Development of a Ring Mode Cleaner and Efficient Mode-Matching for Initial LIGO 10 Watt Laser

N. Uehara, E. Gustafson, M. M. Fejer, and R. L. Byer

Stanford University

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LIGO-G960287-00 R

Contents.

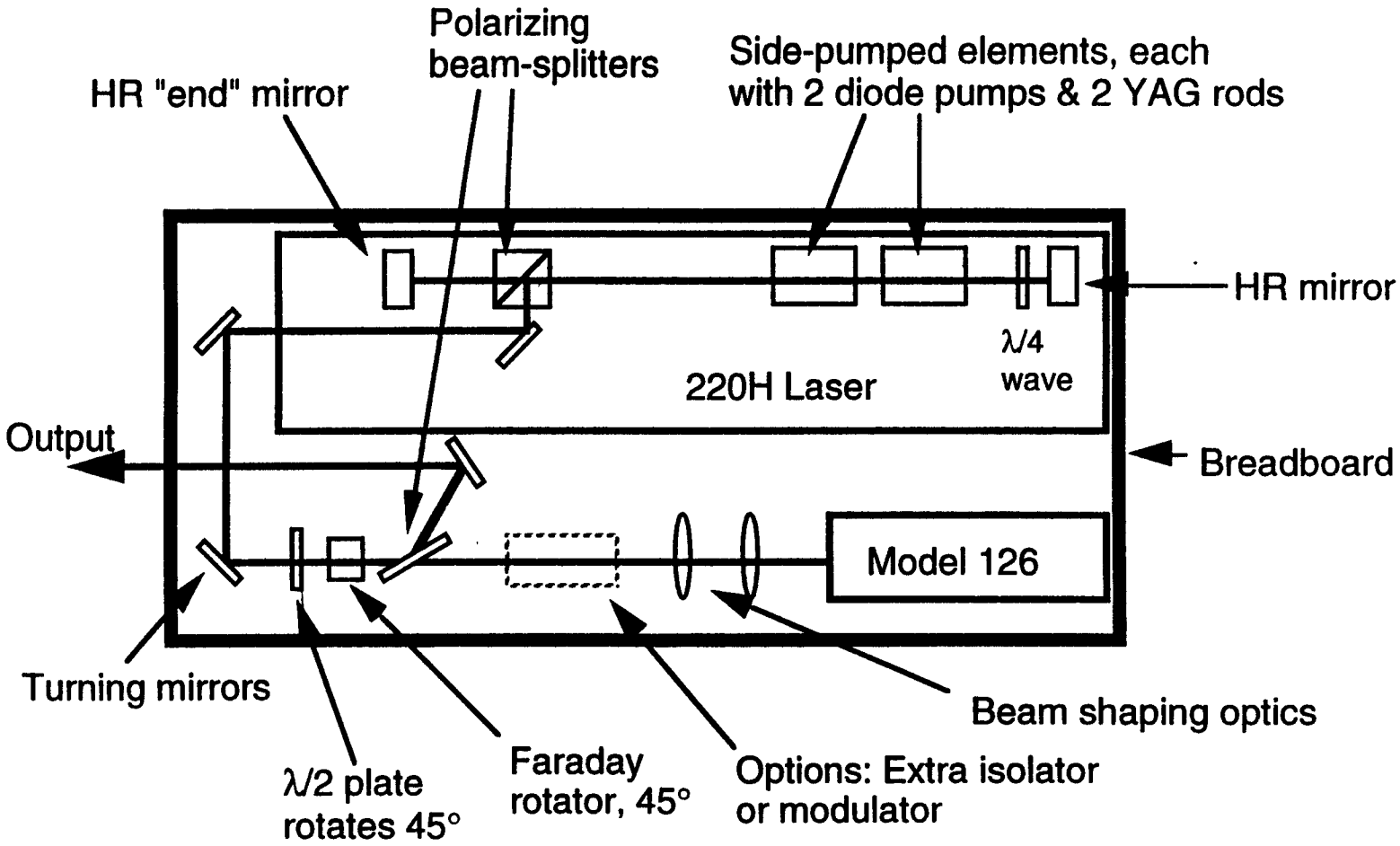
(1) Initial LIGO 10 Watt Laser.
(2) Why ring mode cleaner?
(3) Experimental Plan.
(4) Preliminary experiment

(1) Initial LIGO 10 Watt Laser.

- MOPA(Master Oscillator Power Amplifier) system based on a diode-pumped Nd:YAG laser developed by Lightwave Electronics.

NPRO 700 mW ⟶ Amplifier 10 Watt output
G > 11.5 dB (x14) @4 passes

MOPA System Setup in Lightwave Electronics.

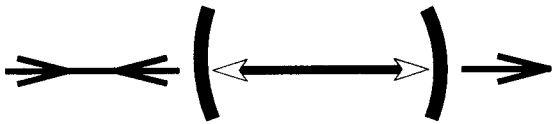


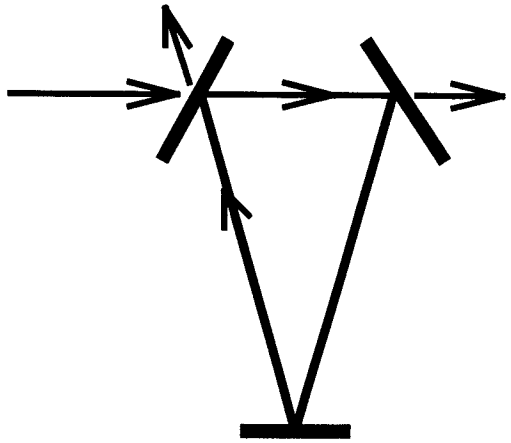
(2) Why Ring Mode Cleaner?

Mode Cleaner = Optical Fabry-Perot Cavity.

- Operate as a spatial-mode selector.
  → TEM_{00} transverse eigenmode output.
- Operate as a low-pass filter on resonance.
  → Intensity and frequency noise reductions at high frequencies.

