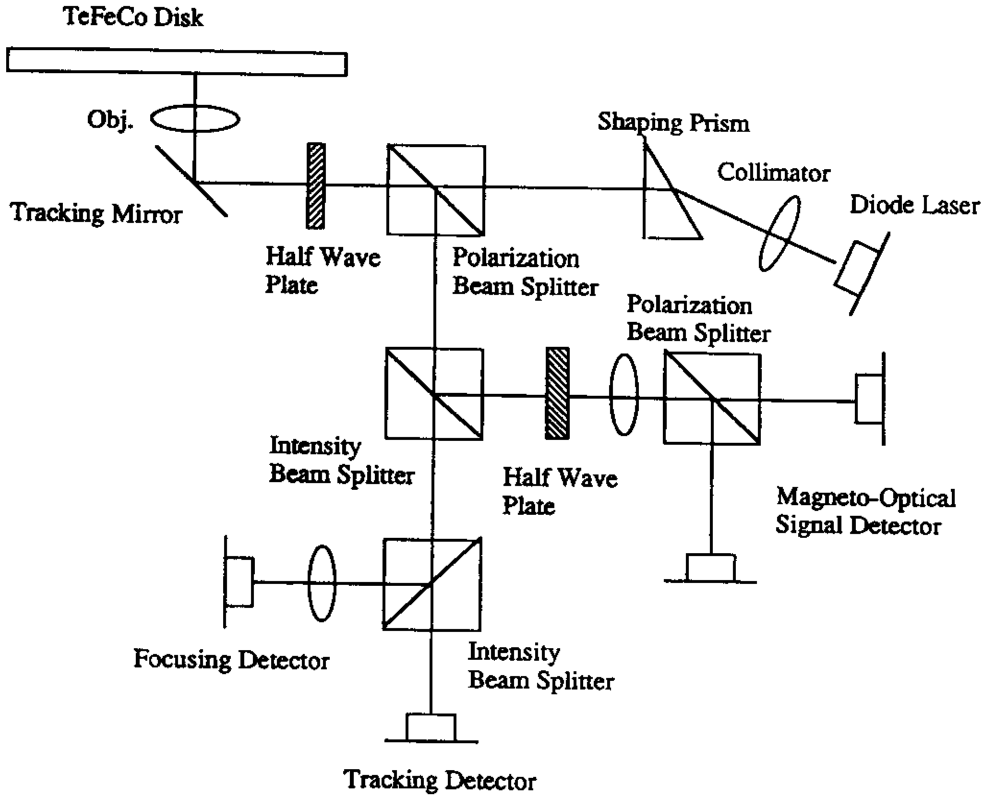



Market size and the Diode Laser Cost

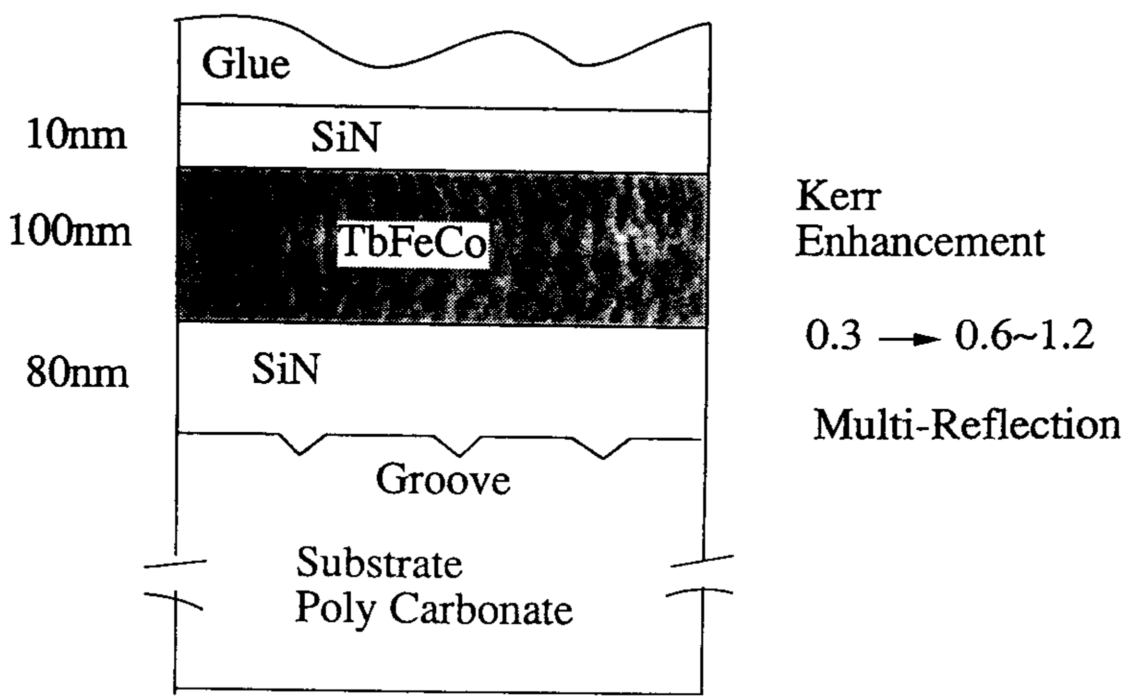
## Principles of Magneto-Optic Memory



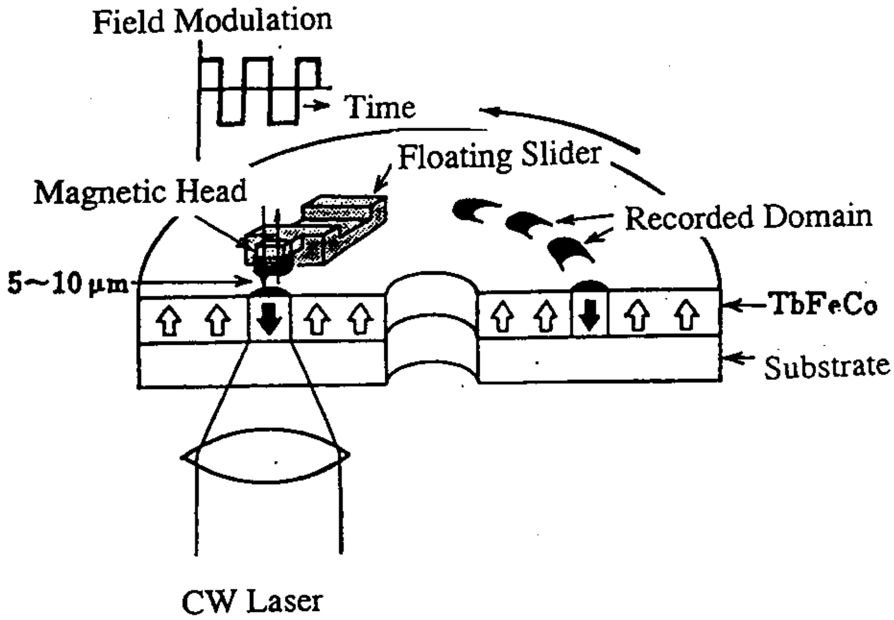
## Magneto- Optical Head Structure

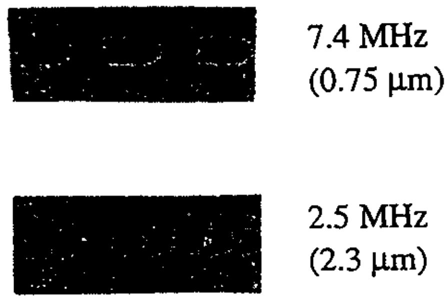



## Magneto-Optical Disk Structure



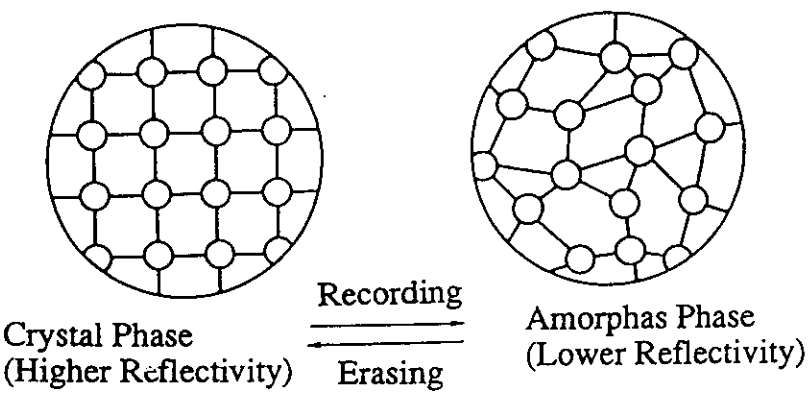
## Magnetic Field Modulation M/O Disk

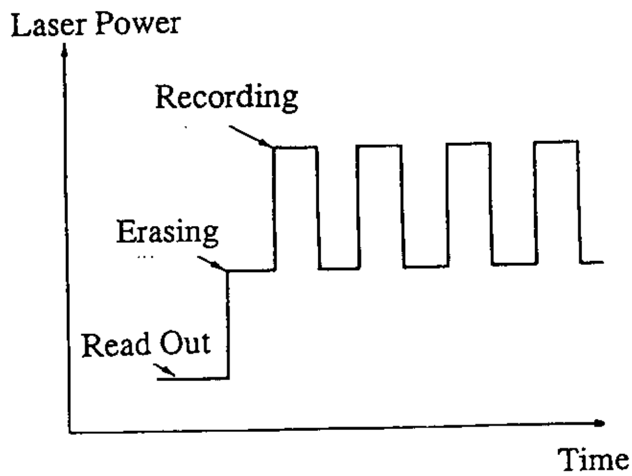


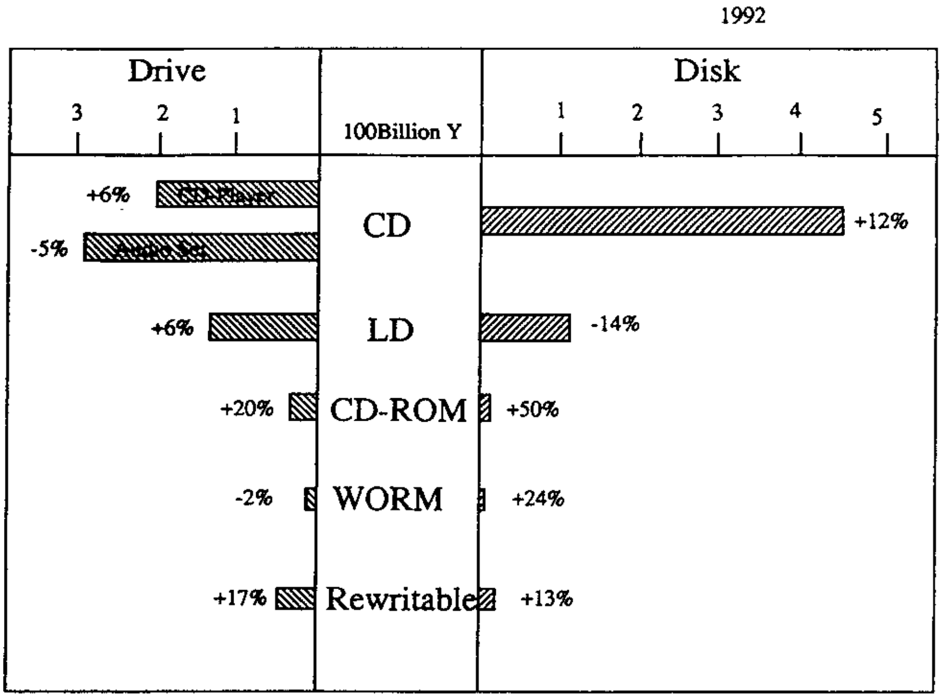

Recording
Power : 12mW

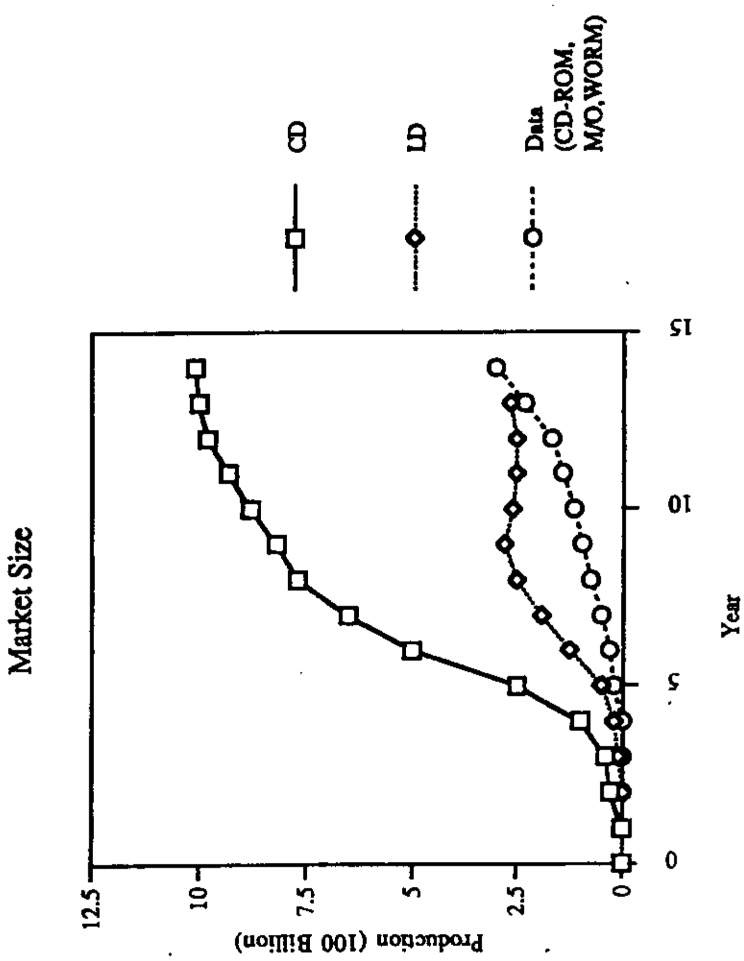
## Phase Change Erasable Optical Disk



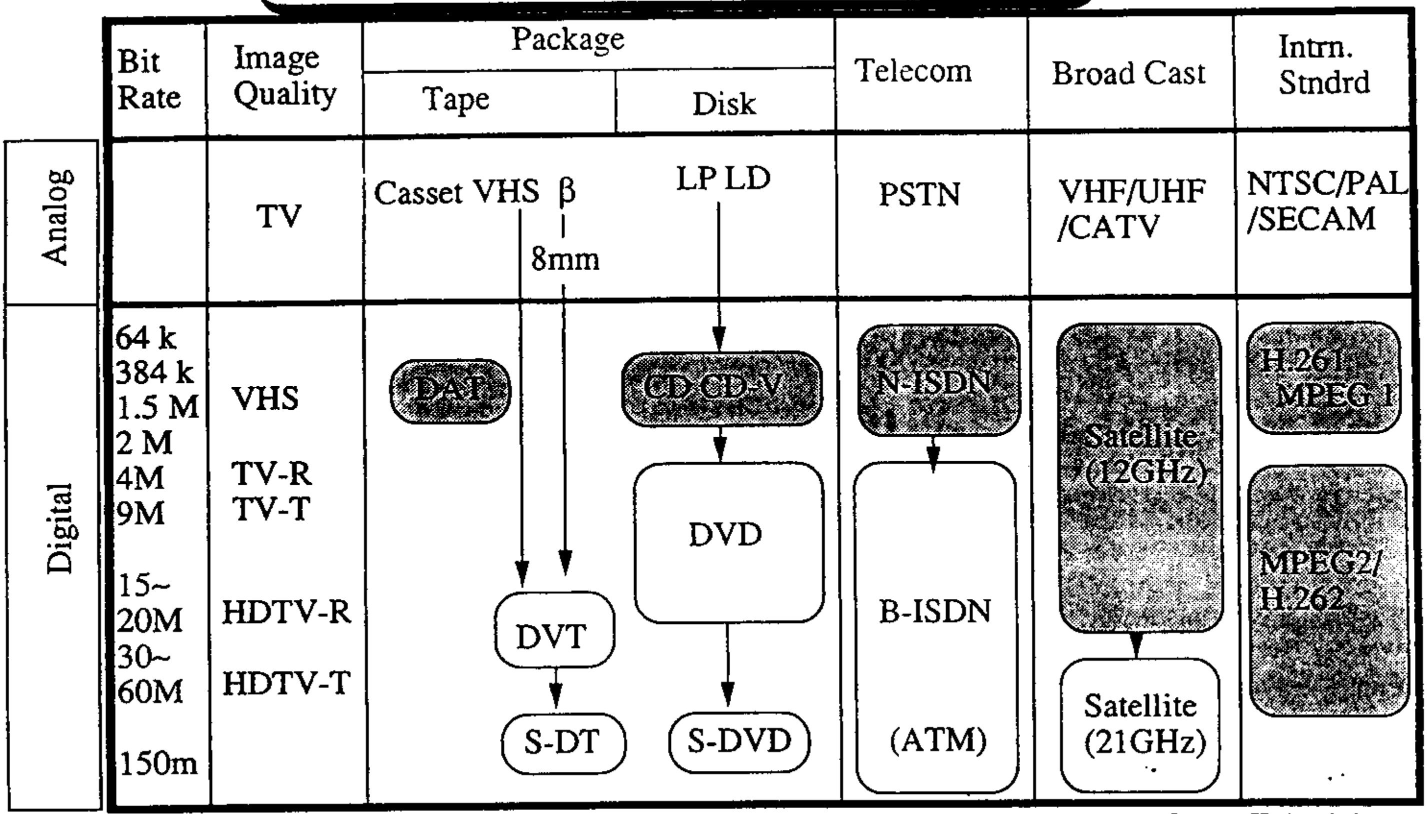



# Domestic Optical Disk Production



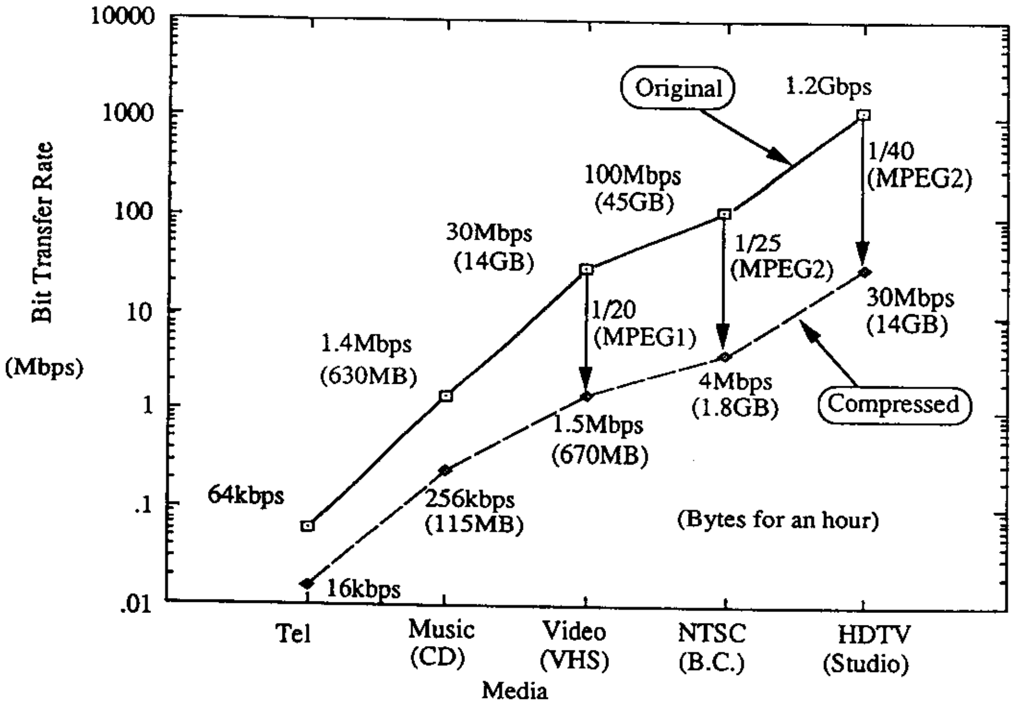
## Multimedia and PKG/Telecom/Broad Cast

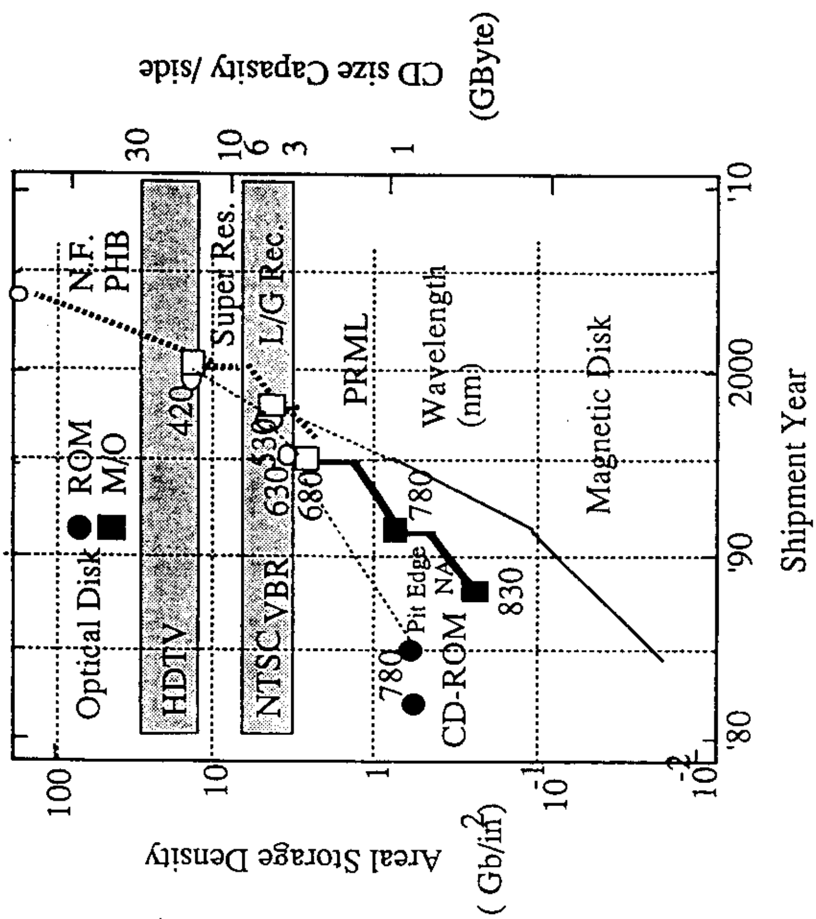



