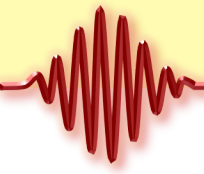
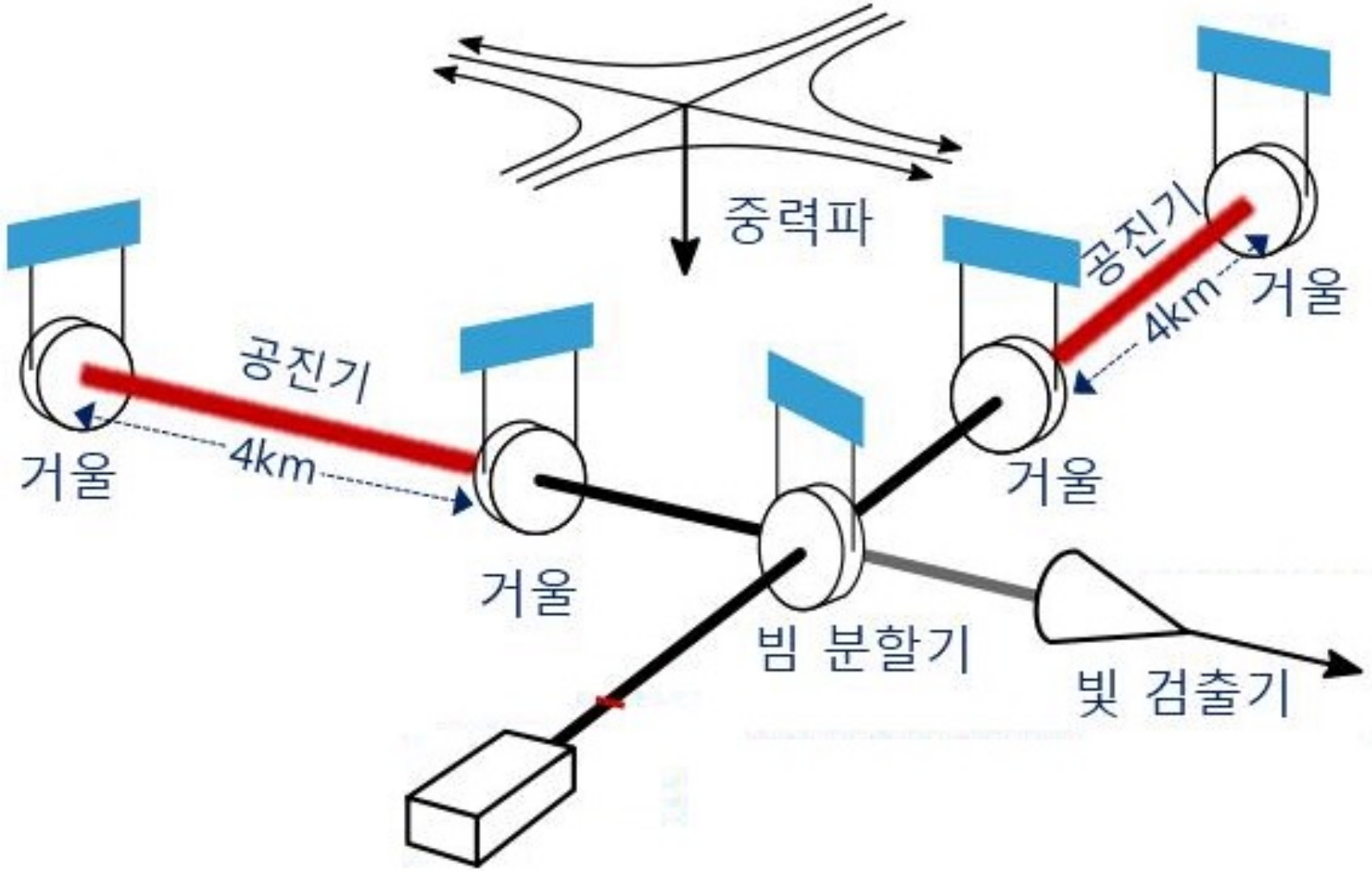
중력파 검출 기술 개발

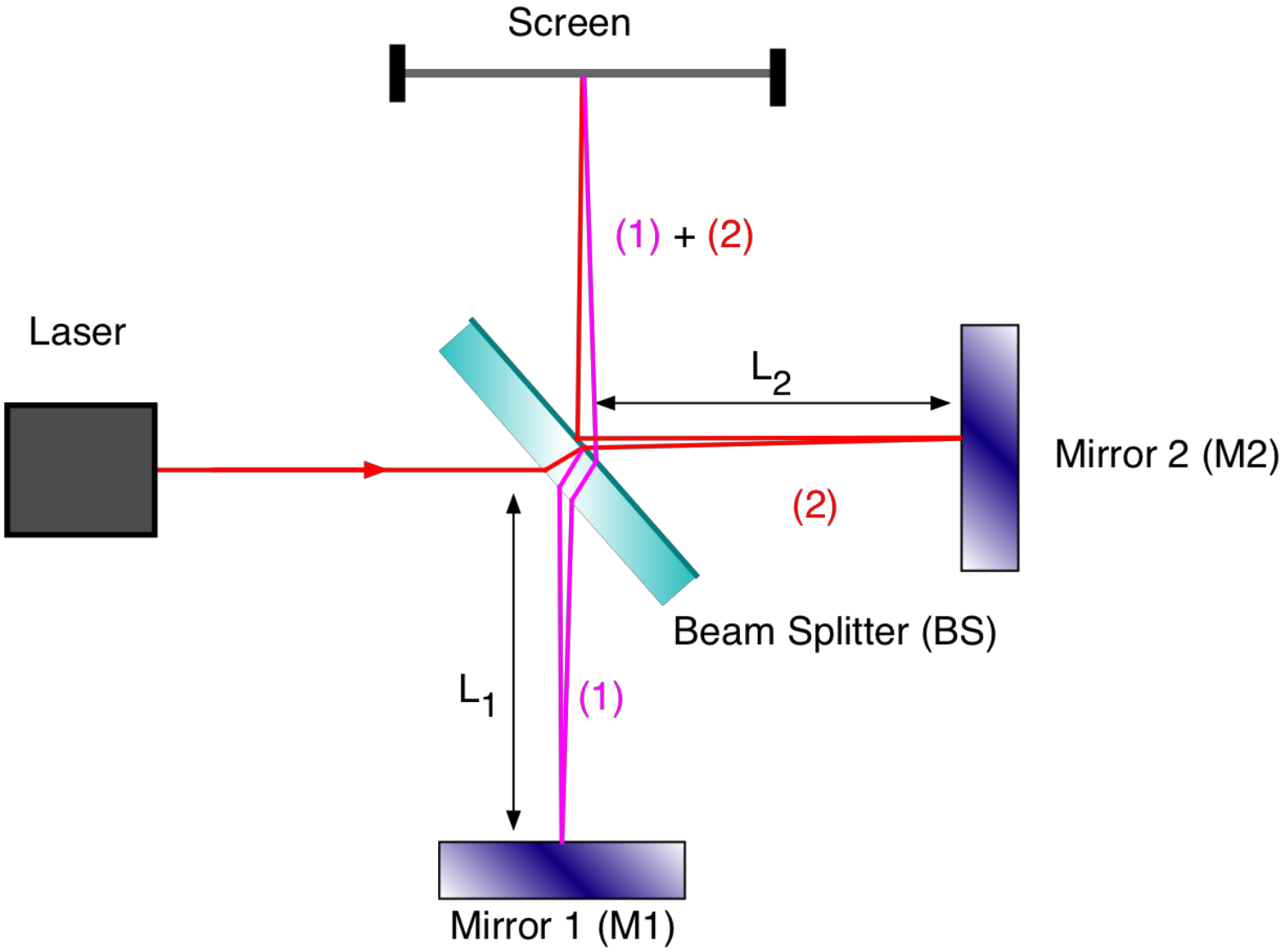


박병준 (KASI)