Optical feedback





Linear mode cleaner

Ring mode cleaner

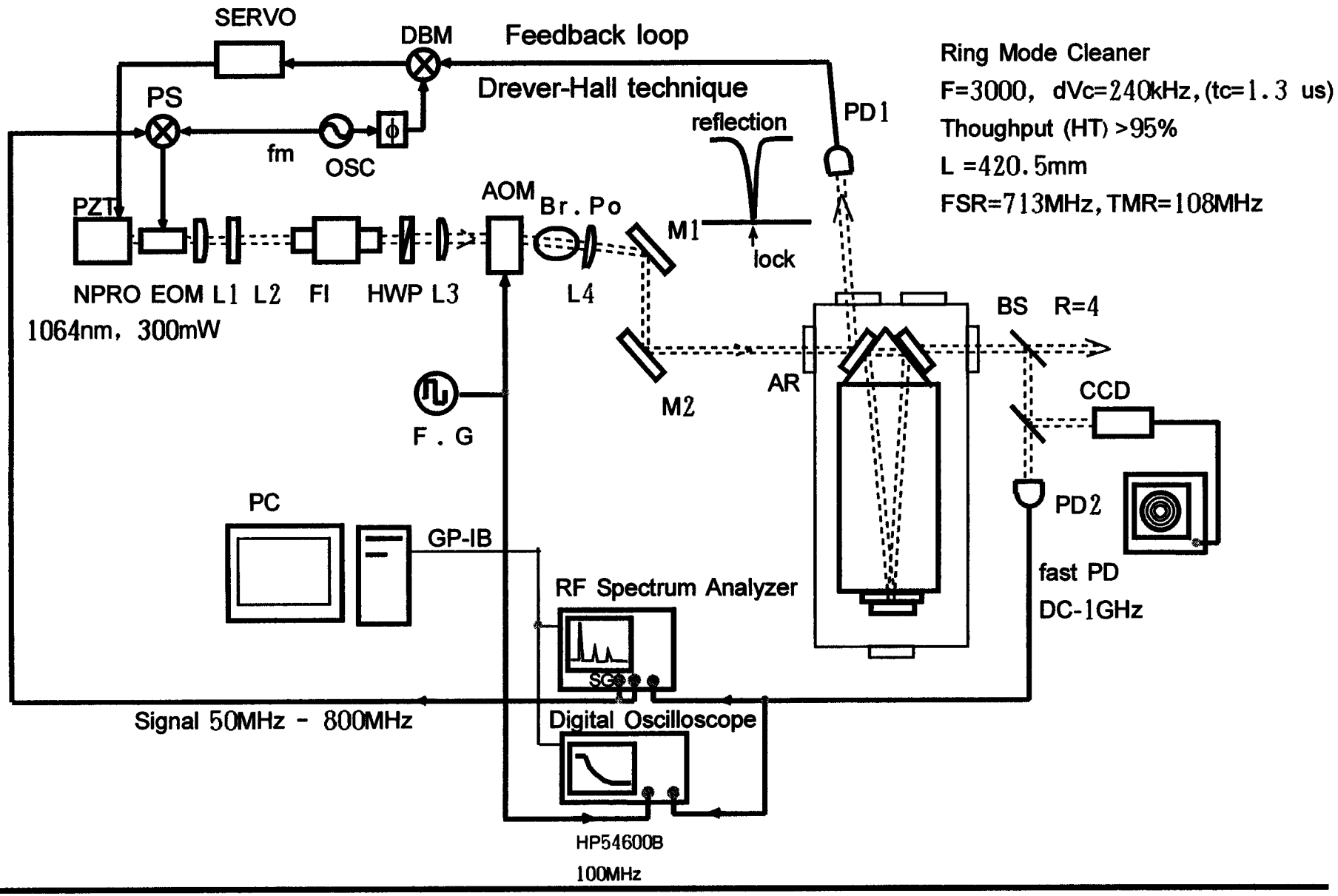
(3) Experimental Plan.