PSTN:Public Switched Telephone Network
NTSC:National Television System Committee
PAL:Phase Alternation by Line
SECOM:Sequentia a Memoire Color Television
ISDN:Integrated Services Digital Network
ATM:Asynchronous Transfer Mode

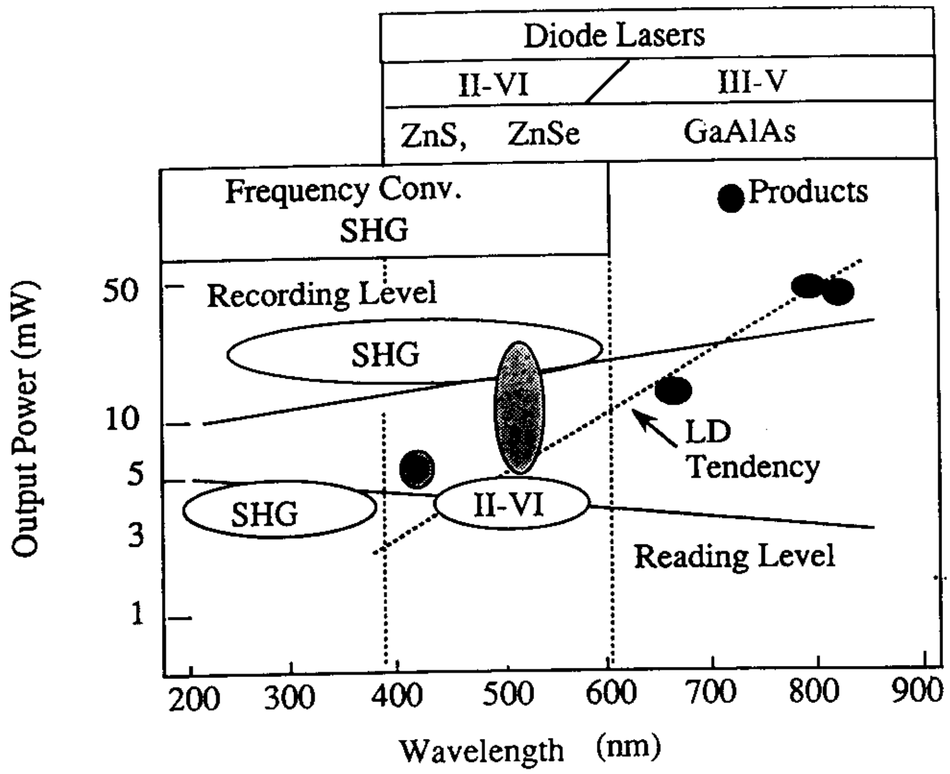
## Digital Data Compression

| Image Quality | Standarization | | Bit Tr Rate | Ratio | Data/hour |
|---|---|---|---|---|---|
| TV-Telephone | H.261 (CCITT) | | 64Kbps ~1.9Mbps | ~1/30 | |
| PKG media CD-V CD-Karaoke | MPEG 1 (ISO/IEC) | | ~1.5Mbps | 1/26 | 650MB |
| High Quality PKG media | MPEG 2 | NTSC [VBR] | 3.0Mbps 4.5Mbps | 1/50 1/40 | 1.5GB 2.4GB |
| Braod Cast | | [Fxd} | 8.4Mbps | 1/20 | 3.8GB |
| Hi-Vision | | HDTV | 24Mbps | 1/40 | 10.8GB |