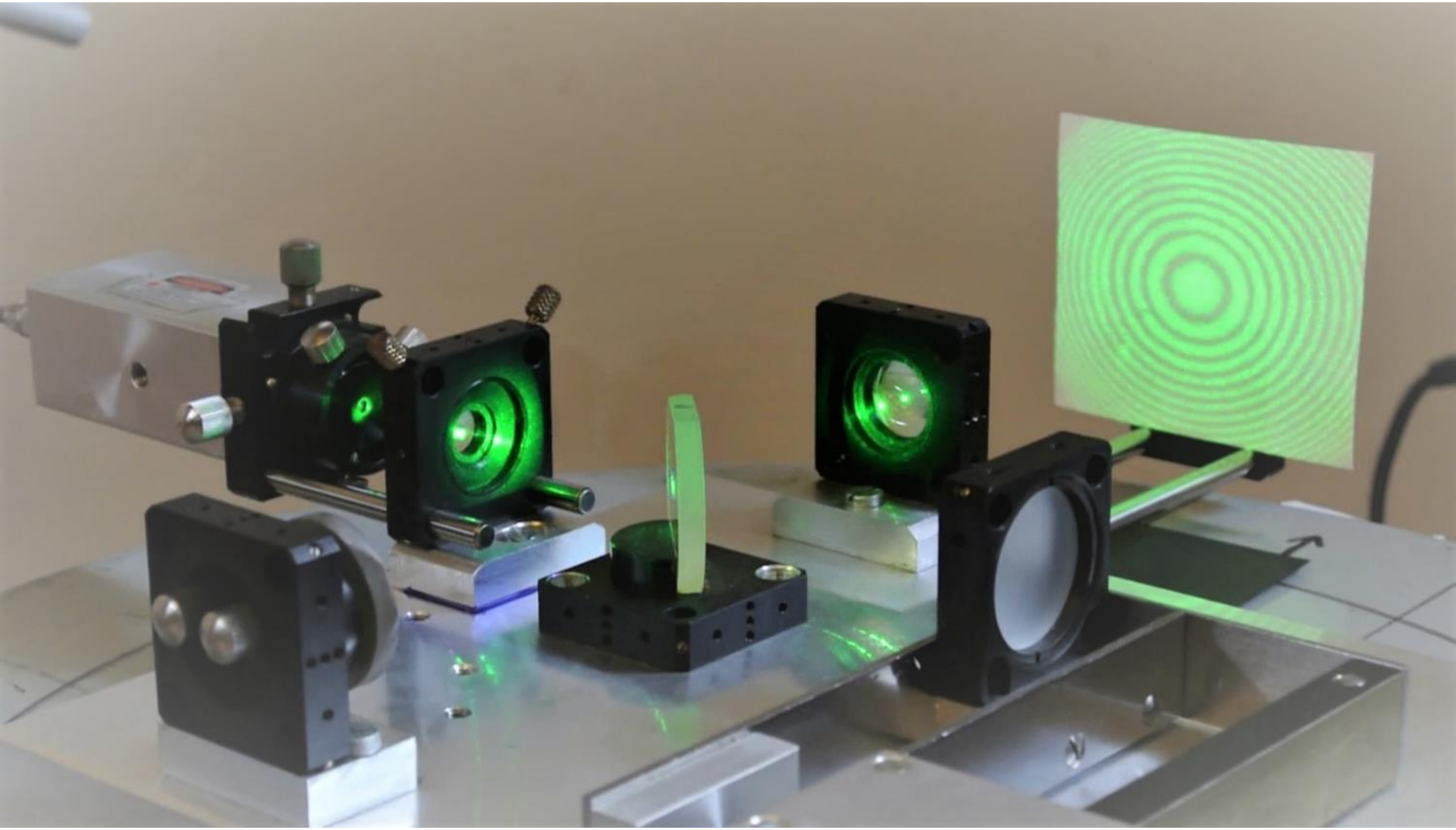
중력파 검출기



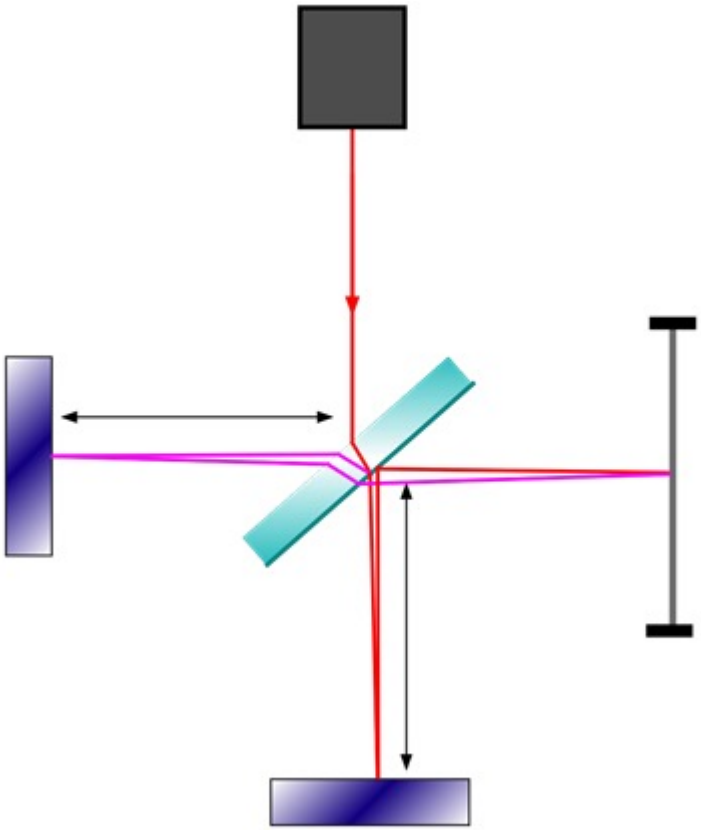
마이켈슨 간섭계

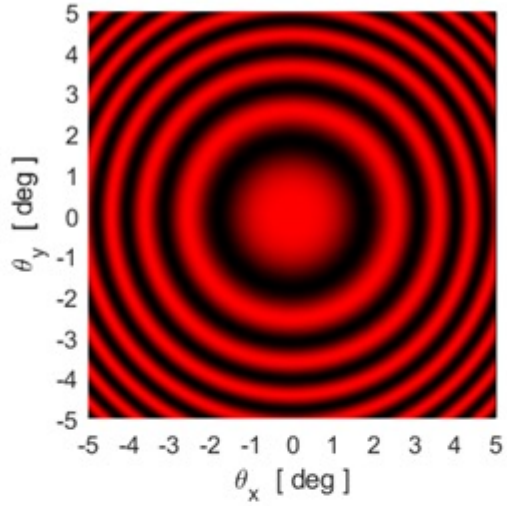

Screen
(1) + (2)
Laser
L_2
Mirror 2 (M2)
(2)
Beam Splitter (BS)
L_1
(1)
Mirror 1 (M1)

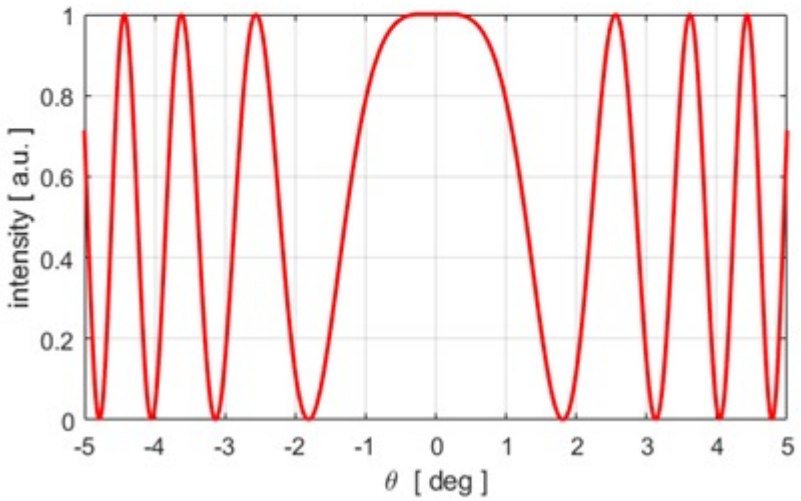
마이켈슨 간섭계



간섭 패턴




5
4
3
2
1
0
-1
-2
-3
-4
-5
θ_y [deg]
-5 -4 -3 -2 -1 0 1 2 3 4 5
θ_x [deg]


1
0.8
0.6
0.4
0.2
0
intensity [a.u.]
-5 -4 -3 -2 -1 0 1 2 3 4 5
θ [deg]

중력파 노이즈 저감 기술

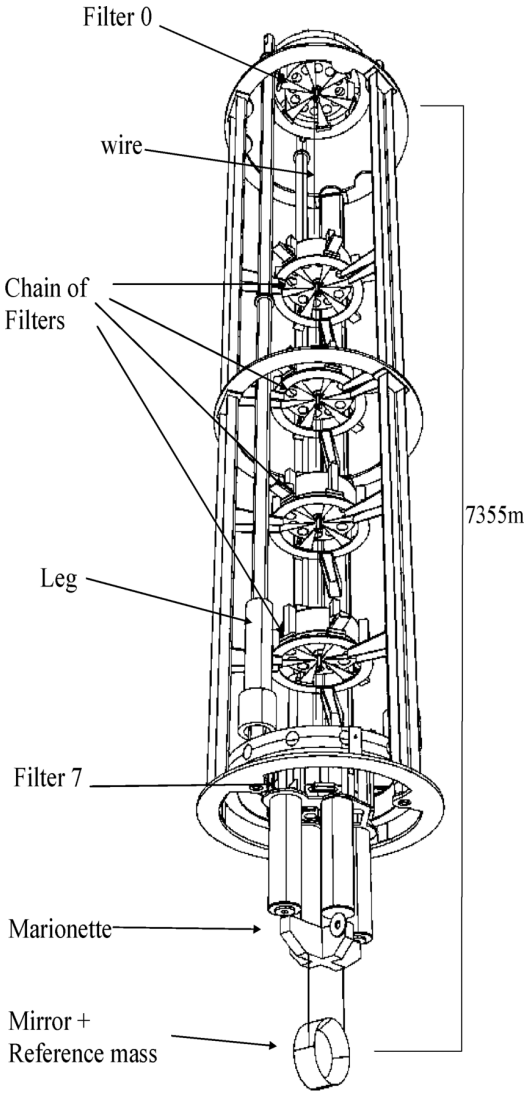


Image from : The real-time distributed control of the
Virgo Interferometric Detector of Gravitational Waves

중력파 노이즈 저감 기술

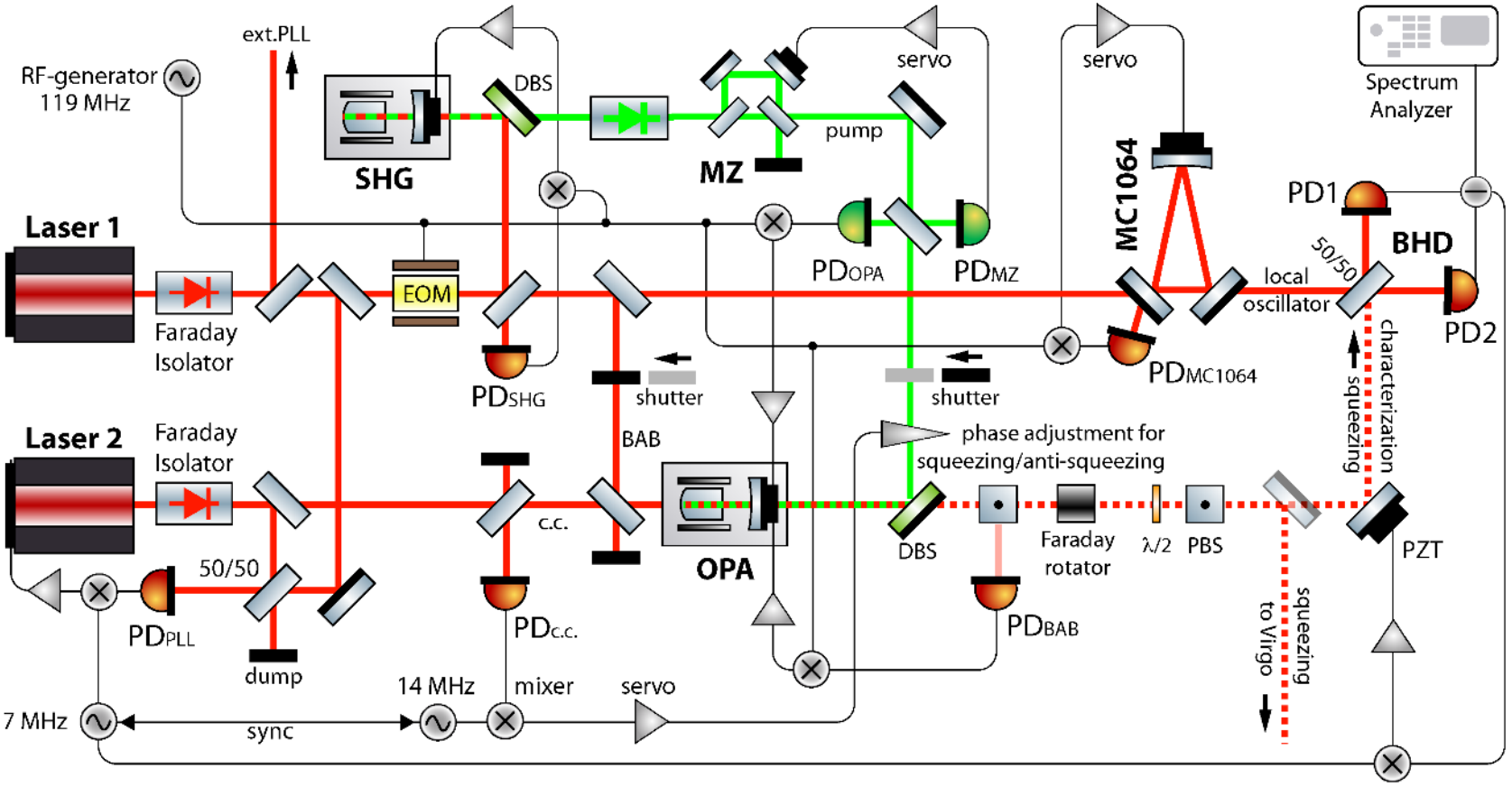
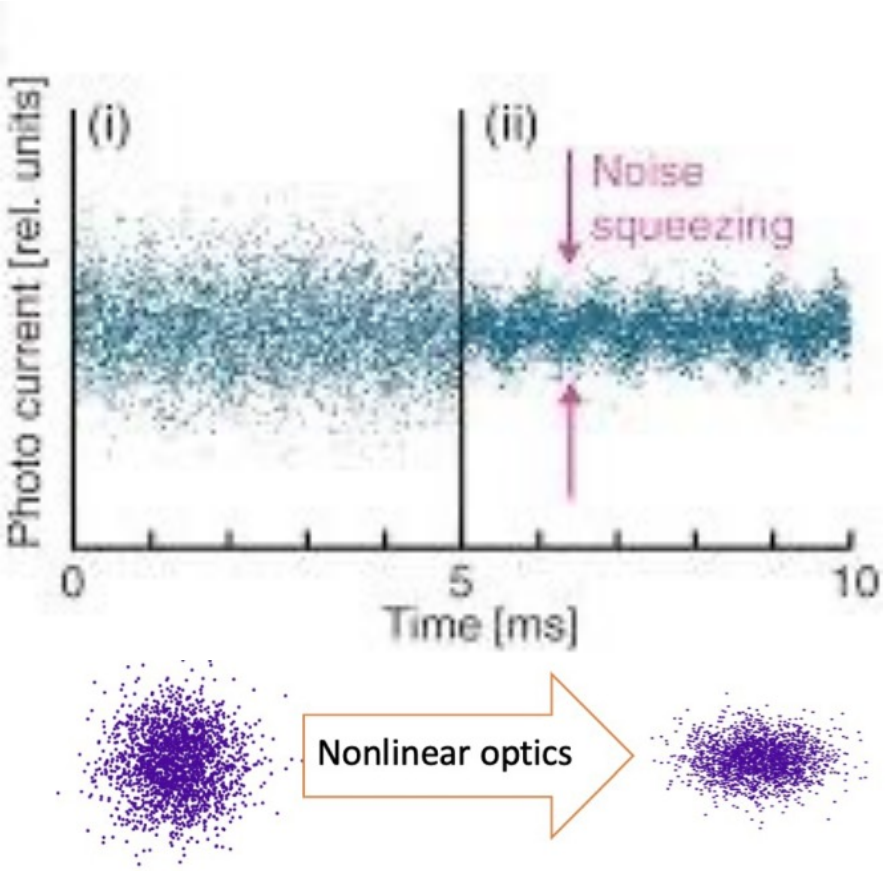