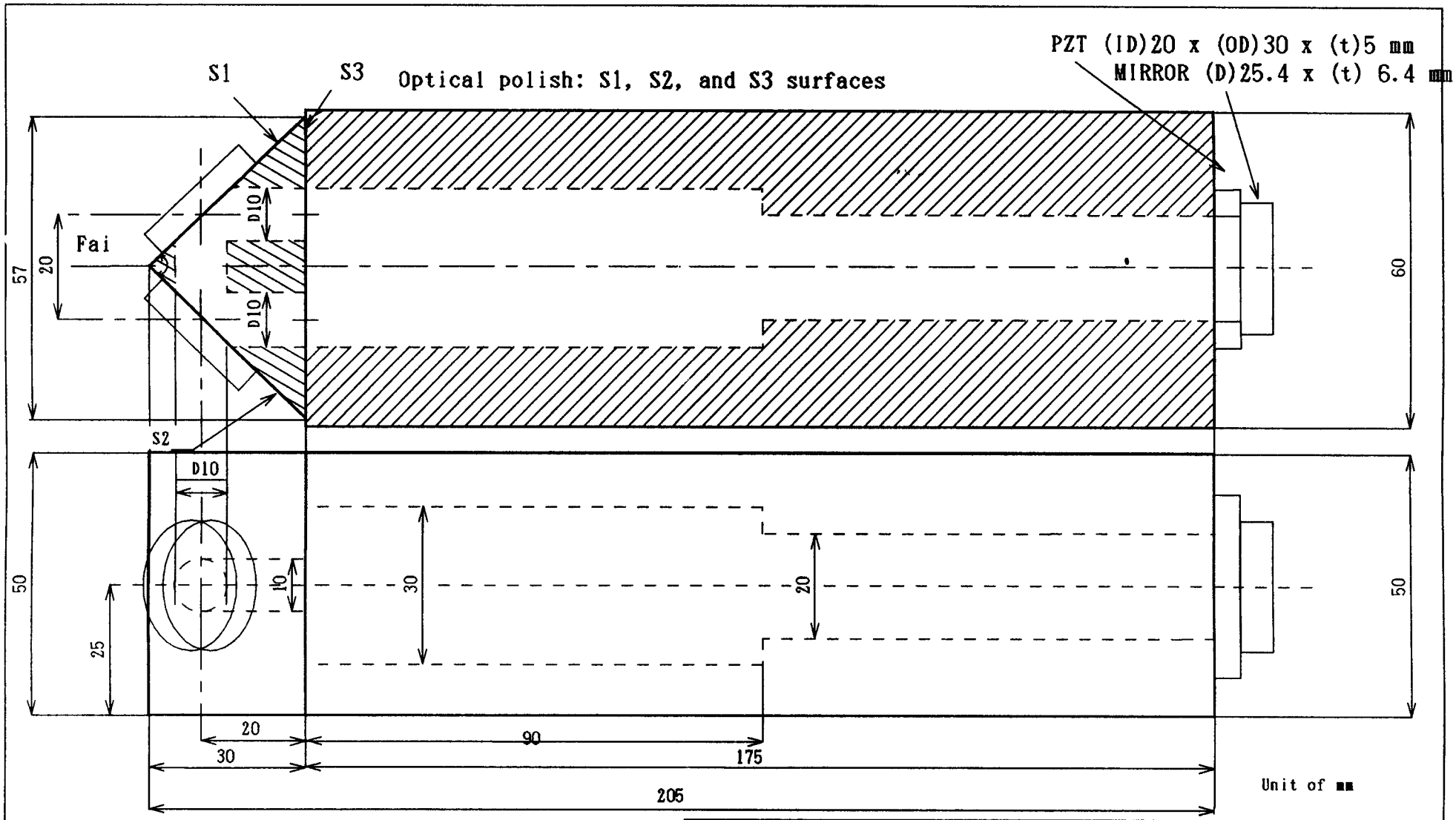
- Design a ring mode cleaner.
- Attempt to couple a 10 watt laser into the mode cleaner.
- Accurate evaluation of optical characteristics;
  - a) cavity finesse (F)
  - b) transmission efficiency (η_T) : throughput
  - c) mode-matching ratio (M_{00})
- Accurate measurement of thermal effect on the mirror substrate.
  Ex. Internal intensity > 4 MW/cm^2,
  if the finesse 3,000, beam radius 0.4 mm.

In future,

- Mirror contamination experiment.
- Automatic alignment-control system.
- Wavefront-control system.

Development of Ring Mode-Cleaner and Efficient Mode-Matching to the Cavity for the LIGO 10 Watt Laser





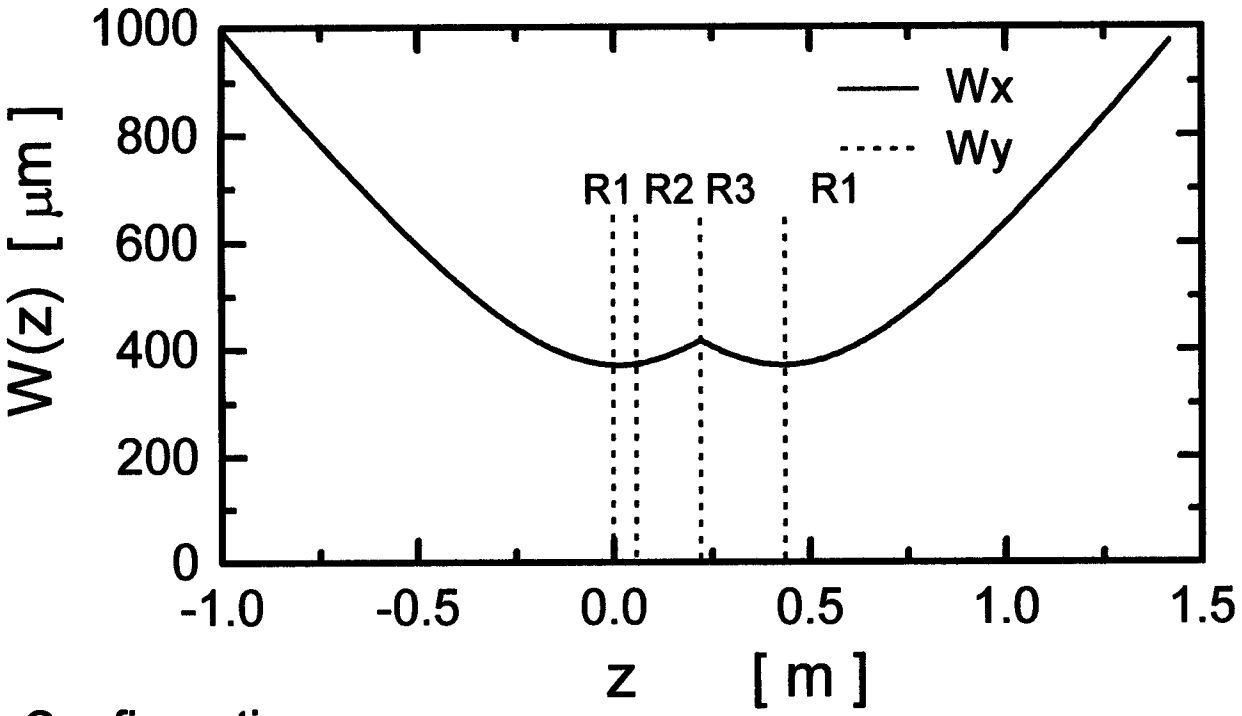
Fai = 87.14 +/- 2 Min.

Error : +/- 0.1 mm

TITLE	Ring Cavity		DATE	August 23, 96		QTY	2
FILENAME	¥RINGCAV¥RING02_3.JWC	SCALE	1 / 1	MATERIAL	ULE	DESIGNER	NOBORU UEHARA GINZTON LAB., STANFORD UNIV.