Bit Transfer Rate
(Mbps)
10000
1000
100
10
1
.1
.01
Original
1.2Gbps
1/40
(MPEG2)
100Mbps
(45GB)
30Mbps
(14GB)
1/25
(MPEG2)
1/20
(MPEG1)
30Mbps
(14GB)
1.4Mbps
(630MB)
4Mbps
(1.8GB)
Compressed
1.5Mbps
(670MB)
64kbps
256kbps
(115MB)
(Bytes for an hour)
16kbps
Tel
Music
(CD)
Video
(VHS)
NTSC
(B.C.)
HDTV
(Studio)
Media


CD size Capasity /side
(GByte)
Areal Storage Density
( Gb/in²)
Shipment Year
Optical Disk
ROM
M/O
N.F.
PHB
HDTV
Super Res.
NTSC VBR
L/G Rec.
PRML
Wavelength
(nm)
Magnetic Disk
CD-ROM
Pit Edge
NA
420
530
630
680
780
830

## Lasers for Optical Disks




## Second Harmonic Generation

1. Phase Matchig Condition

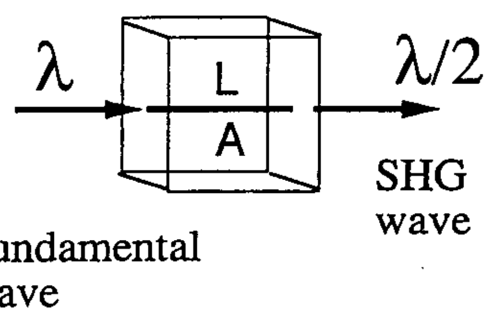
   Birefringence : $n(\lambda/2)=n(\lambda)$

2. Conversion Efficiency

$$P(\frac{\lambda}{2}) \propto \frac{P^2(\lambda)}{A} d^2 L^2$$

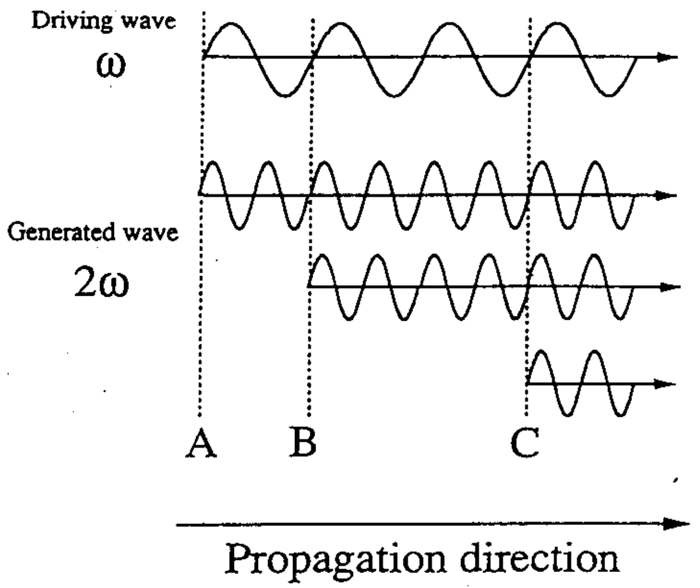
| | |
|---|---|
| $P(\lambda)$ | Fundamental |
| A | Beam Cross Section |
| d | Nonlinear Coefficient |
| L | Interaction Length |

Nonlinear Crystal

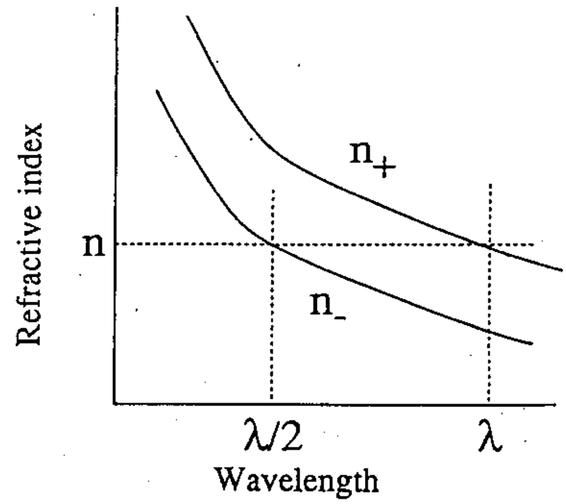


## Phase Matching Condition

$\Delta k=0$ $\quad v(\omega)=v(2\omega)=c/n \longrightarrow n_-(\lambda, \theta, \phi)=n_+(\lambda/2, \theta, \phi)$




(1) Wavelength dependency




(2) Propagation direction dependency
$(\theta,\phi)$



## SHG Characteristics

$$S_{2\omega}=\frac{2\mu_0^{\frac{3}{2}}\varepsilon_0^{\frac{1}{2}}\omega^2 d^2 L^2}{\pi w_0^2 n_{2\omega} n_\omega^2} S_\omega^2 \frac{\sin^2(\Delta kL/2)}{(\Delta kL/2)^2}$$

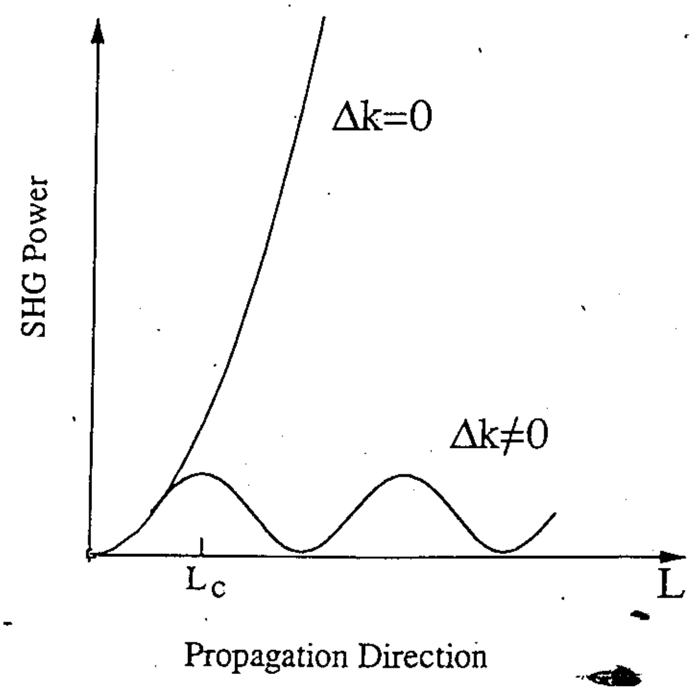
I) when $\Delta k=0$
SHG power is proportional to

1) the square of the fundamental power

2) $d^2/n^3$ : figure of merit

3) $L^2/\lambda^2$

II) when $\Delta k\neq 0$ : sinusoidal
$\longrightarrow$ Maker Fringe




Coherence length is given by

$L_c = \lambda/4\,(n_{2\omega}-n_\omega) \sim 3\mu m$

## Phase matching angle calculation

**Input**

1. Wavelength
   Fundamental λ
   SHG λ/2
2. Sellmeier's coefflsients

→

**CPU**

1. Sellmeier's equation

   $n_x, n_y, n_z$

2. Fresnel's wavenormal equation

   $n_\pm(\lambda, \theta, \phi), \quad n_\pm(\lambda/2, \theta, \phi)$

3. Type of phase matching
   Type I
   Type II
   SFG

→

**Output**

Phase matching angle $(\theta,\phi)$

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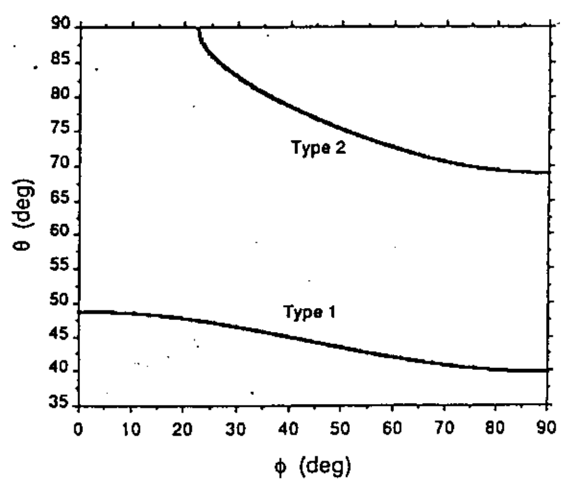
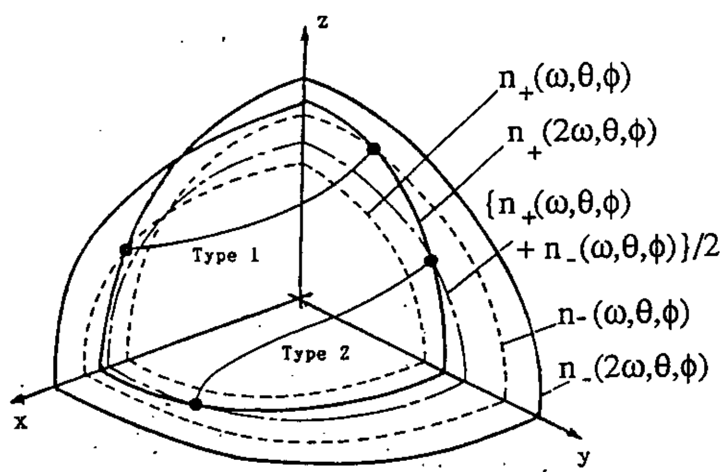
## Phase Matching Angle for KTP



# SHG Crystals

| Crystal | Transparent Wavelength (µm) | Nonlinear Coefficient (pm/V) | Temperature Tolerance (° cm) | Crystal Sise (cm) |
|---|---|---|---|---|
| $LiNbO_3$ (LN) | 0.4~4.4 | $d_{31}$=-6.5<br>$d_{33}$=-34.0 | 0.7 | CZ<br>9ϕx10 |
| $LiTaO_3$ (LT) | 0.28~4.4 | $d_{33}$= 26 | | |
| $KTiOPO_4$(KTP) | 0.35~4.0 | $d_{24}$ = 7.0<br>$d_{33}$ = 13.7 | 25.0 | Flux<br>2x3x5 |
| $KNbO_3$ (KN) | 0.3~4.0 | $d_{31}$=-12<br>$d_{33}$=-20 | 0.3 | TSSG<br>2x2x4 |
| β–$BaB_2O_3$(BBO) | 0.19~3.5 | $d_{11}$=1.6 | 55.0 | CZ<br>1.5ϕx5 |