Image from : Mehmet, M.; Vahlbruch, H. The Squeezed Light Source for the Advanced Virgo Detector in the Observation Run O3. Galaxies 2020, 8, 79. https://doi.org/10.3390/galaxies8040079

중력파 노이즈 저감 기술



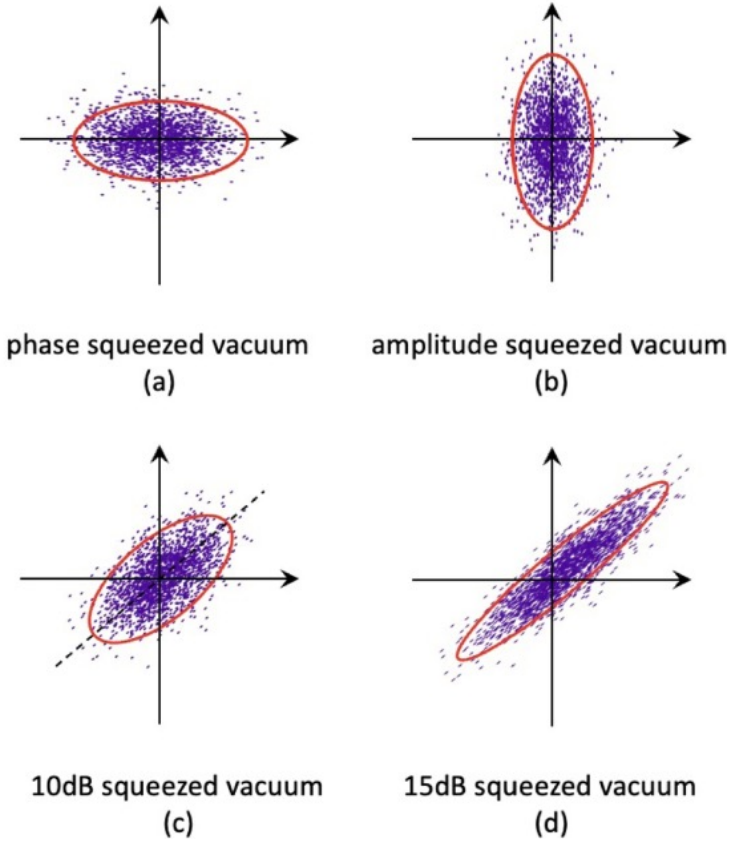


Image from : Mehmet, M.; Vahlbruch, H. The Squeezed Light Source for the Advanced Virgo Detector in the Observation Run O3. Galaxies 2020, 8, 79. https://doi.org/10.3390/galaxies8040079

중력파 노이즈 저감 기술

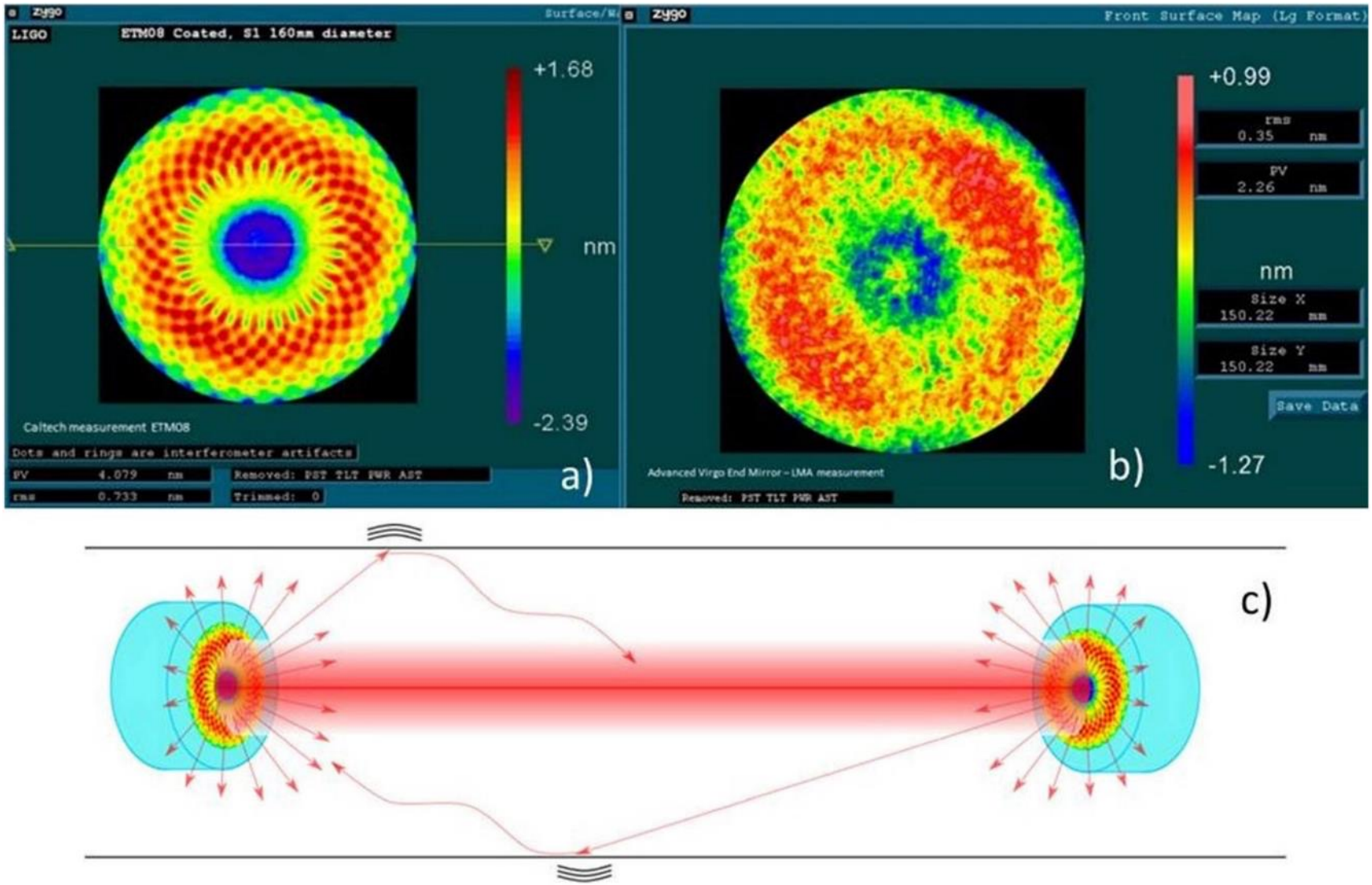
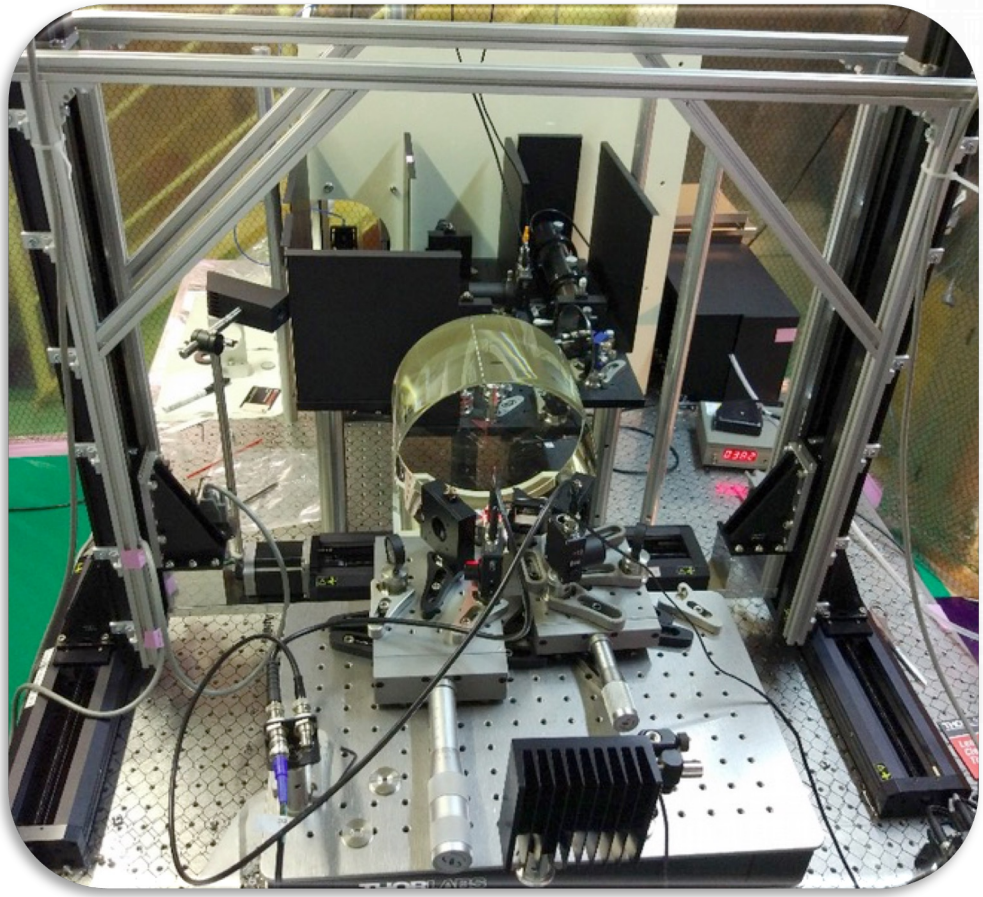
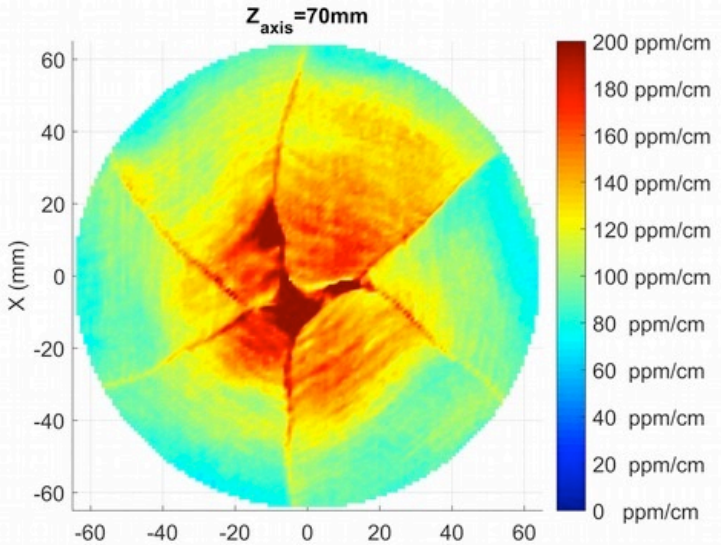
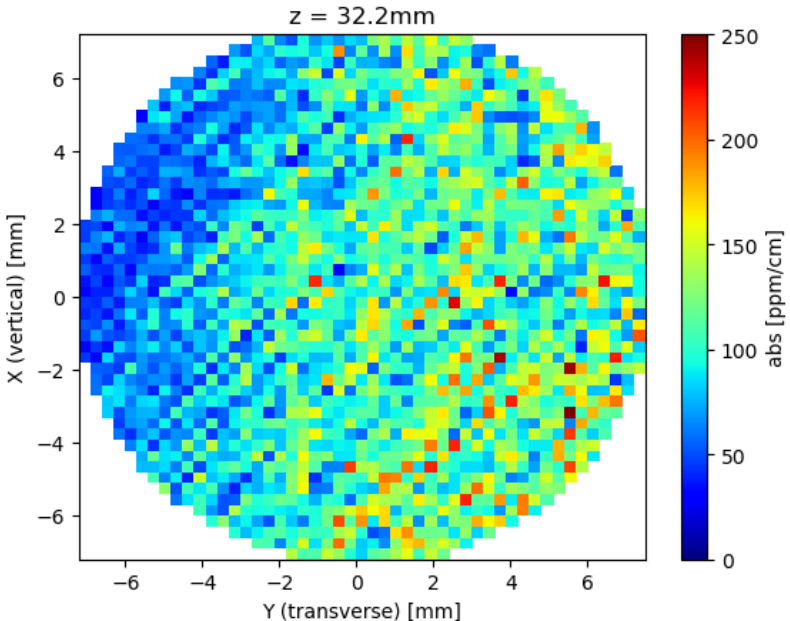


Image from : Gianpietro Cagnoli,; Advanced optical coatings for the discovery of gravitational waves