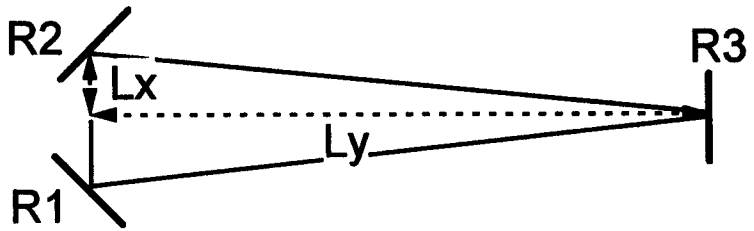
10 mm

Beam propagation of eigenmodes of a ring mode cleaner

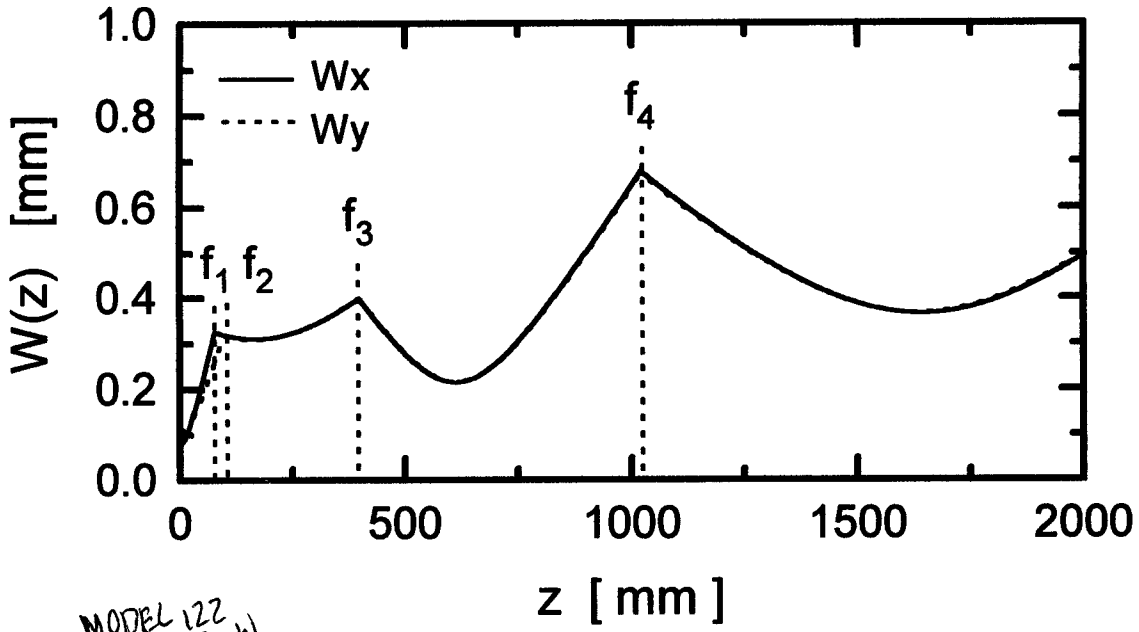


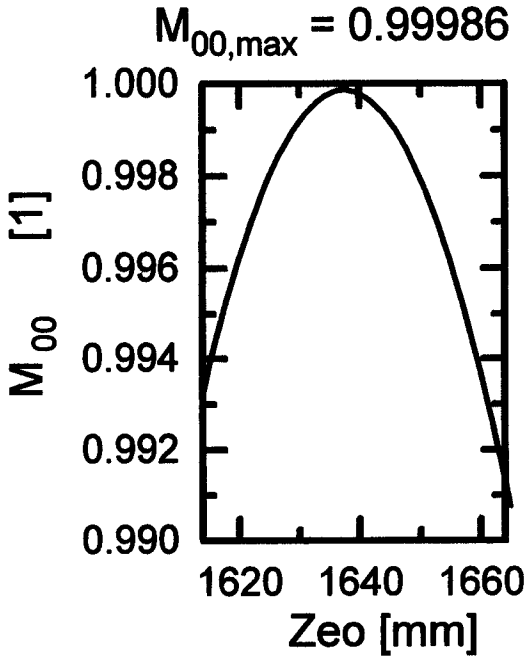
Conditions:
Lx = 10 mm
Ly = 200 mm
θ_1 = 43.6 deg.
θ_3 = 2.9 deg.
R1 & R2 : Flat
R3 : r = 100 cm (cc)
Lt = 420.5 mm
FSR = 713.4 MHz
TMRx = 108.10 MHz
TMRy = 108.25 MHz
Gx = 6.60
Gy = 6.59
Beam Waists:
Wox = 371.6 μm
Woy = 371.4 μm
Woy / Wox = 0.9992
θ_x = 0.9113 mrad
θ_y = 0.9120 mrad

Configuration



Beam propagation between NPRO and a ring mode cleaner and calculated mode-matching ratio as a function cavity position





MODEL 122
300 mW

NPRO:
θ_x = 4.16 mrad
θ_y = 3.12 mrad
θ_x / θ_y = 1.33

Optics
f1 = 75 mm (cyl:X)
f2 = 100 mm (cyl:Y)
f3 = 200 mm (sph)
f4 = 300 mm (sph)

Results
Wox = 0.3670 mm
Woy = 0.3684 mm
Wox/Woy = 0.9962
θ_x = 0.923 mrad
θ_y = 0.919 mrad
Zox = 1639 mm
Zoy = 1636 mm

Eigenmode
Wox = 0.3716 mm
Woy = 0.3714 mm
θ_x = 0.9113 mrad
θ_y = 0.9120 mrad

A. Expected Optical Characteristics @*P*-polarization.

Parameters	Minimum	Maximum
Reflectance (R)*	98.4 %	99.1 %
Transmittance (T)	0.90 %	1.6 %
Loss (A)	2 ppm	20 ppm
T/A	450	8,000
Finesse (F)	196	349
Cavity bandwidth ($\Delta\nu_c$)**	2.0 MHz	3.6 MHz
Transmission efficiency (η_T)	99.56 %	99.98 %
Reflection efficiency (η_R)	1.5×10^{-6}	4.8×10^{-6}
Internal intensity (Ic)***	0.29 MW/cm^2	0.52 MW/cm^2

* Expected by dielectric thin-film layers (HL^{20}).