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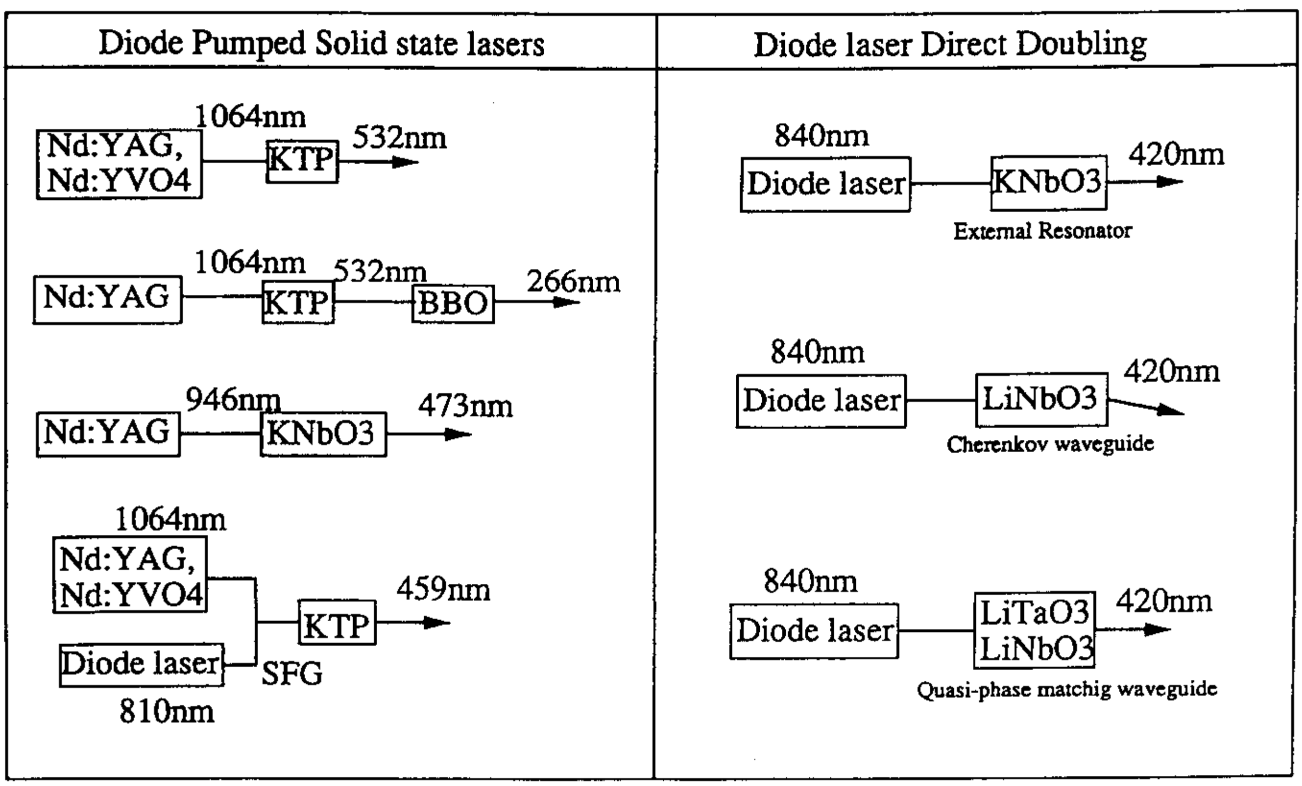
# Harmonics Generation



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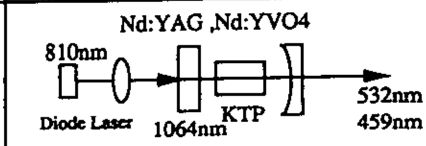
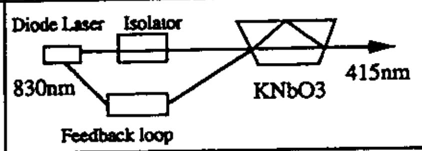
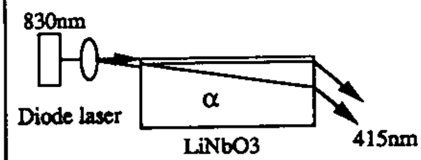
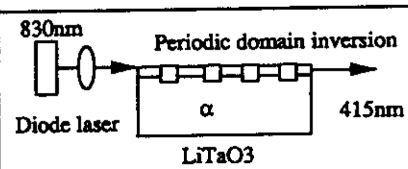
# Comparison of SHG devices

| | Phase matching | Structure | Evaluations |
|---|---|---|---|
| Bulk | Intracavity |   | Efficiency<br>**Difficulty Single mode**<br>**Direct modulation** |
| | External Resonator |   | High Efficiency<br>**Diode wavelength controle** |
| Waveguide | Cherenkov<br>$\cos\alpha = N(\omega)/n\,(2\omega)$ |   | Wavelength tolerance<br>**Collimation Difficulty** |
| | Quasi-phase matching |   | Point source<br>**Wavelength tolerance ~ 0.2nm** |

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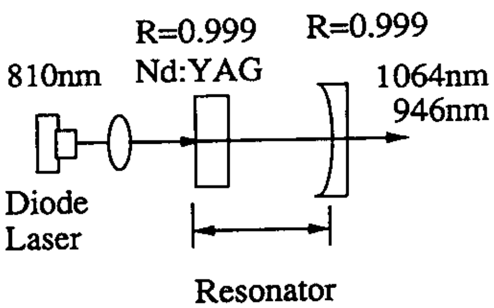
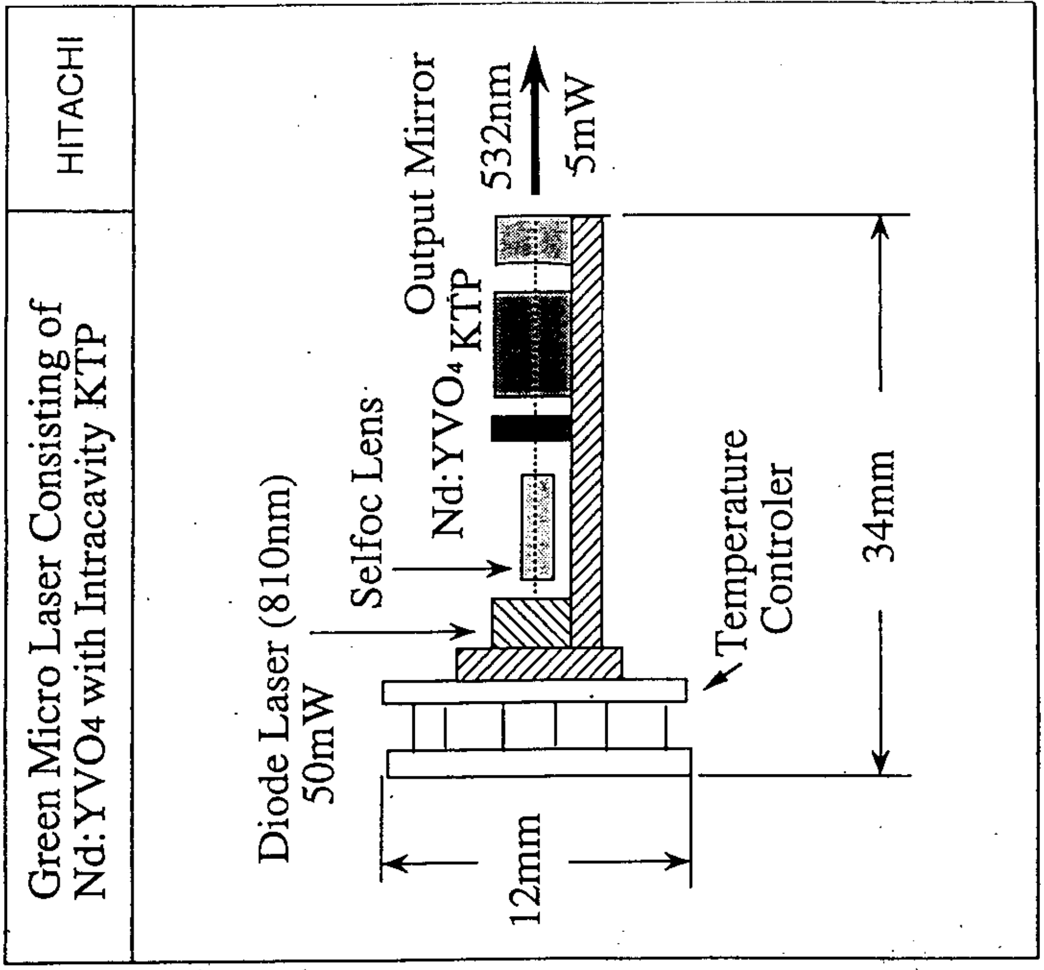
# Intracavity SHG

Diode laser pumped solid state laser $\quad I_{th} \propto \sigma\tau$




1. Laser itself tune resonance frequency
2. Impedance matching

| | $\lambda$ nm | emission cross sec. $\sigma$ $cm^2$ | life time $\tau$ $\mu s$ | $\lambda_{abs.}$ nm | abs. $cm^{-1}$ |
|---|---|---|---|---|---|
| Nd:YAG | 1064<br>946 | 4.6E-19 | 230 | 809 | 7.5 |
| Nd:$YVO_4$ | 1064 | 2.5E-18 | 90 | 809 | 40 |
| LNP | 1047 | 1.7E-19 | 130 | 805 | 115 |
| NYAB | 1062 | 10E-19 | 60 | 804 | 6.8 |
| Nd:GdVO | 1064 | 6E-19 | | 808 | 70.0 |
| Nd:S-VAP ($Sr_5(VO_4)_3F$) | 1064 | 5E-19 | 230 | 809 | |

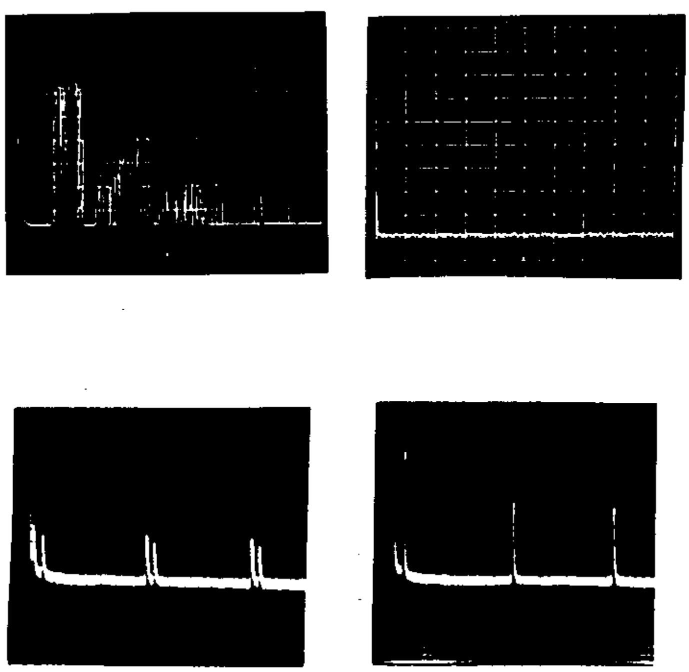



## Green Problem = Intracavity Problem

Noise supression in Intracavity SHG

| Axial mode |
| --- |
| 1. Elimination of spatial holeburning<br>Twisted mode<br>Traveling wave ring resonator<br>2. Mode selection<br>Etalon |
| Polarization mode |
| 1. KTP to be a Total wave plate<br>2. Quarter wave plate |