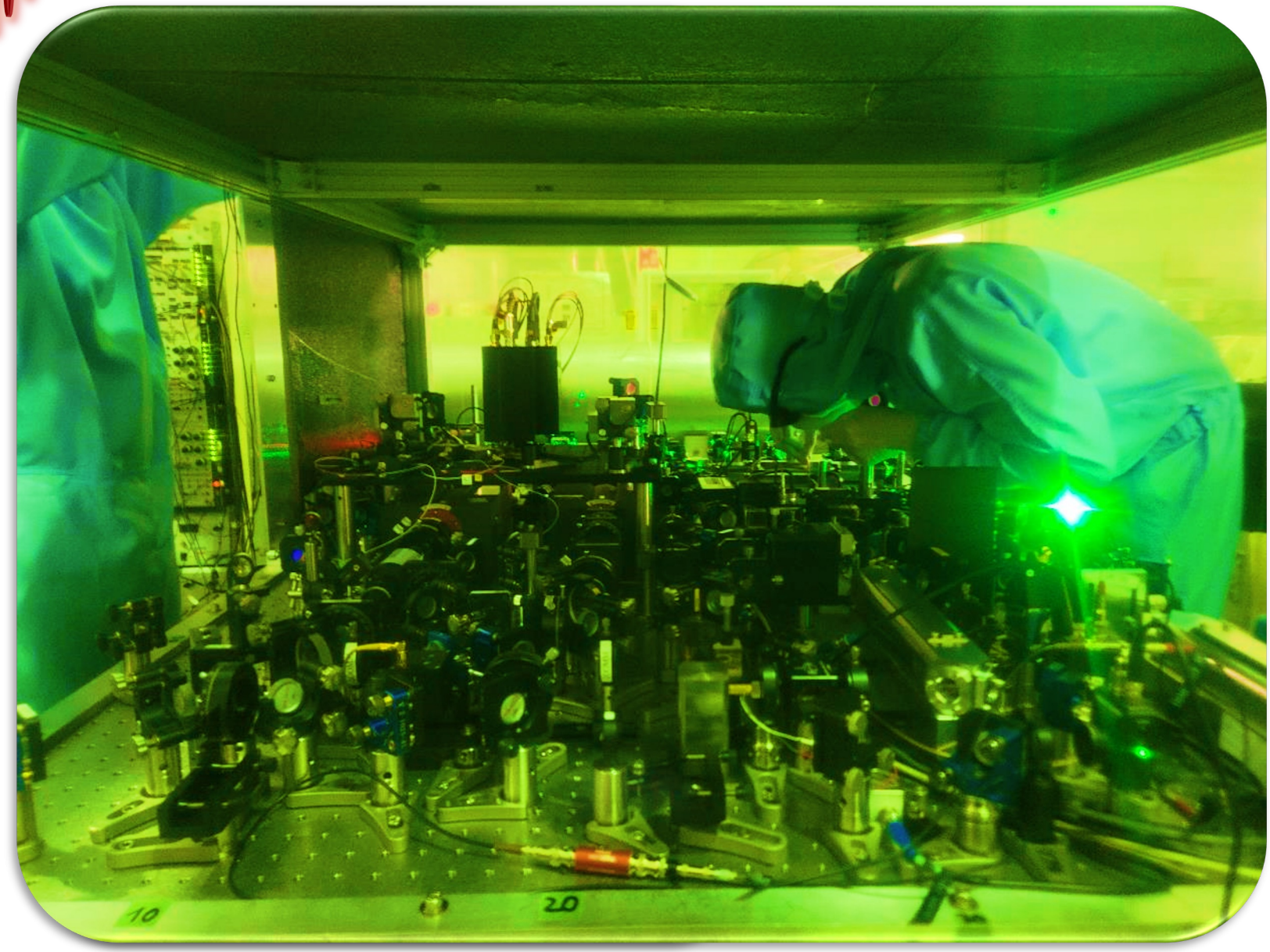
중력파 노이즈 저감 기술



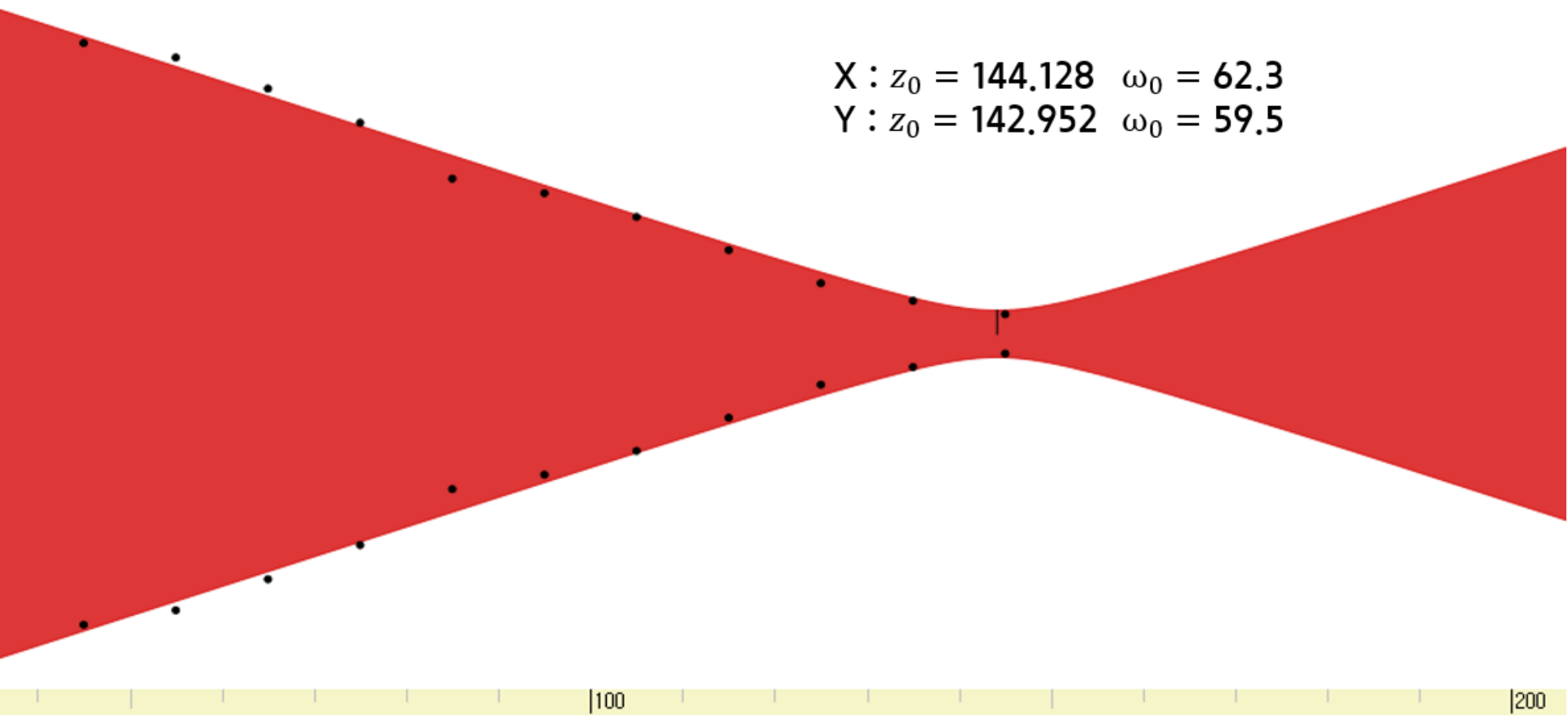

Z axis =70mm
X (mm)
60
40
20
0
-20
-40
-60
-60 -40 -20 0 20 40 60
200 ppm/cm
180 ppm/cm
160 ppm/cm
140 ppm/cm
120 ppm/cm
100 ppm/cm
80 ppm/cm
60 ppm/cm
40 ppm/cm
20 ppm/cm
0 ppm/cm


z = 32.2mm
X (vertical) [mm]
6
4
2
0
−2
−4
−6
−6 −4 −2 0 2 4 6
Y (transverse) [mm]
250
200
150
100
50
0
abs [ppm/cm]