** Free-spectral range; FSR = 713MHz

*** Power 10 Watt, Beam width ; W_0=0.37 mm

B. Expected Optical Characteristics @*S*-polarization.

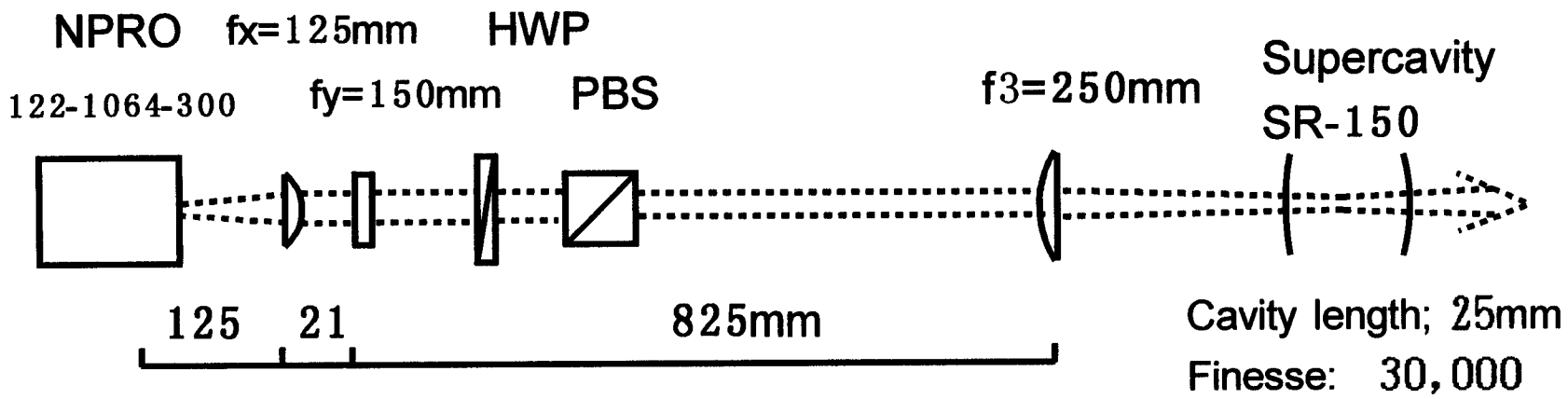
Parameters	Minimum	Maximum
Reflectance (R)*	99.8850 %	99.9150 %
Transmittance (T)	0.0830 %	0.1148 %
Loss (A)	2 ppm	20 ppm
T/A	41.5	574
Finesse (F)	2,732	3,696
Cavity bandwidth ($\Delta\nu_c$)**	193 kHz	261 kHz
Transmission efficiency (η_T)	95.3 %	99.7 %
Reflection efficiency (η_R)	0.003 %	0.055 %
Internal intensity (Ic)***	4.0 MW/cm^2	5.5MW/cm^2