Noise spectrum



Multimodes Single mode

Single-Polarization-Mode Operation with KTP to be a Wave Plate

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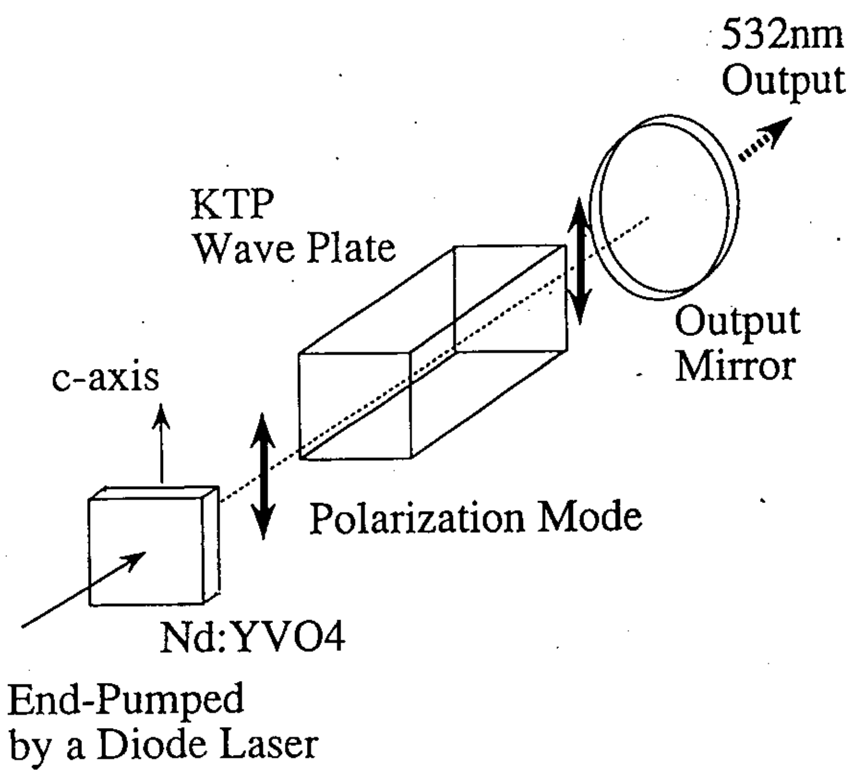
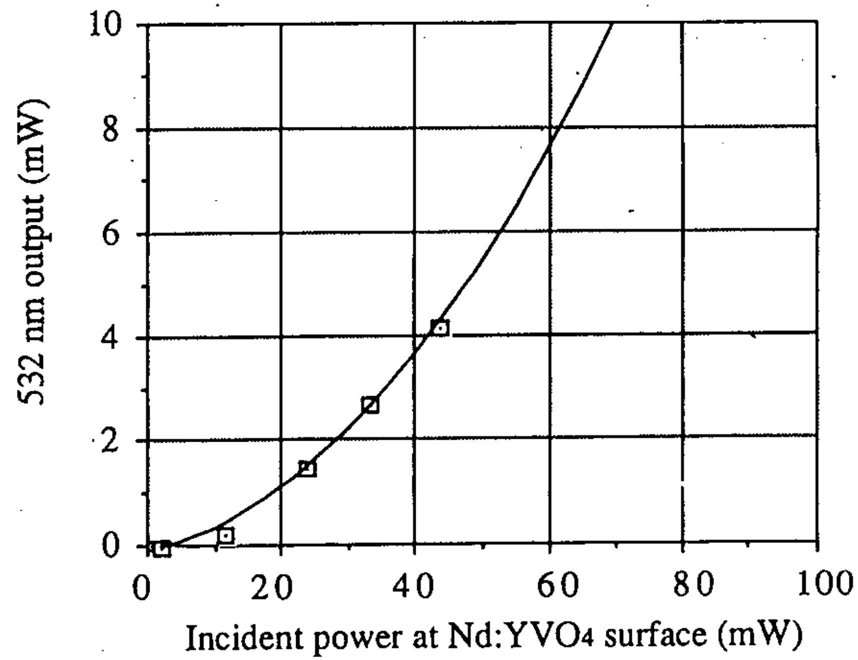
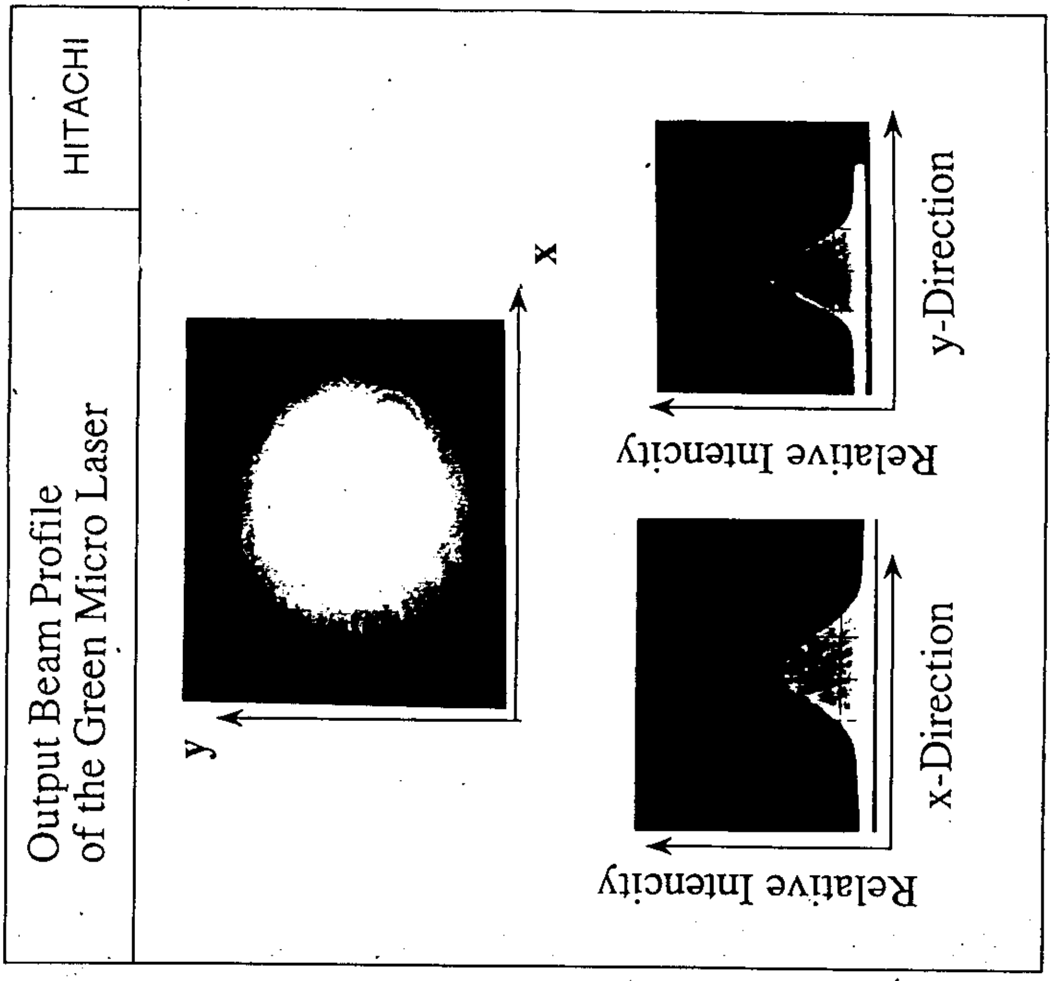



Conversion Efficiency from 810nm to 532nm

HITACHI






## Sum-frequency Generation

$$\omega_3 = \omega_1 + \omega_2 \quad , v = \omega\lambda/2\pi$$

$$k_3 = k_1 + k_2 \quad , k = 2\pi/\lambda$$

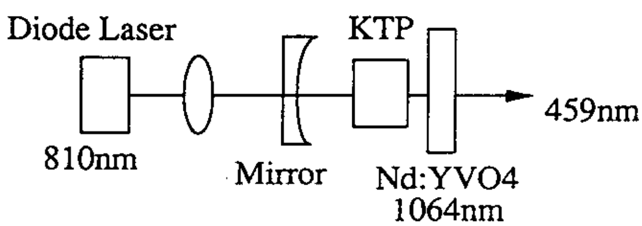
$$\omega_3 n_3 = \omega_1 n_1 + \omega_2 n_2$$

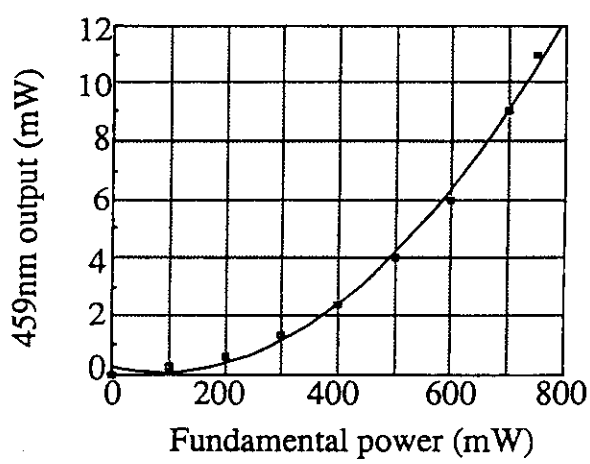
$\omega_1 \neq \omega_2$ : SFG

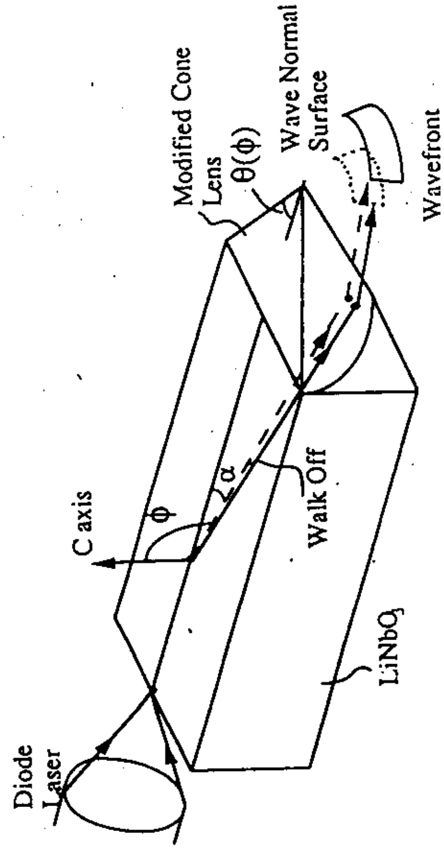
$\omega_1 = \omega_2$ : SHG

$n_1 = n_2$: Type I

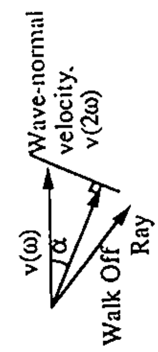
$n_1 \neq n_2$ : Type II






1) Phase Matching Condition

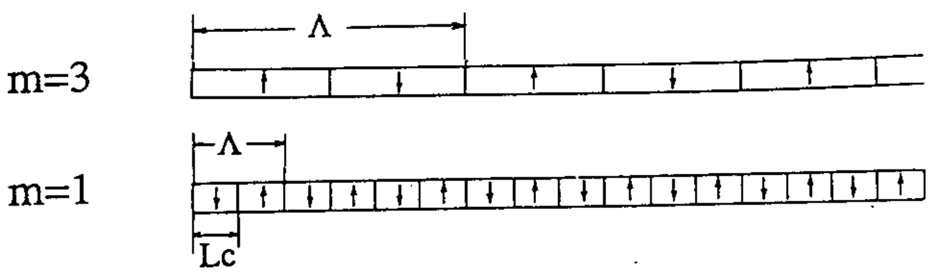



$$\cos\alpha = \frac{N(\omega)}{n_e(2\omega)}$$

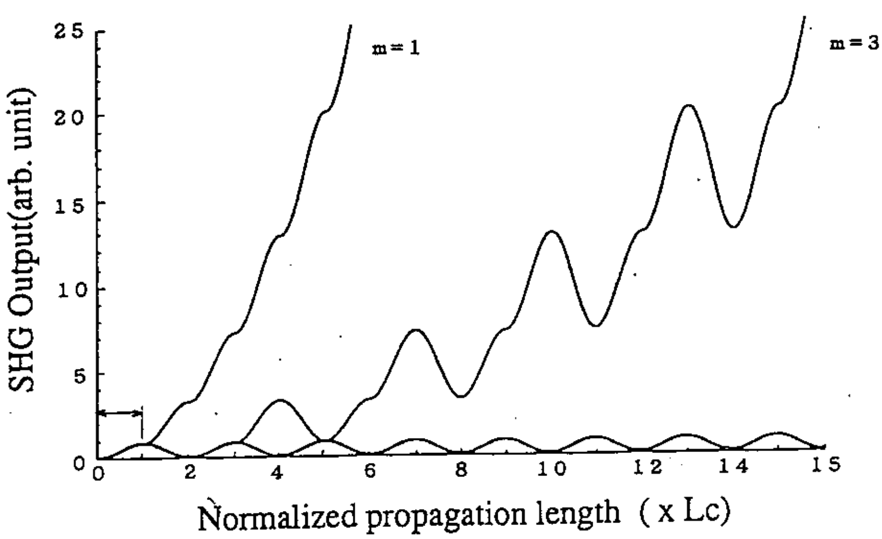
2) Modified Apex Angle of Conic Lens

$$\theta(\phi) = \frac{\pi}{2} - \tan^{-1}\left[\frac{\sin\alpha(\phi)}{\cos\alpha(\phi) - \frac{1}{n_e(\phi)}}\right]$$

## Quasi-phase Matching




$\Lambda = 2\,m\,Lc$,
m : odd integer

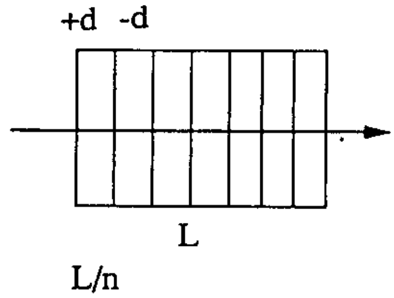


# Efficiency of QPM-SHG

Equation (2)

$$\frac{\partial E}{\partial z} = -i\frac{2\omega^2}{k_{2\omega}}\varepsilon_0\mu_0\chi^{(2)}E_\omega^2\exp(i\Delta kz) \quad , \quad d = \chi^{(2)}/2$$