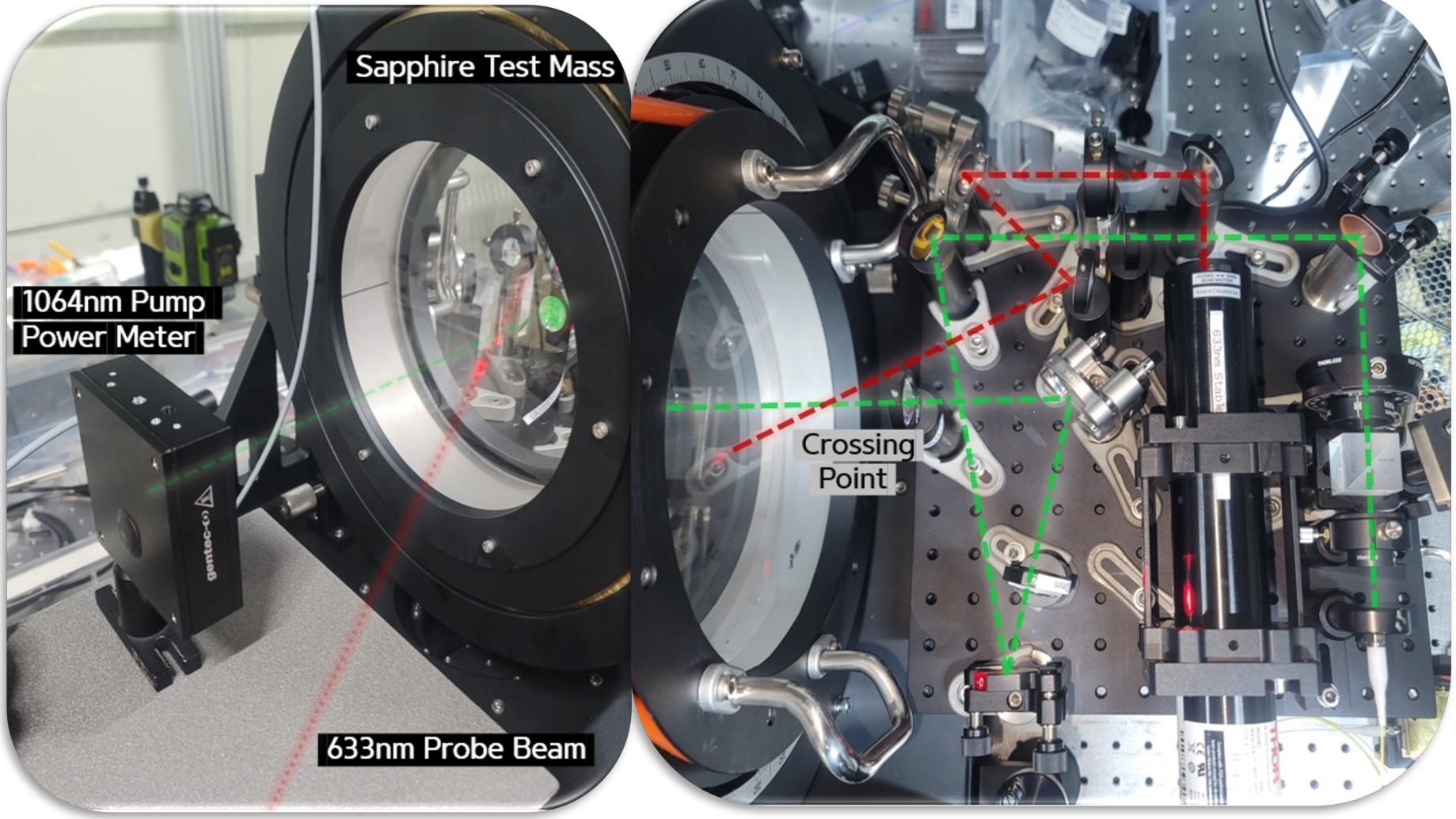
실험



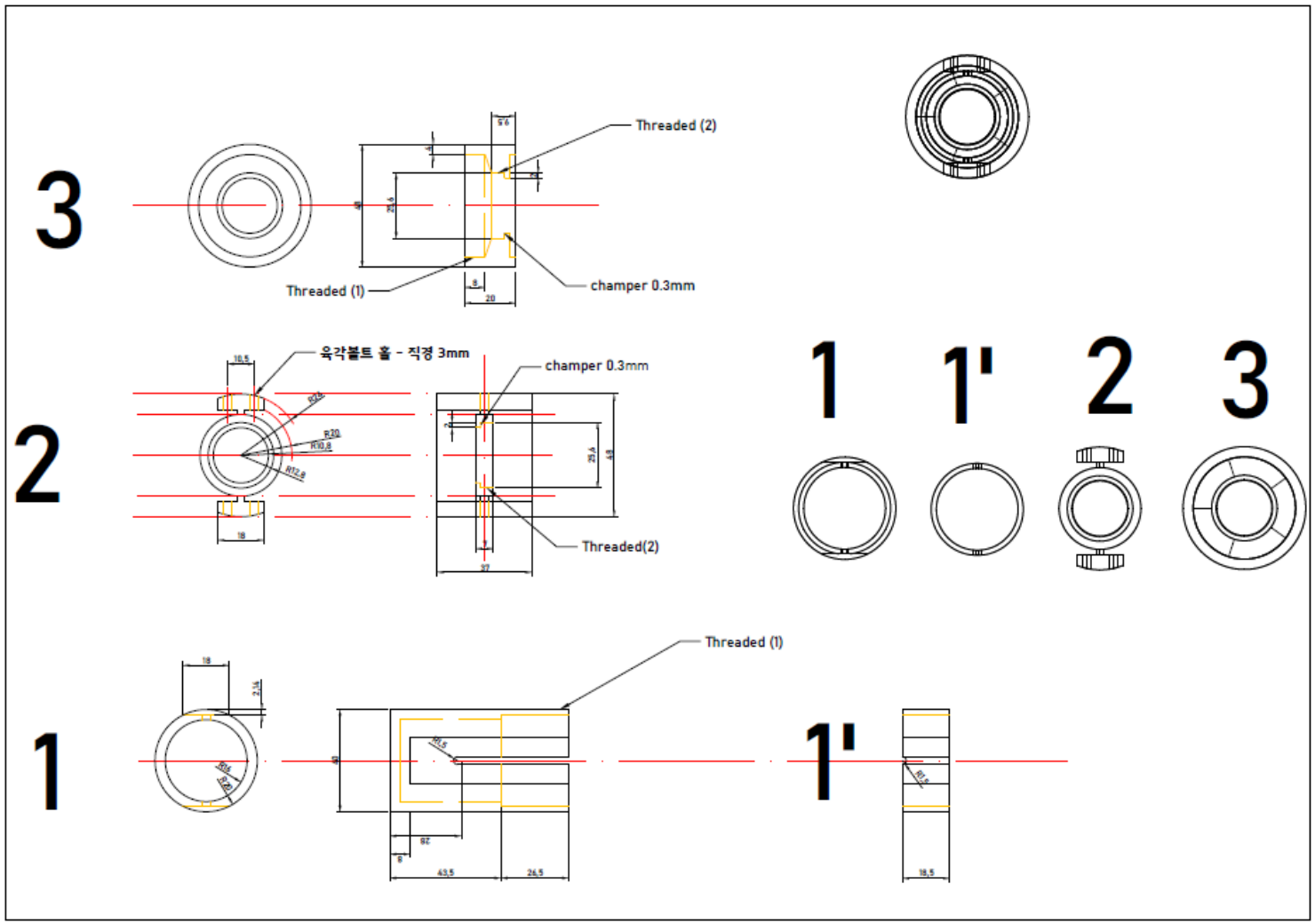
시뮬레이션



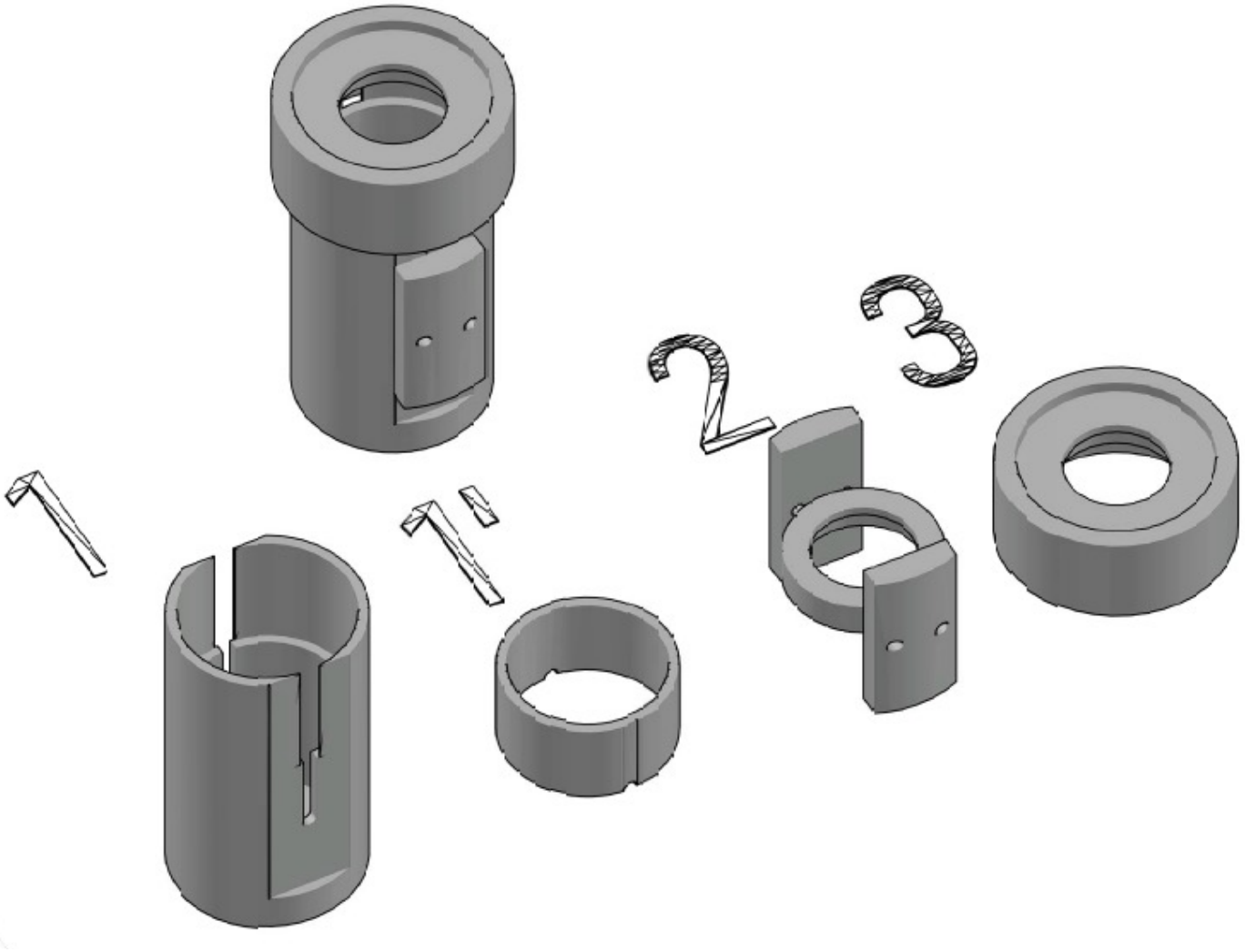
실험


Sapphire Test Mass
1064nm Pump
Power Meter
633nm Probe Beam
Crossing
Point

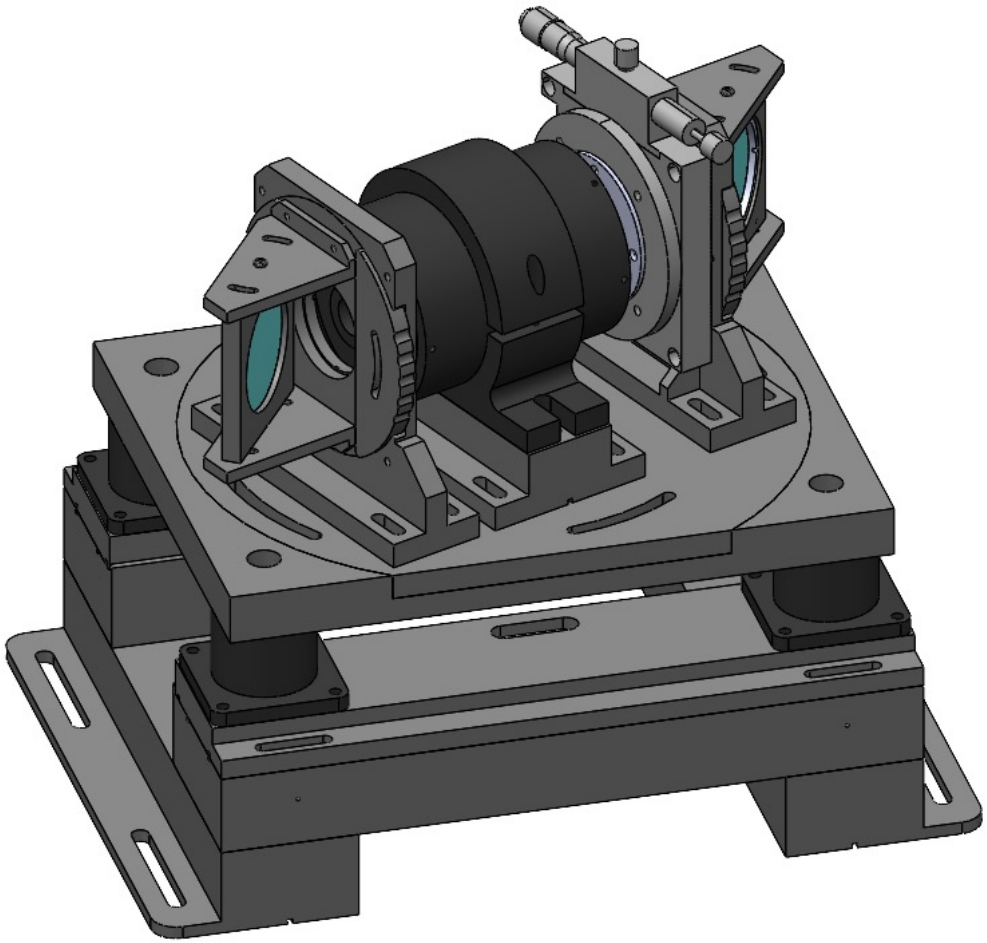
모델링

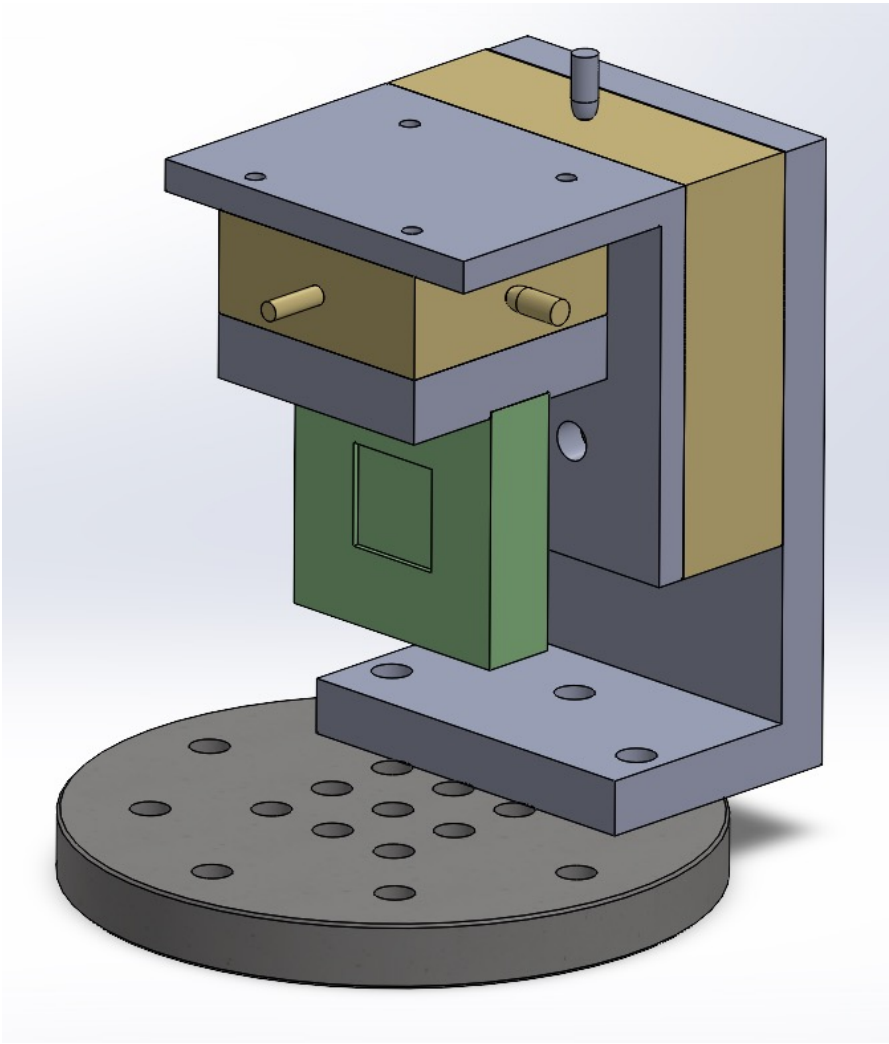

3
Threaded (2)
Threaded (1)