* REO specification

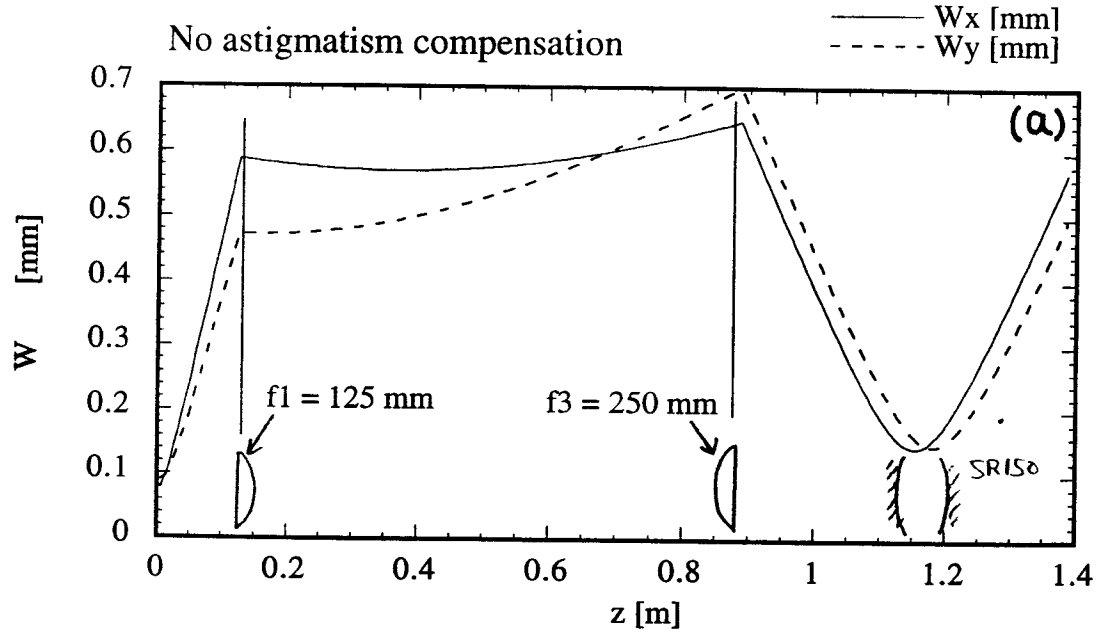
** Free-spectral range; FSR = 713MHz

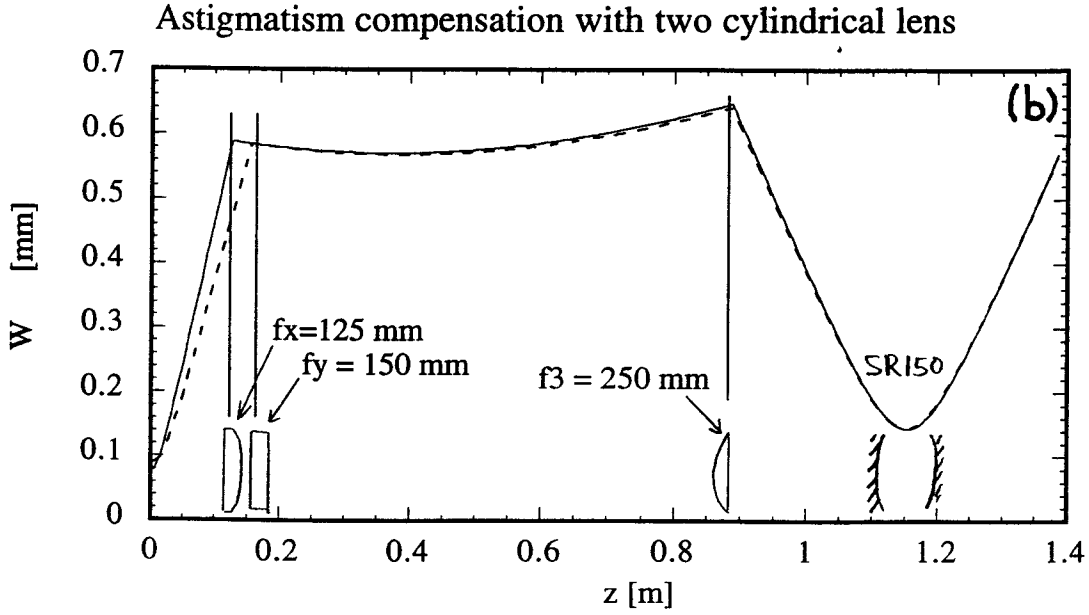
*** Power 10 Watt, Beam width ; W_0=0.37 mm

(4) Experimental setup for efficient mode-matching to a Supercavirty

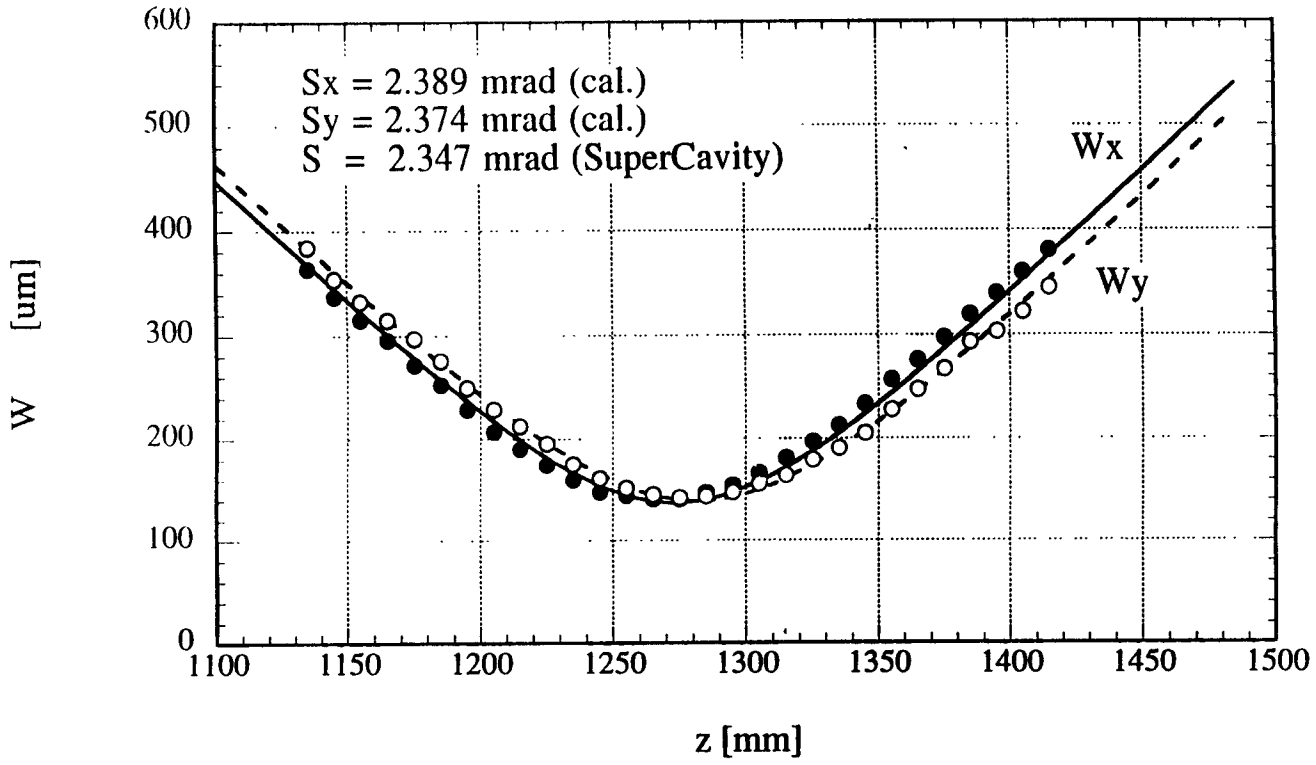


Date: August 21, 96


No astigmatism compensation
Wx [mm]
Wy [mm]
(a)
W [mm]
z [m]
f1 = 125 mm
f3 = 250 mm
SR150
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.2
0.4
0.6
0.8
1
1.2
1.4


Astigmatism compensation with two cylindrical lens
(b)
W [mm]
z [m]
fx=125 mm
fy = 150 mm
f3 = 250 mm
SR150
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.2
0.4
0.6
0.8
1
1.2
1.4