L is devided into n parts and sign of d changes periodically in the integration




when $L/n = mLc = m\pi/\Delta\kappa$   m : odd number

$$E(2\omega) \propto i(2d_{eff}\ /m\pi)L$$

Quasi-phase matching nonlinear coefficient is given by

$$d_{QPM} = (2/m\pi)\ d_{eff}$$

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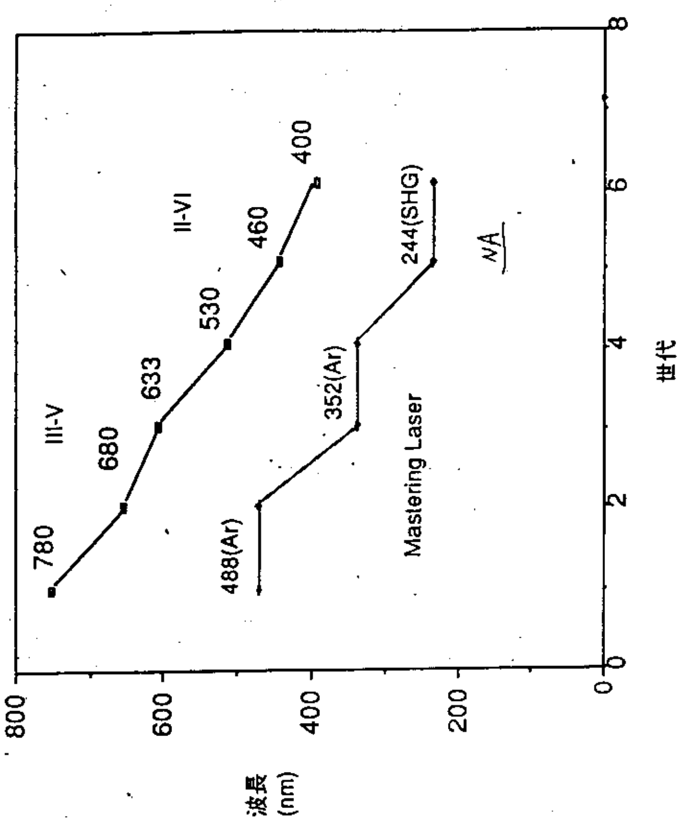
## UV-SHGの必要性

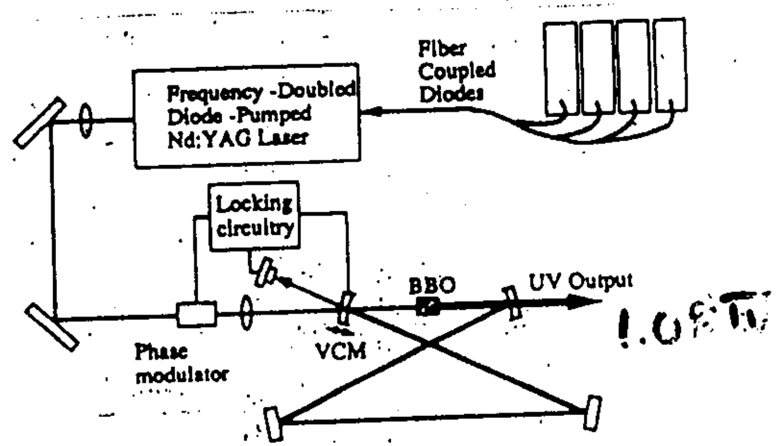



| 特性 | Arレーザ | 紫外SHGレーザ | エキシマレーザ |
|---|---|---|---|
| 波長 nm | 488/352 | 257、244 | 248、193 |
| 出力 mW | 100mW | 100mW/1W(Ar) | 1W/100W |
| 発振 | 連続 | ← | パルス |
| モード 横 | 基本単一 回折限界 | ← | 高次、多数 |
| モード 縦 | 単一 | ← | 多数 |
| スペクトル幅 | 1pm以下 | ← | 数pm/0.5nm |
| 狭スペクトル化 | 不要 | ← | フィルタ要 |

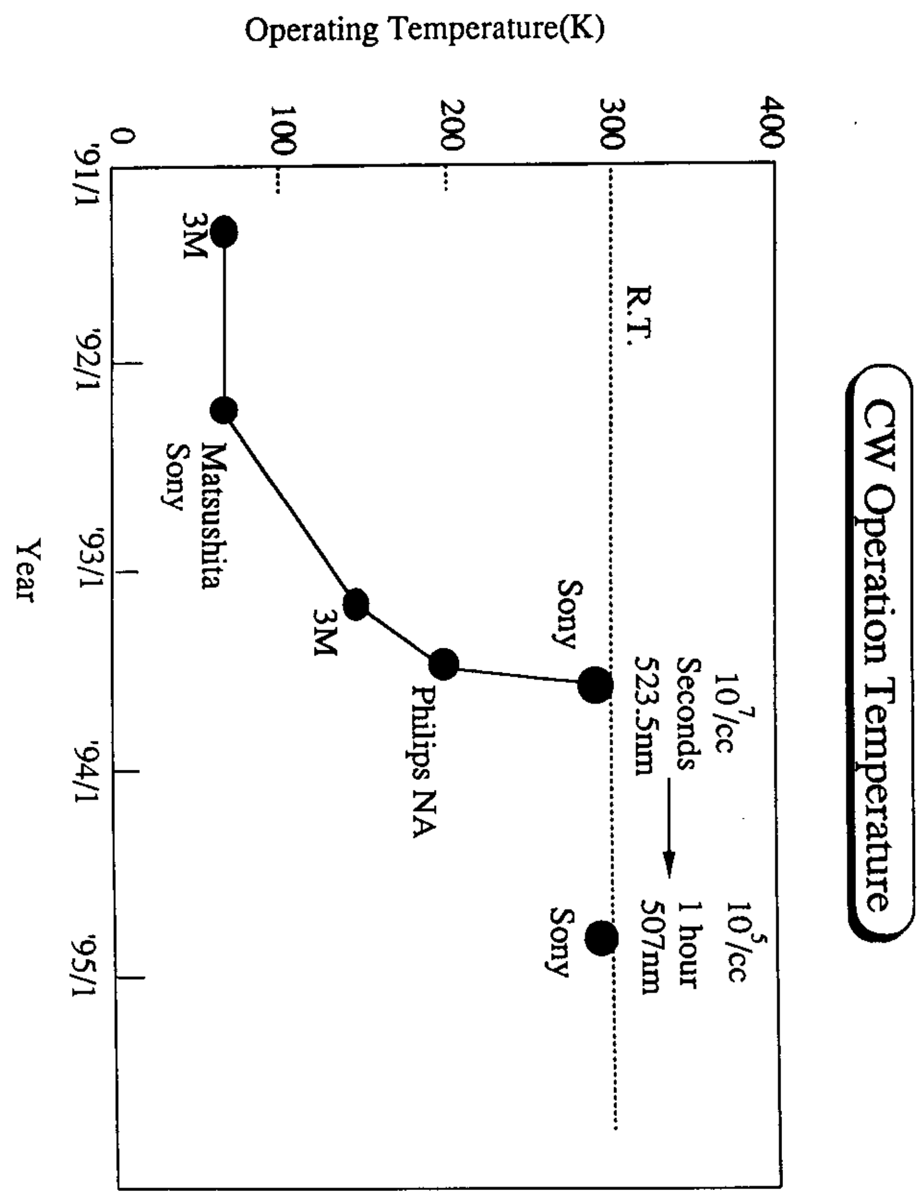
**CThM1** **2:30 pm**

**1-W cw 266-nm radiation from an external resonant cavity using a novel voice-coil-motor actuator**

M. Oka, N. Eguchi, L. Y. Liu, W. Wiechmann, S. Kubota, *Kubota Optoelectronics Laboratory, Sony Corporate Research Laboratories, 6-7-35, Kitashinagawa, Shinagawa-ku, Tokyo, 141 Japan*



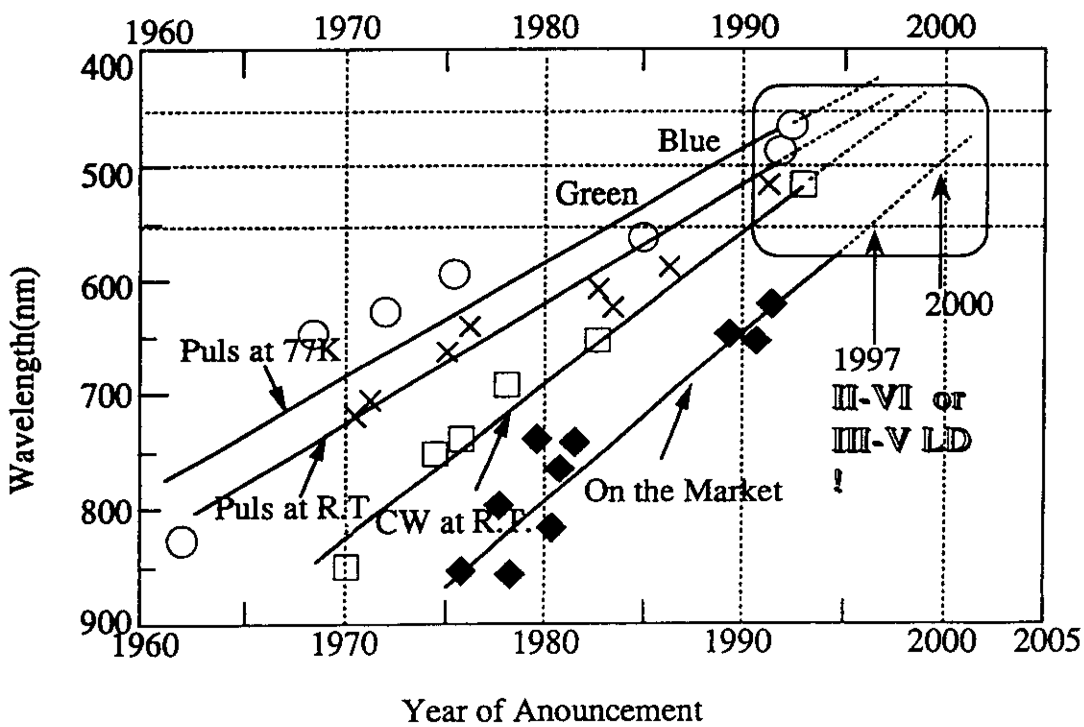

**CThM1 Fig. 2.** Schematic of cw frequency quadrupled diode-pumped Nd:YAG laser.



# II-VI lasers today's status

| | Requirements for practical use | II-VI lasers Status ( 507nm) |
|---|---|---|
| CW operation | 3-5mW at RT | 1mW/5μm at RT |
| Lateral mode | Diffraction limited | Multimode |
| Longitudinal | Single or Multi | Multimode |
| Output power | >300mW at RT | 70mW pulsed at RT |
| Operating Temp. | 0~50 C | CW to 293K |
| Voltage | 2.0 V | 6~7V |
| Device lifetime | 10,000 hours | 1 hour CW at RT |

A. Ishibashi & S. Itoh:LEOS'94 PD-1-1(Boston) Oct.31~Nov 3

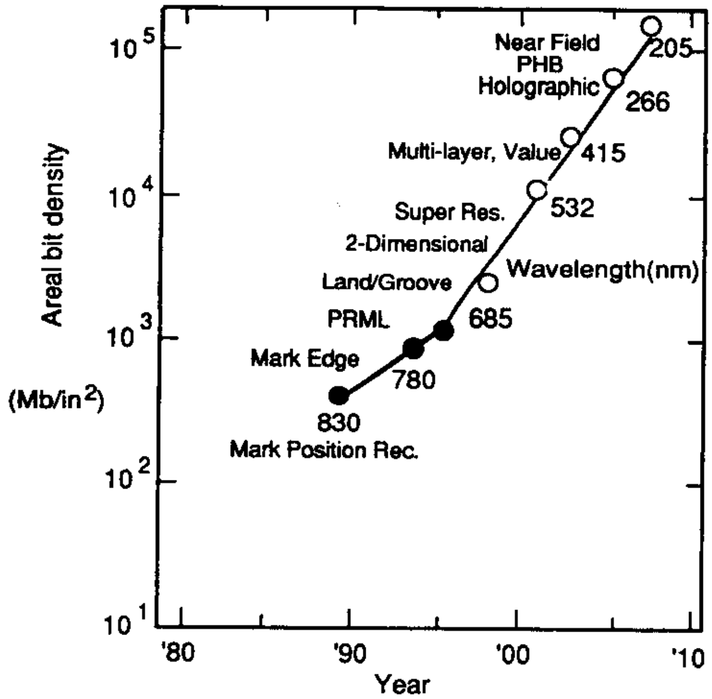


## Progress of compact blue/green lasers for optical storage

| Type | SH-Crystal | Wave-length | SHG Scheme | Conv. efficiency SH/LD | Size | Application | Maker | Ref |
|---|---|---|---|---|---|---|---|---|
| Bulk | KTP | 532 | LDpump-Nd:YAG Intracavity | 5mW/150mW | 8cc | Read only | Sony | [5] |
| | | 532 | LDpump-Nd:YVO Intracavity | 5mW/50mW | 5cc | M/O-SH read/ LD write | Hitachi | [3] |
| | KN | 429 | LD direct External cavity | 54mW/125mW | 1000cc | M/O direct mod. | IBM Coherent | [6] |
| Waveguide | KTP | 430 | BPM-Segment | 2mW/150mW | 3.5cc | — | DuPont SDL | [7] |
| | LT | 429 | QPM Proton ex. heat | 2mW | 8cc | — | Matsushita | [8] |
| LD | ZnCdSe | 508 | — | 1mW,60min RT | 0.1cc | — | Sony | [9] |
| LED | GaN | 450 | — | (2mW) | 0.1cc | — | Nichia | — |