champer 0.3mm
2
육각볼트 홀 - 직경 3mm
champer 0.3mm
Threaded(2)
1
1'
2
3
1
Threaded (1)
1'

모델링



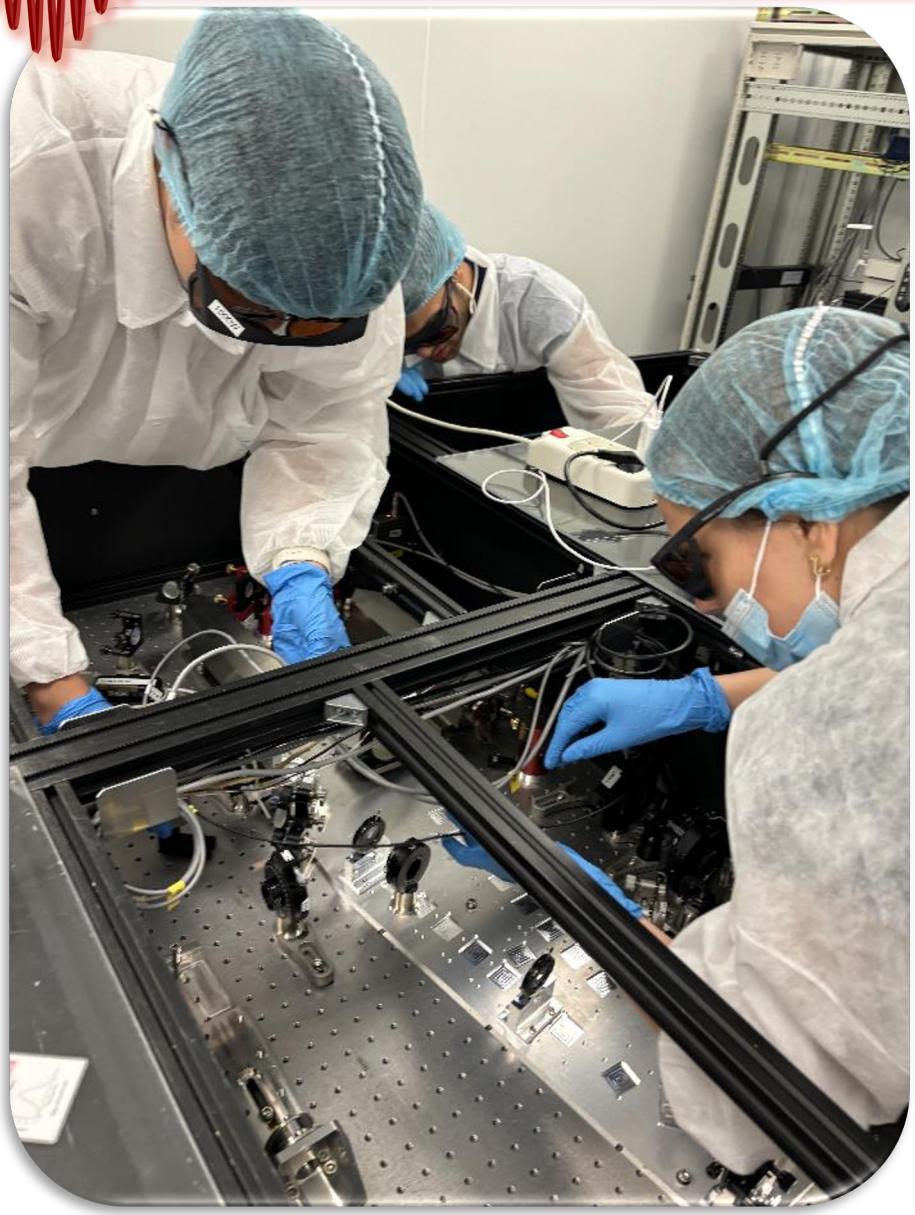
모델링

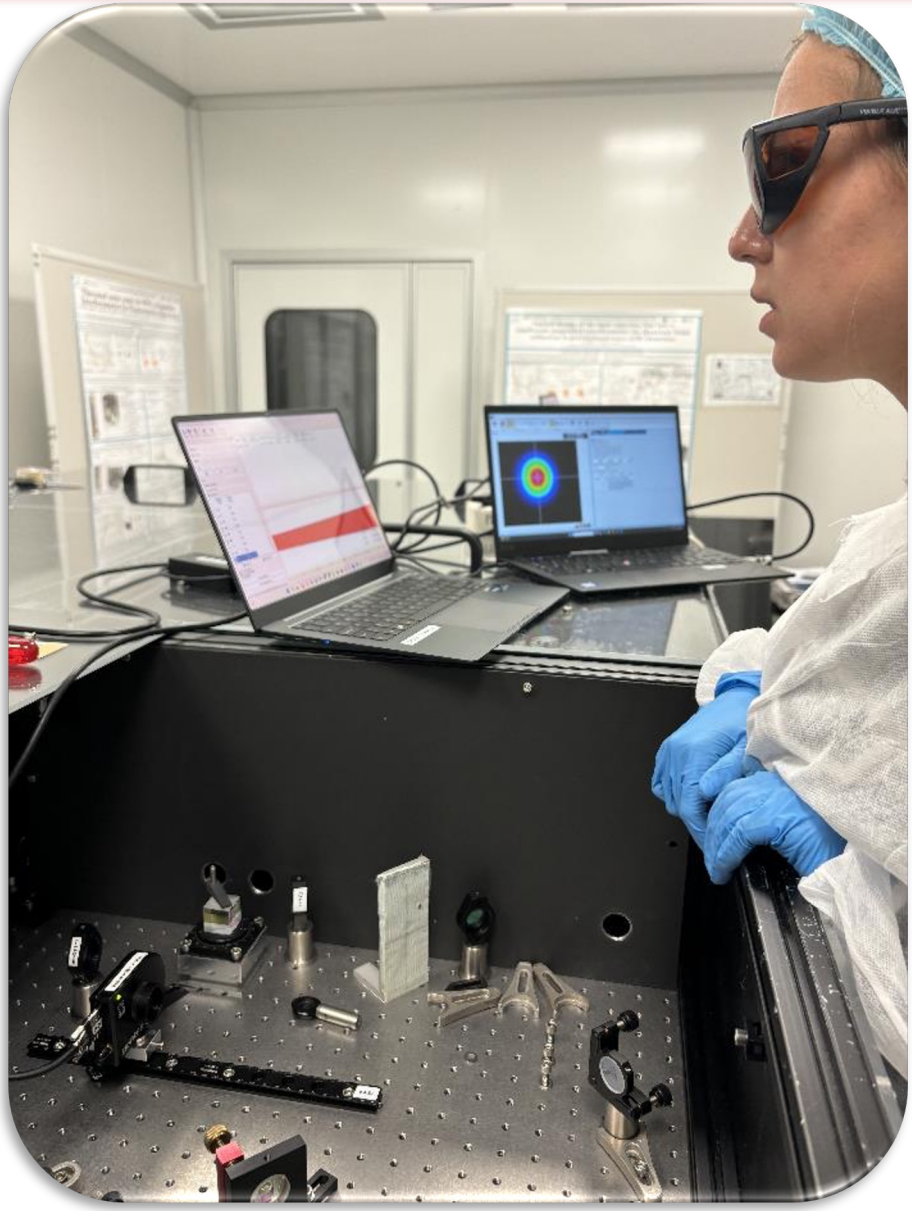




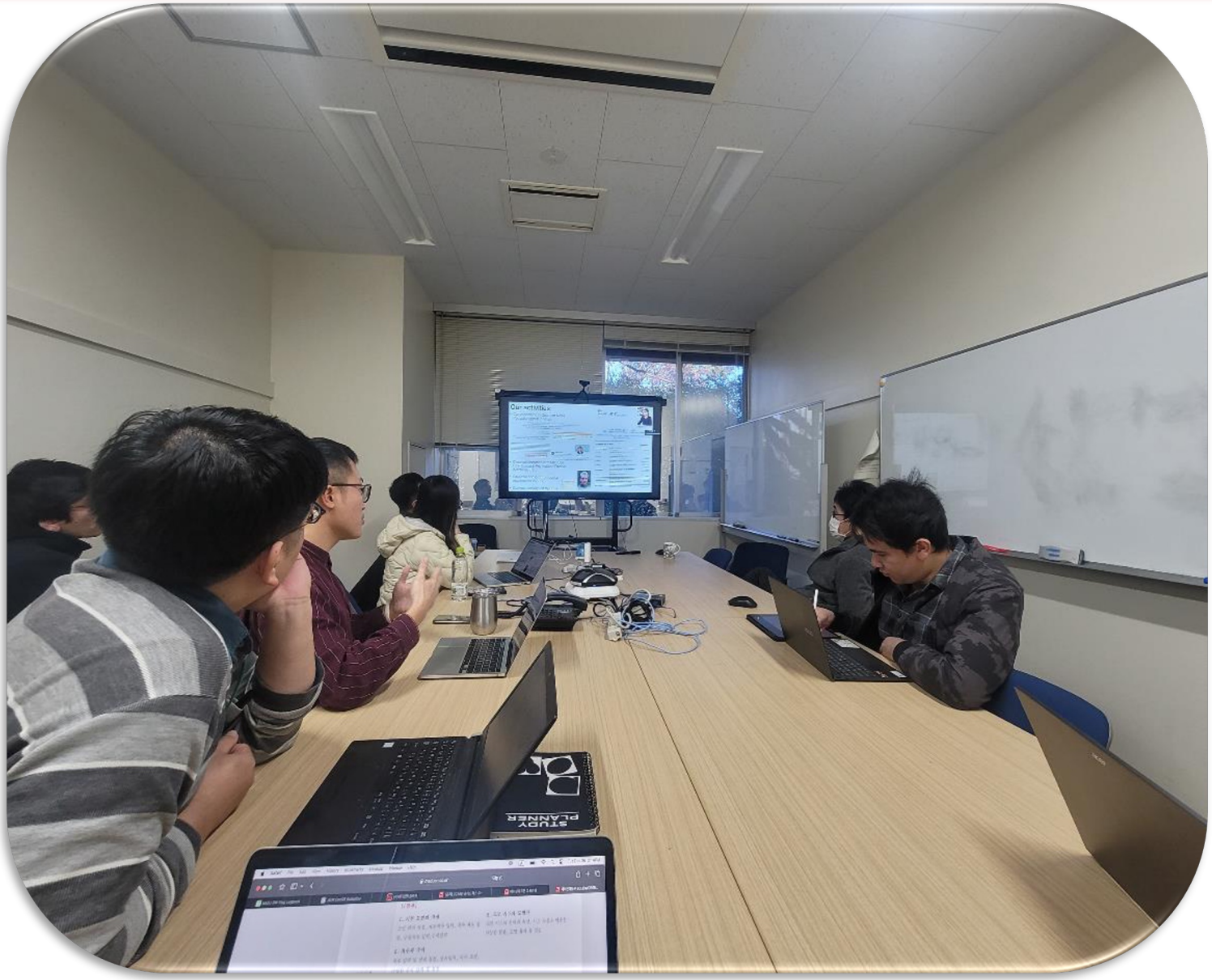
Cascina, Italy

Cascina, Italy





NAOJ, Japan



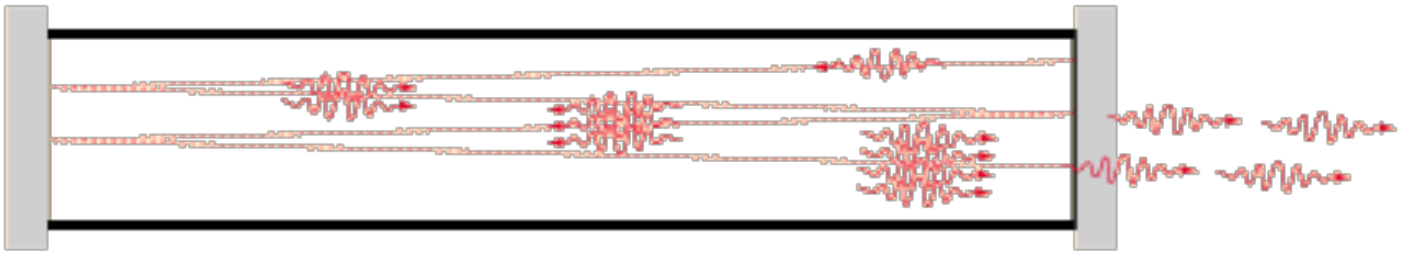
QnA

이 다음으로는 레이저 이론 내용을 설명합니다.