Focused beam propagation to a SuperCavity SR-150

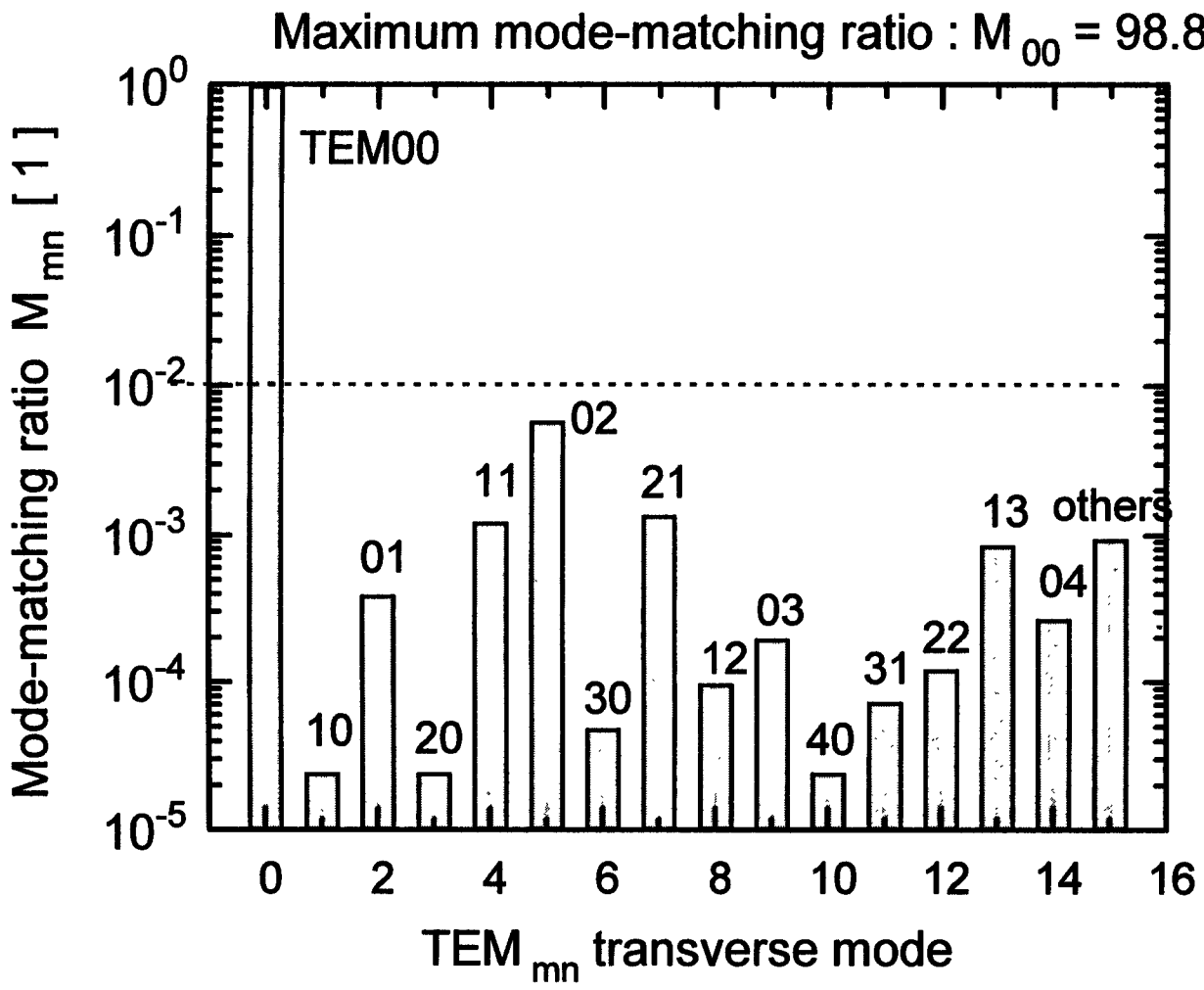


BPF_004F.DAT

measured by Super BeamAlyzer(SKP003, Melles Griot)