## Status of Blue/Green Light Sources for Optical Disks

| | Approaches | | Status |
|---|---|---|---|
| SHG | Diode pumped laser Intracavity | | Single mode operation for the Long term stability, Size, Cost |
| | Direct doubling of diode lasers | External cavity | Diode laser stability, λ locking, Size, Cost |
| | | QPM-Waveguide | Diode laser stability, λ locking,Efficiency, Size, Cost |
| Diodes | Wide band gap | II-VI | Reduction of Defects to realize 10,000 hrs |
| | | III-V | 80,000 hrs LED Lasing |

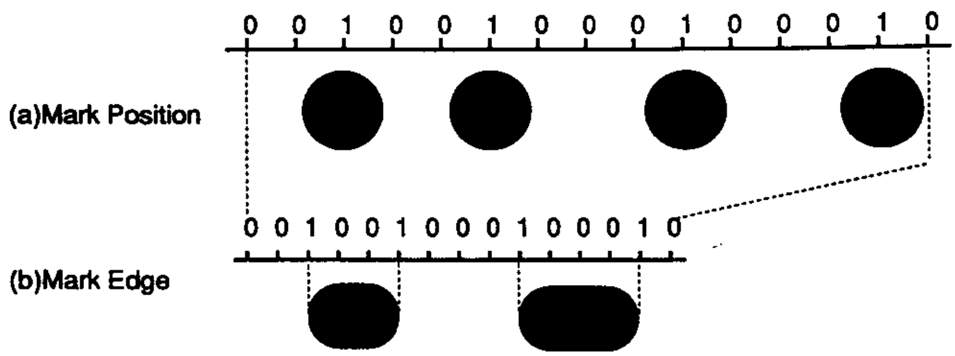


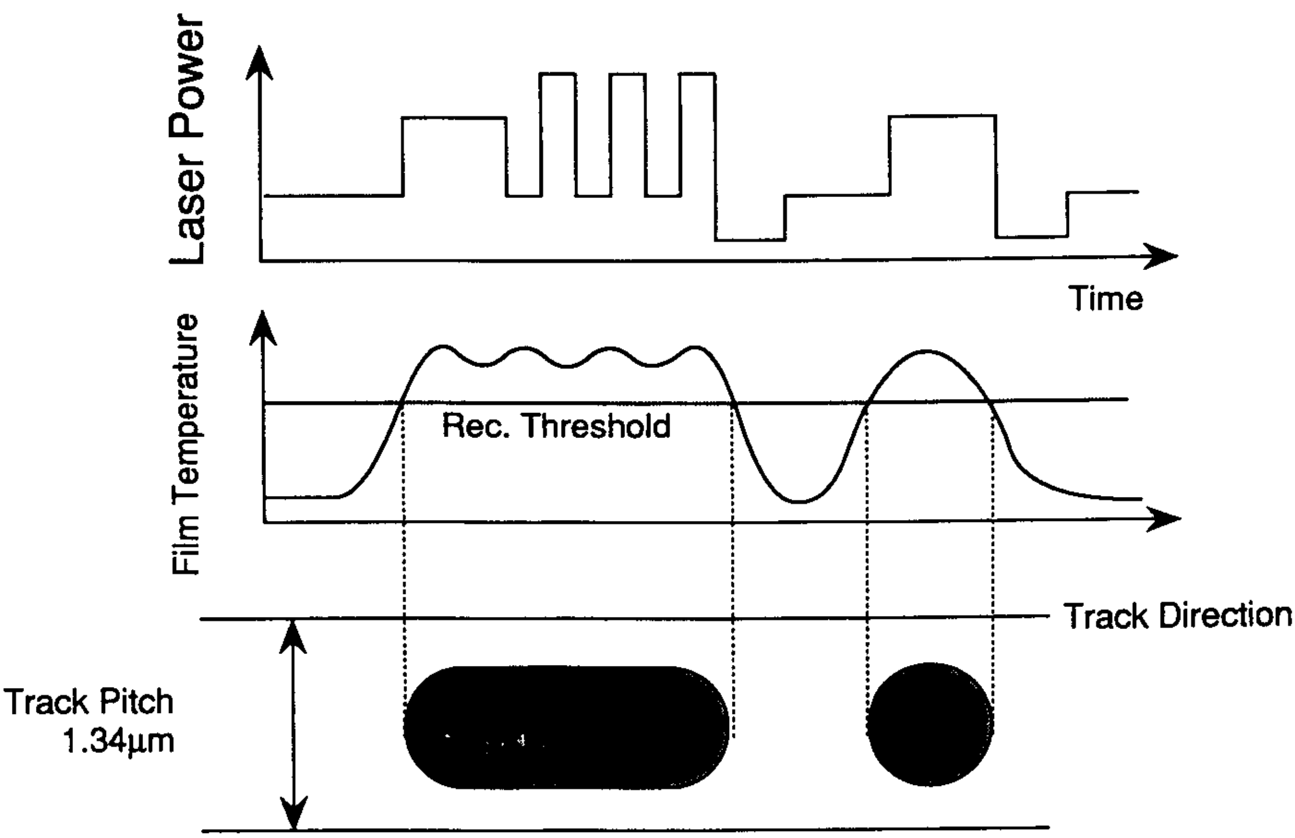

## Approaches for M/O higher density

## Mark Edge Recording

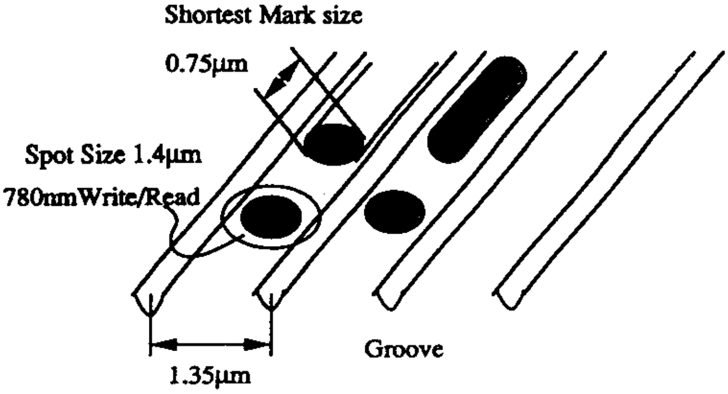
| | 1st Gen. | 2nd Gen. (3 X) | Enhance |
|---|---|---|---|
| Rec. Method | Mark Position<br>1 0 1 | Mark Edge<br>1 0 1 0 1 0 0 0 1 | 1.8 X |
| Disk Format | CAV<br>Inn. Dens. > Outer Dens. | Zoned CAV<br>Uniform Dens. | 1.5 X |
| Track Pitch | Optical Spot 1.6 $\mu$m | 1.34 $\mu$m | 1.2 X |