이전 내용에 대해 알고 싶은 것이 있으시다면 질문 해 주세요.

레이저?

Light Amplification by Stimulated Emission of Radiation



레이저는 어떻게 나와요?

레이저는 어떻게 나와요?

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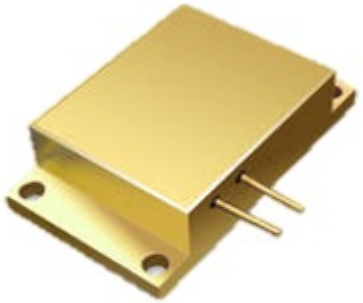
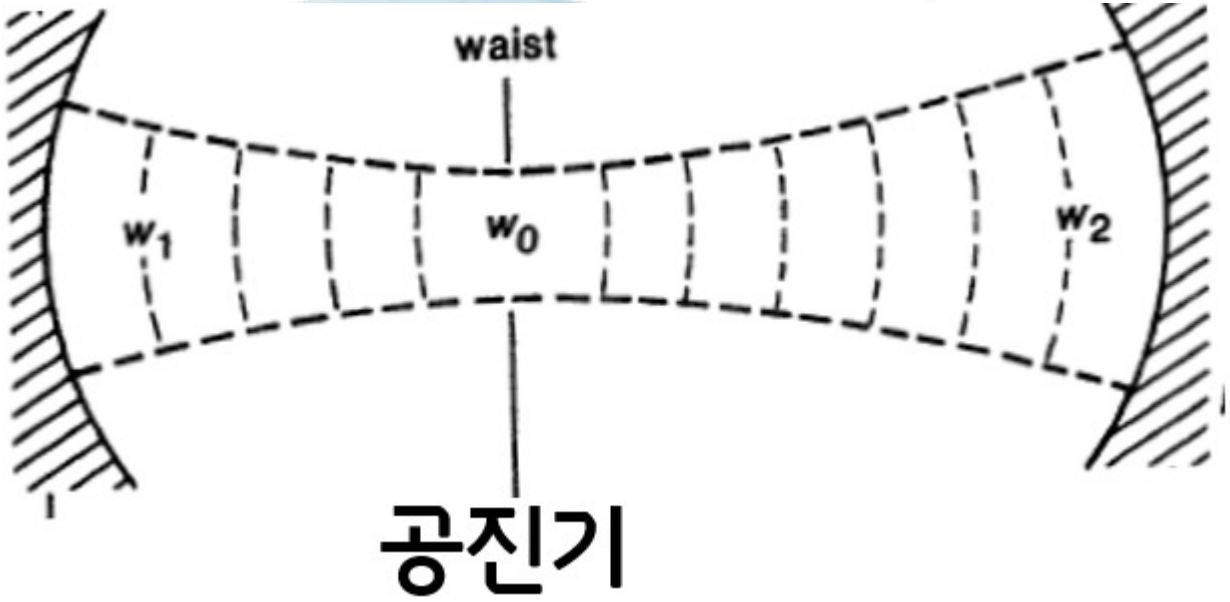


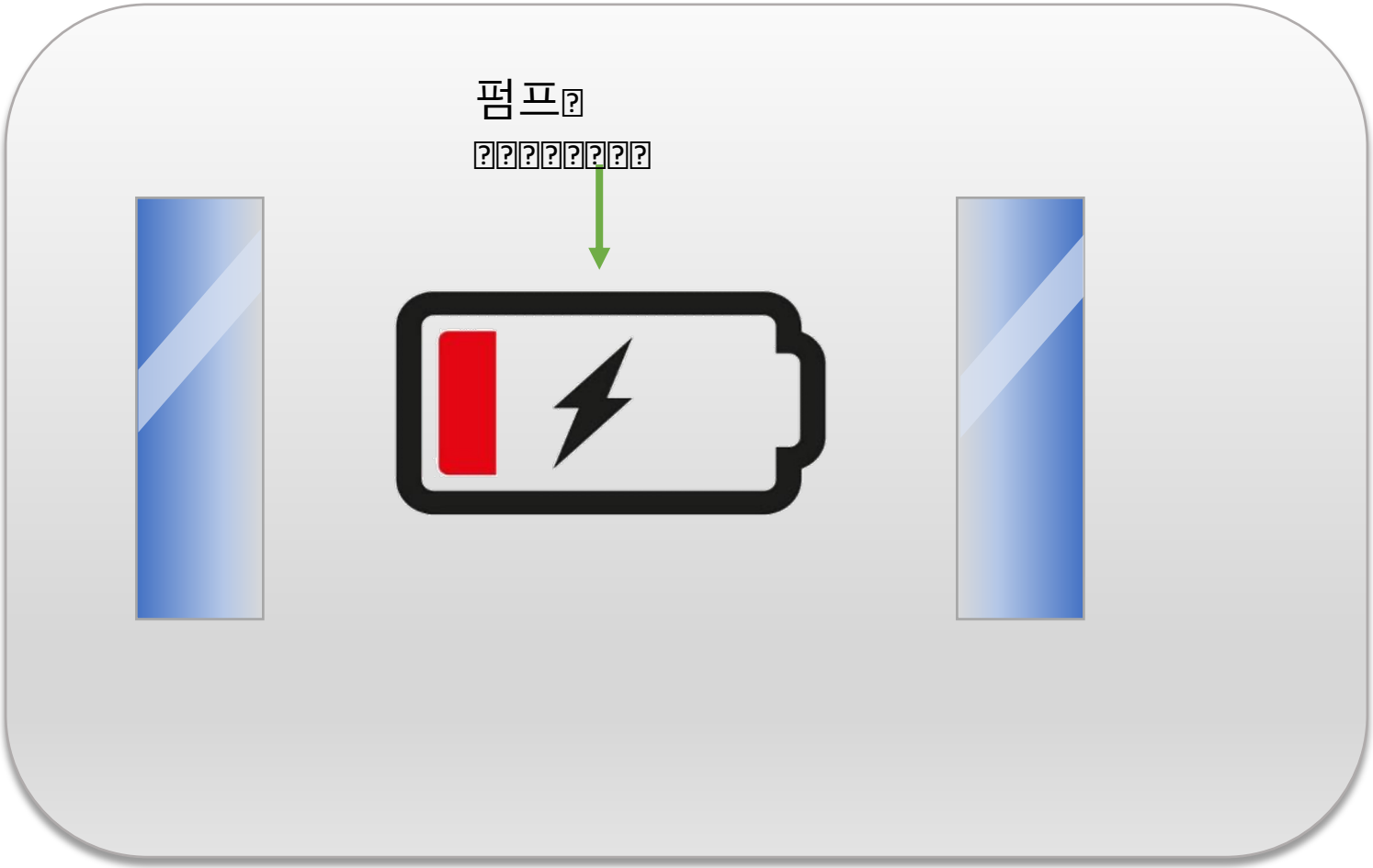
펌프

이득 매질

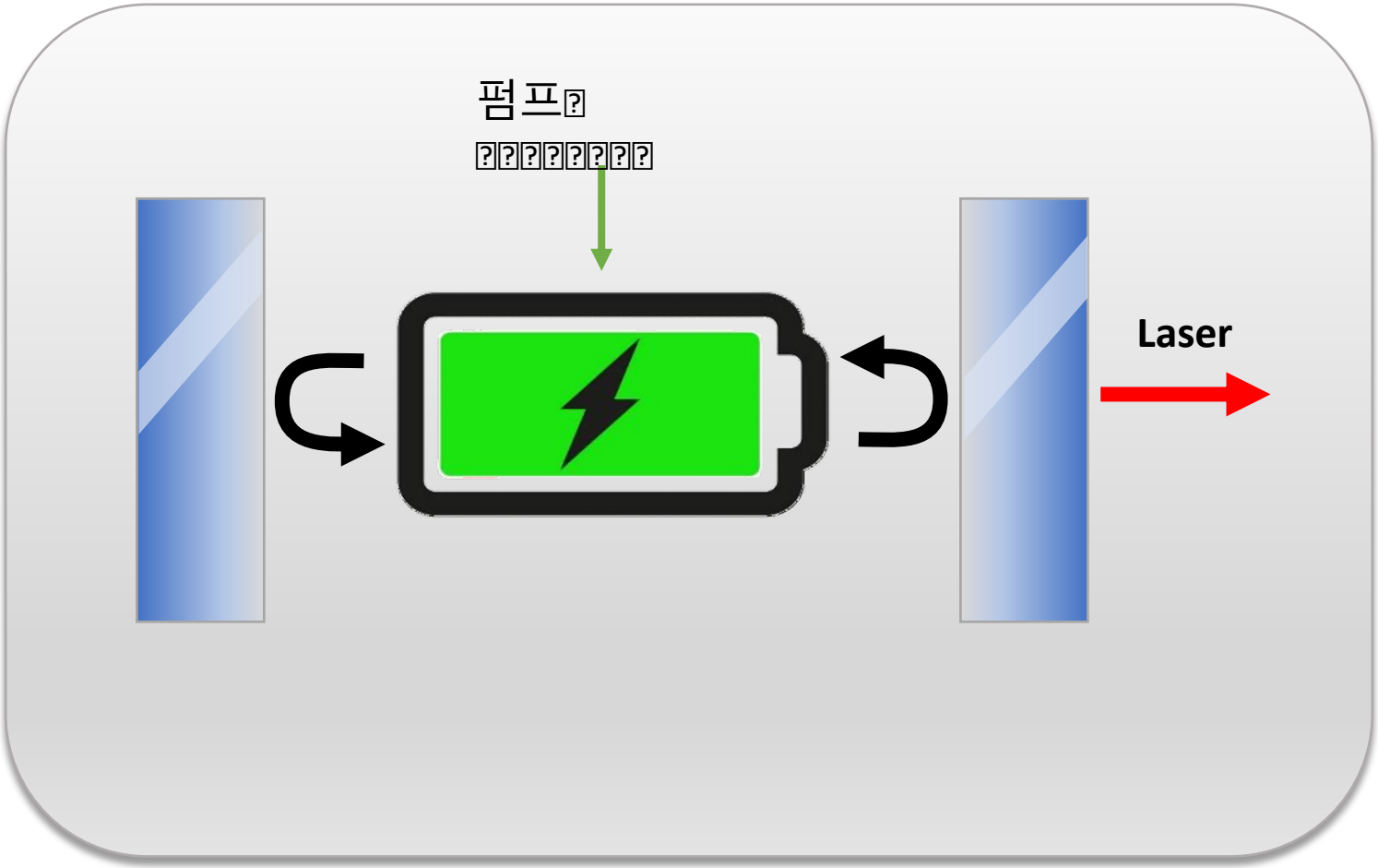


공진기

레이저는 어떻게 나와요?



레이저는 어떻게 나와요?