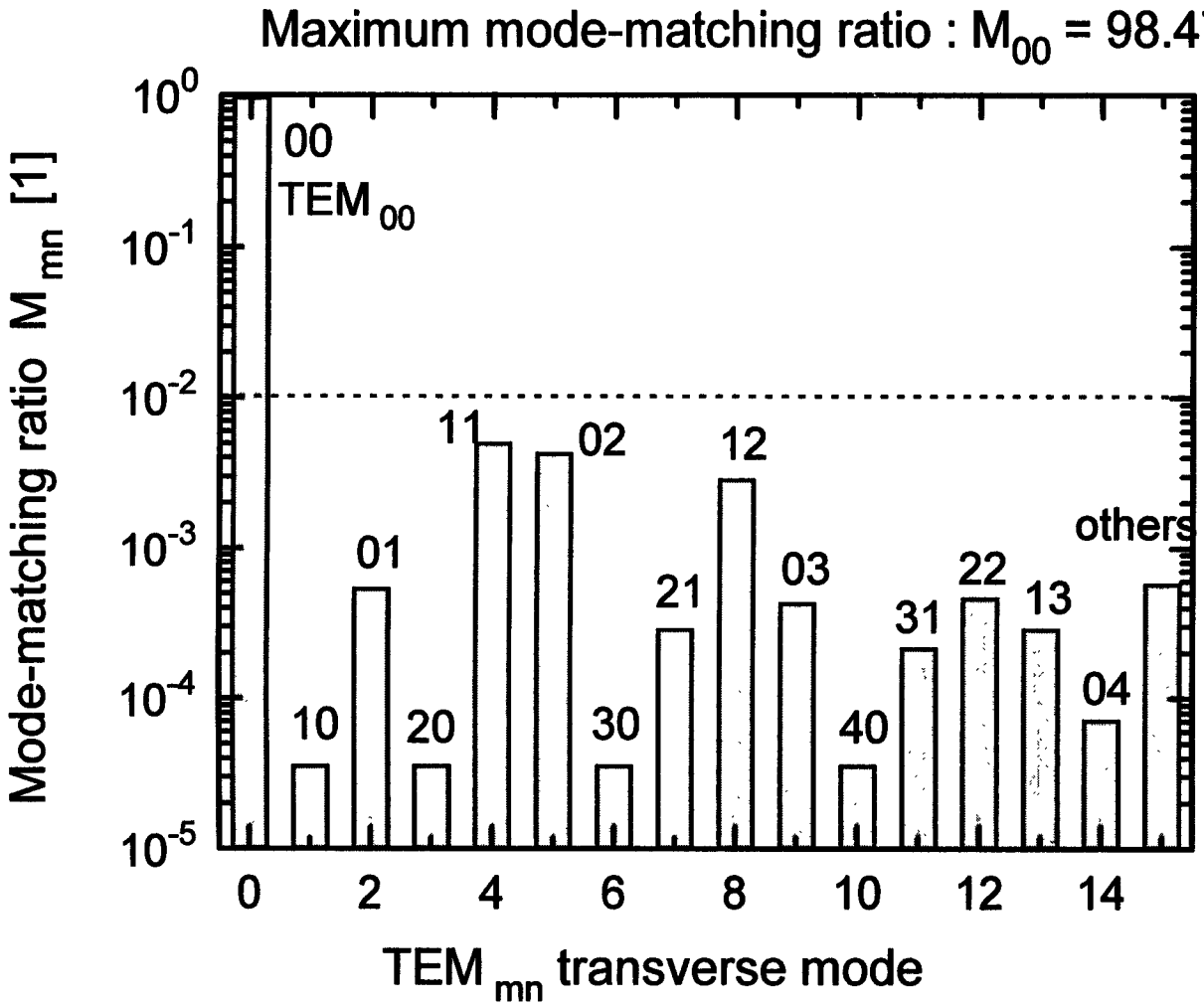
Date : Aug. 15, 96

Measured mode-matching ratios between NPRO and Supercavity



Optics
Laser; NPRO(122-1064-300)
lens; fx=125 mm(cyl, <λ/2)
lens; fy=150 mm(cyl, <λ/2)
λ / 2 plate (AR/AR, <λ/10)
PBS(<λ/4)
lens; f3 = 250 mm (sph.,<λ/10)
λ / 4 plate(AR/AR, <λ/10)
Supercavity(SR-150, Newport)

Measured mode-matching ratios between NPRO and Supercavity



Optics
Laser: NPRO(122-1064-300)
EOM : 4003($LiNbO_3$)
lens; fx = 100 mm (cyl., <λ/2)
lens; fy = 150 mm (cyl., <λ/2)
λ / 2 plate(AR/AR, <λ/10)
PBS(< λ/4)
M1(HR, <λ/5)
M2(HR, <λ/5)
f3 = 250 mm (sph.,<λ/10)
λ / 4 plate(AR/AR, <λ/10)
Supercavity(SR-150, Newport)

List of optical components for mode-cleaner experiment (September 25, 1996)

Item		Model	Vendor	Unit	Unit price $	Amount $
Spherical lens	f=200 mm	PLCX-25.4-103.0-C-1064	CVI Laser corp.	1	160.00	160.00
//	f=300 mm	PLCX-25.4-154.5-C-1064	//	2	160.00	320.00
//	f=400 mm	PLCX-25.4-206.0-C-1064	//	1	160.00	160.00
Cylindrical lens	f=75 mm	RCX-40.0-25.4-38.1-C-1064	//	1	464.00	464.00
//	f=100 mm	RCX-40.0-25.4-50.9-C-1064	//	1	464.00	464.00
//	f=125 mm	RCX-40.0-25.4-63.6-C-1064	//	1	404.00	404.00
//	f=150 mm	RCX-40.0-25.4-76.3-C-1064	//	1	404.00	404.00
Thin film plate polarizing beam splitter		TFP-1064-PW-1025-C	//	1	485.00	485.00
Half waveplate		QWPO-1064-10-2	//	1	570.00	570.00
Laser Window		W2-PW-0725-C-1064-0	//	6	111.00	666.00
YAG HR mirror		5104	New Focus Inc.	4	100.00	400.00
Electro-Optic Modulator (MgO:LiNbO3) @ 1064 nm		4004D	//	1	3,750.00	3,750.00
Multi-axis stage		9071	//	1	395.00	395.00
Acousto-Optic Modulator		AOM-40R	InterAction corp.	1	650.00	650.00
AOM driver		M-40R	//	1	895.00	895.00
Faraday isolator @1064 nm		1845-5	Electro-Optics Technology, Inc.	1	2,495.00	2,495.00
Translation stage		423 w/SM-25	Newport corp.	15	279.00	4,185.00
//		426 w/DM-13	//	1	718.00	718.00
Rotating stage		481-A	//	1	395.00	395.00
//		UTR-80S	//	1	597.00	597.00
Ginbal mirror		SL25.4BD	//	2	754.00	1,508.00
Angle bracket		360-90	//	8	77.00	616.00
Tilt platform		37	//	1	596.00	596.00
				Total		$ 21,297.00

Vendor Information's

Vendor	Address	TEL.	FAX.	e-mail
CVI Laser corp.	361 Lindbergh Ave., Livermore, CA 94550	(510) 449-1064	(510) 294-7747	cyoung@inreach.com
New Focus Inc.	2630 Walsh Ave., Santa Clara, CA 95051	(408) 980-8088	(408) 980-8883	NewFocus@aol.com
InterAction corp.	3719 Warren Ave., Bellwood, IL 60104	(708) 547-6644	(708) 547-0687	
Electro-Optics Technology Inc.	1030 Hastings St., Ste.140 Traverse City, MI 49686	(800) 697-6782	(616) 935-4046	eot@gtii.com
Newport corp.	1791 Deere Ave., Irvine, CA 92714	(800) 222-6440	(714) 253-1680	