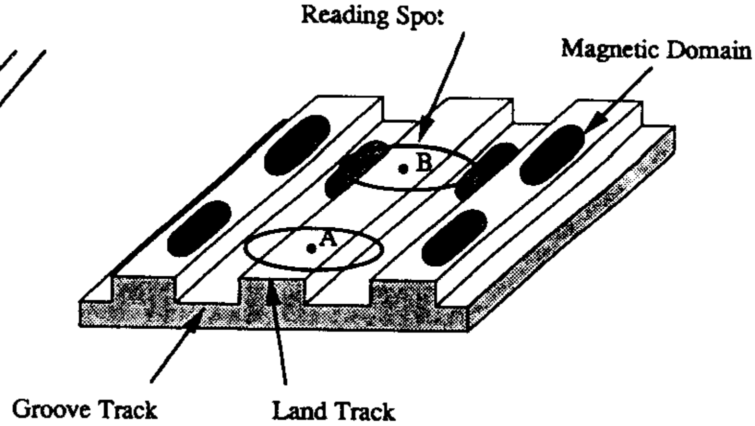
# Mark Edge Recording




Recording Pulse Controle

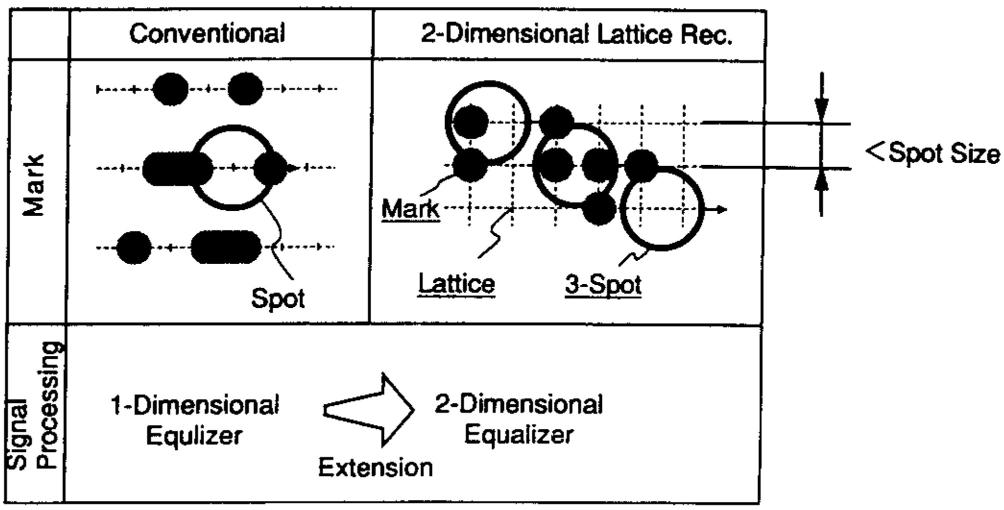


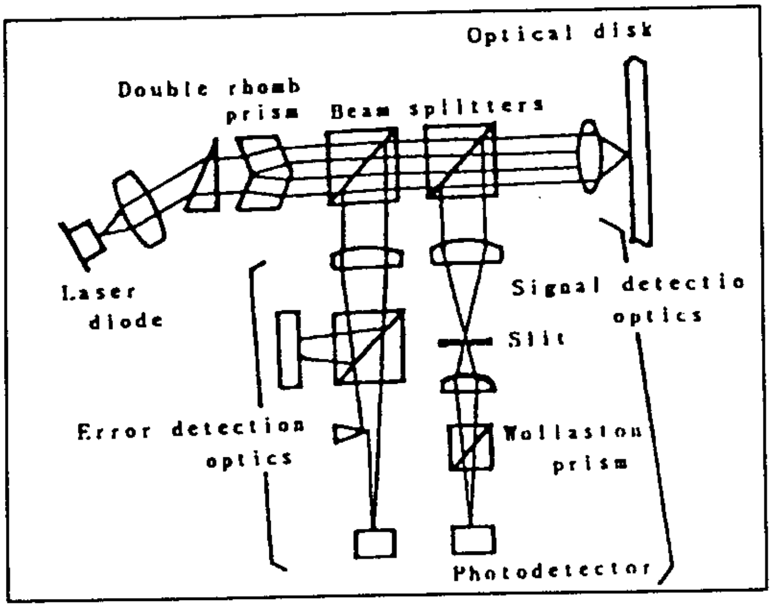




Conventional M/O Disk Structure

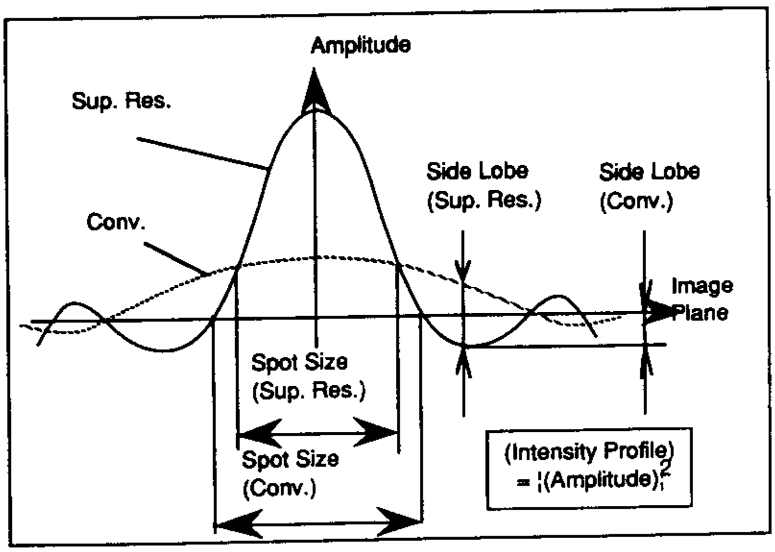
Land/Groove Recording

## 2-Dimensional Lattice Recording

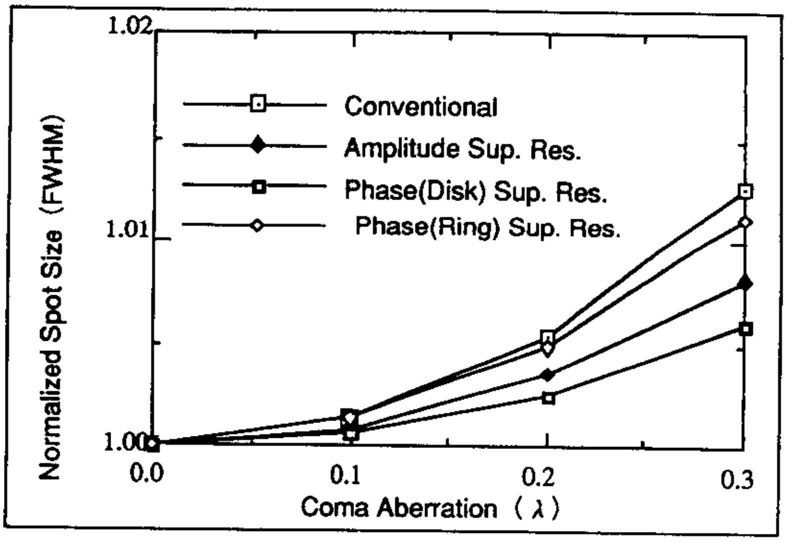





Super Resolution Optical Head

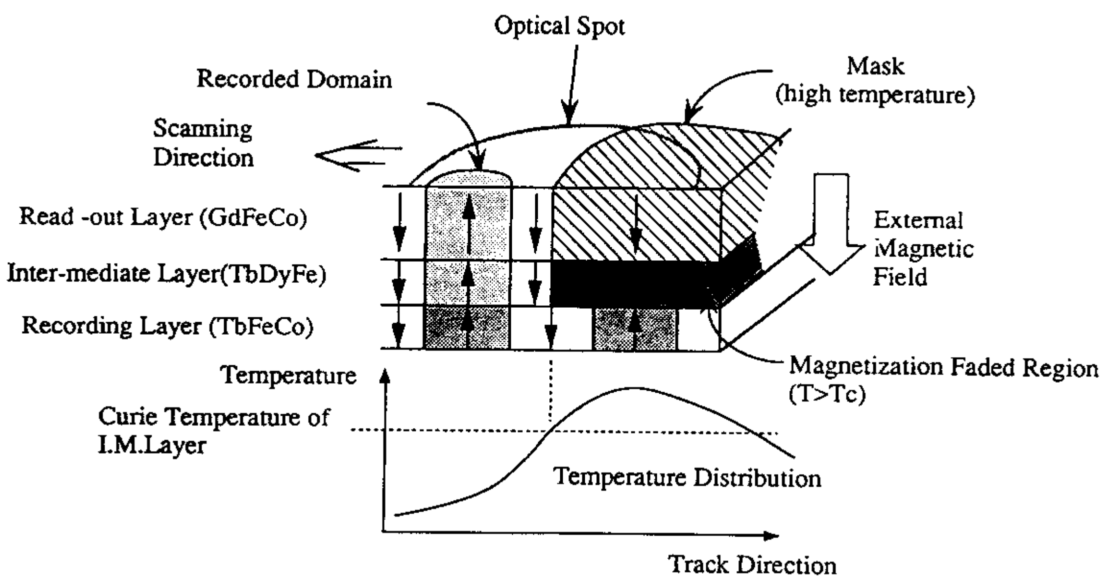



Optical Super Resolution

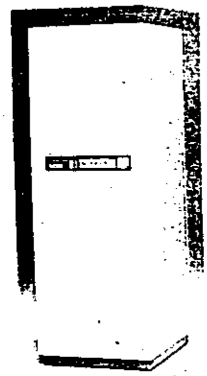
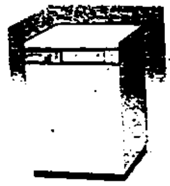



## Super Res. vs Coma Aberration

## Magnetic Super Resolution (FAD)



# TByte File & Wavelength

| Wavelength | 780nm(New Products '93) | 530nm | 420nm | Evanescent Wave |
|---|---|---|---|---|
| |  OL 152-180 |  |  |  |
| Size (mm) | (1850 h ×700 d ×650 w) × 3 | 1850 h ×700 d ×650 w | 700 h ×700 d ×490 w | On your hand |
| 5.25" M/O Disk | 494 pieces | 192 | 60 | 1 |

HCRL-940127-6-3

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## Optical Disks VS Wavelength

| Generation / Wavelength | Audio-Video (5" ,3.5" ,2.5") | Personal Comp. (3.5",2.5") | Juke Box Library (5",12") |
|---|---|---|---|
| 1st / IR '82~ | CD, DVD(60min) MPEG 1 | CD-ROM 650MB 3.5" 128MB M/O | 300GB/unit |
| 2nd/ Red '96~ | DVD(140min /side) MPEG2 | CD-ROM 5GB 3.5" 650MB M/O, PC | 500GB/unit |
| 3rd / Green Blue '99~ | 3.5" DVD 5" HDTV | 2.5" >500MB 3.5" >GB M/O,PC | > TB/unit |

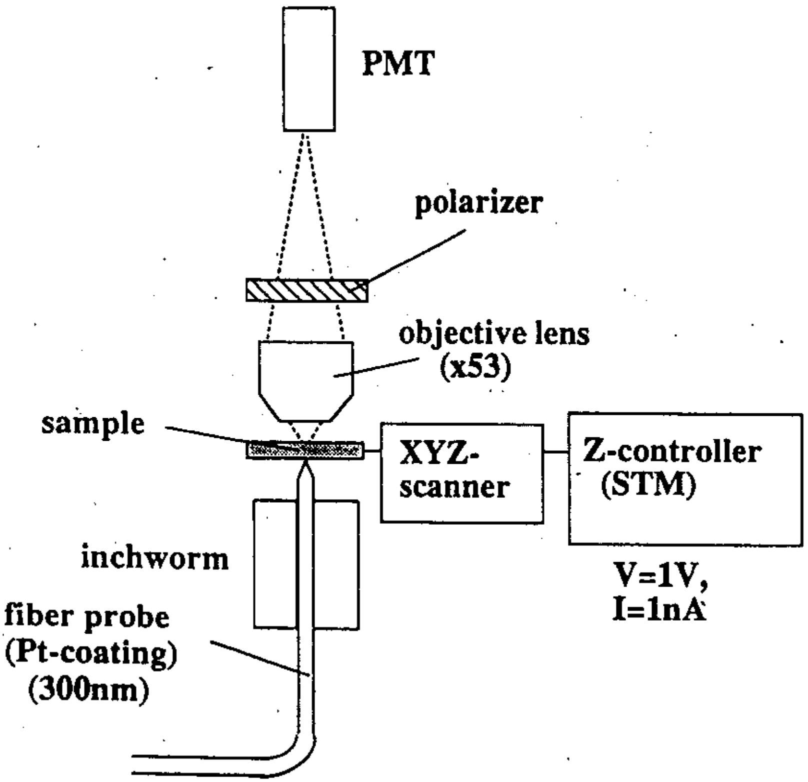



**Fig. 1 Schematic diagram of prototype SNOM.**

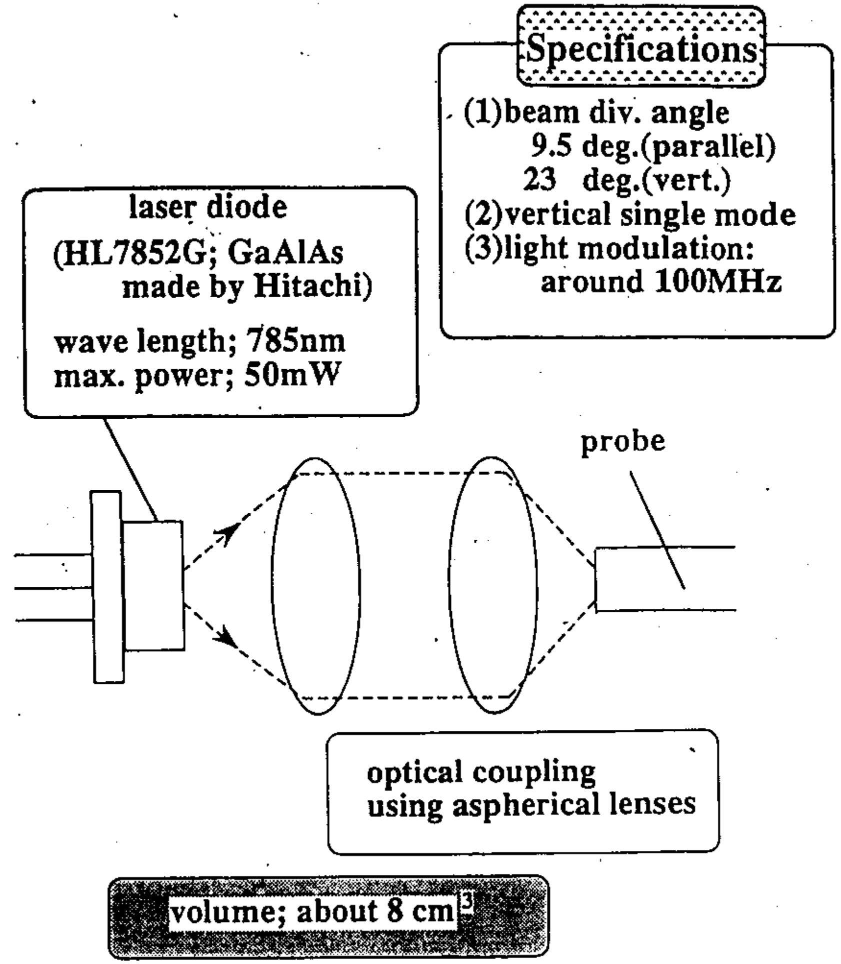
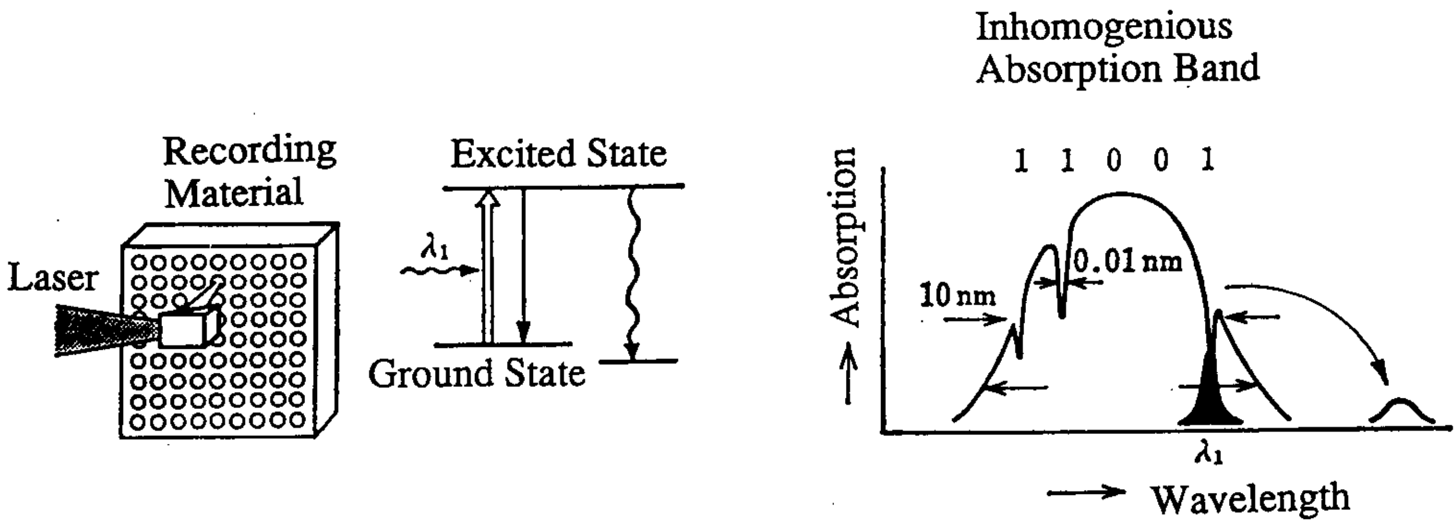



**Fig.2 Schematic diagram of optical coupling between laser diode and optical fiber.**

## Photo-chemical Hole Burning




## Optical Network & Optical Disks