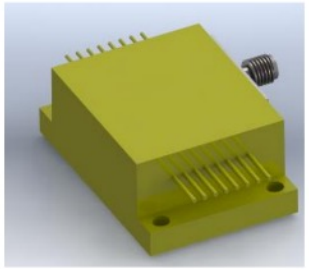


펌프

HAN'S TCS 大族天成半导体

M1064±10-30-D400/22-G3-APK

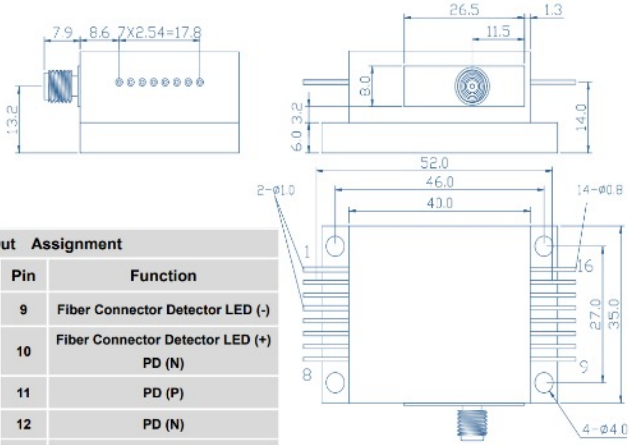
G-Series High Power Laser Diode Module



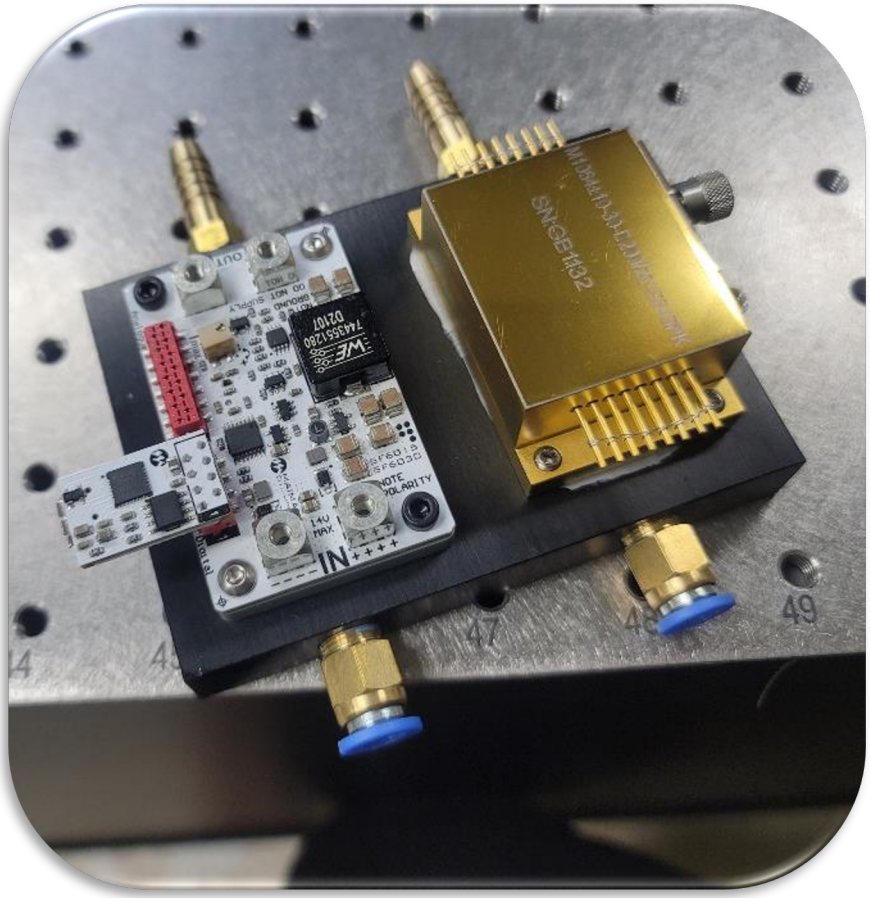
Features
- High output power of 30 W
- 400μm/0.22NA multimode optical fiber
- Center wavelength 1064±10nm

Applications
- Medical Application

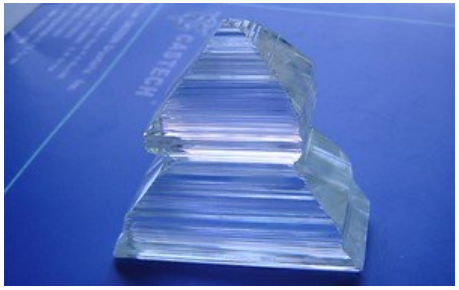
Package Dimensions (mm)

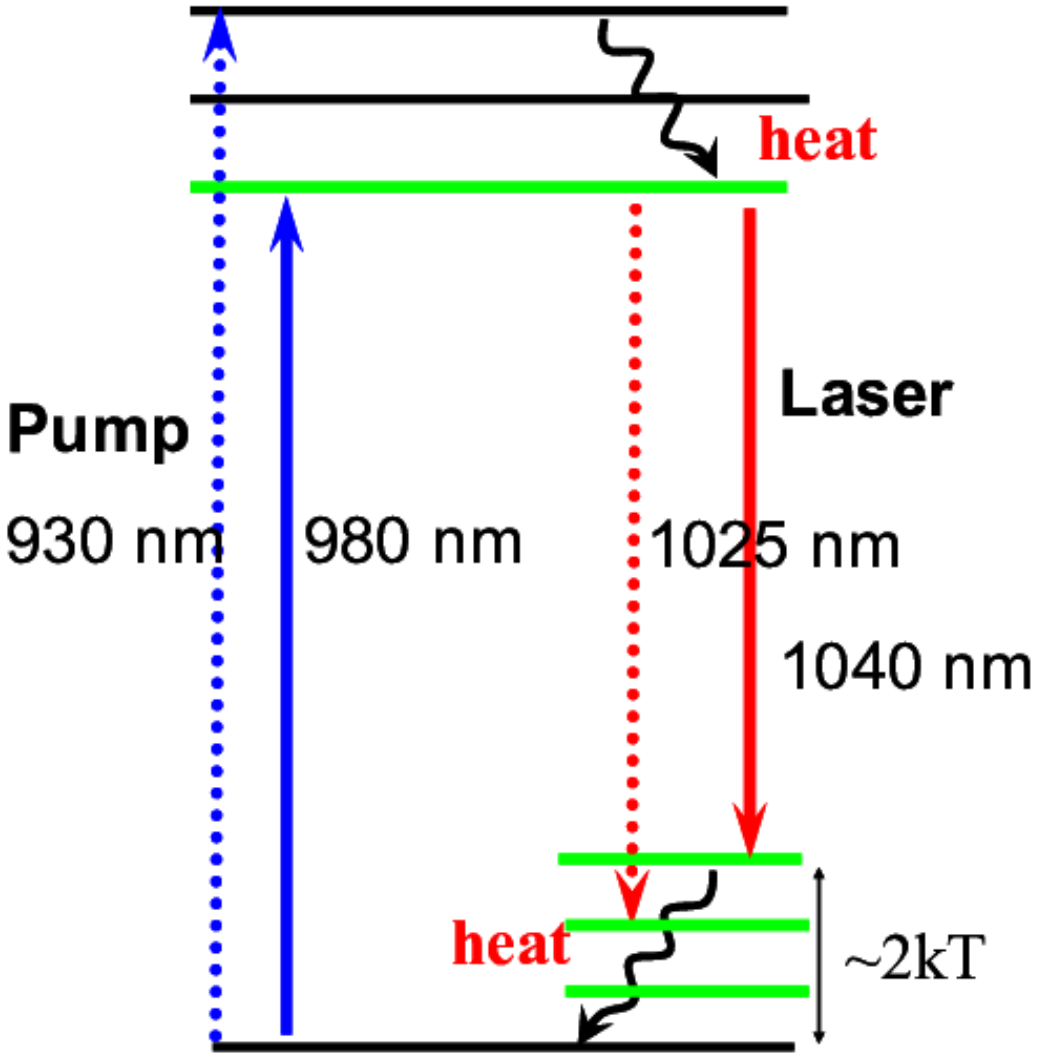


Pin-Out Assignment		
Function	**Pin**	**Function**
LD(+)	9	Fiber Connector Detector LED (-)
-	10	Fiber Connector Detector LED (+) PD (N)
-	11	PD (P)
LD (-)	12	PD (N)
-	13	-
-	14	PD (P)
Aiming Beam（+5V）*	15	Thermistor
Aiming Beam（0）	16	Thermistor

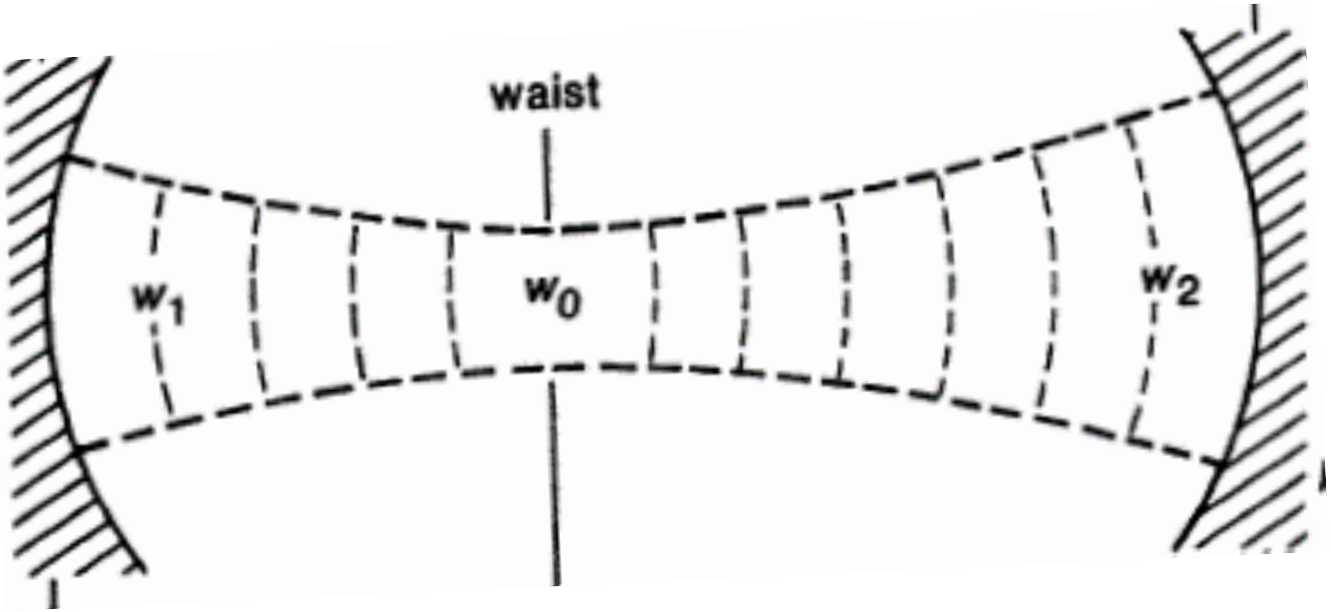


이득매질





공진기

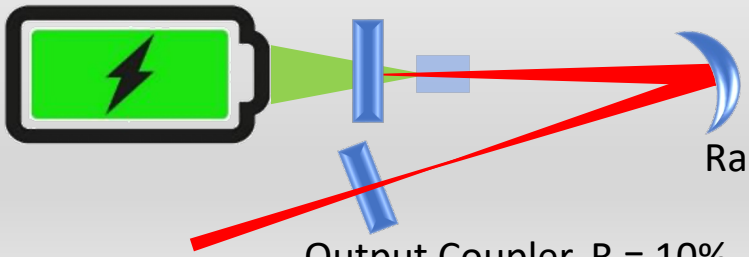


공진기

Cavity type : V-shaped

Gain Medium : Yb(1.5%):KGW 2x2, 5 mm thick N_p-cut, AR Coated (980-1040), water cooled

Dichroic mirror A.R(~980 left) , H.R(1010-1040 right)

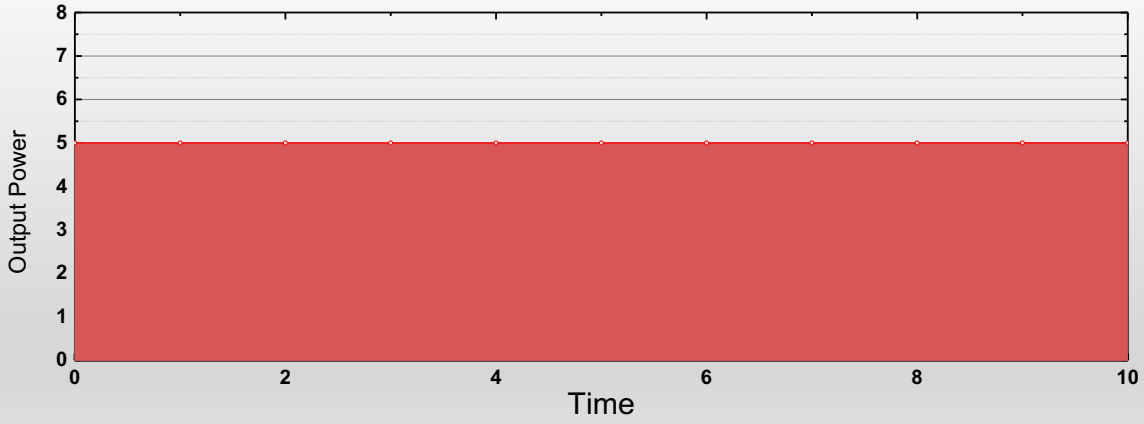


발진

펄스 레이저

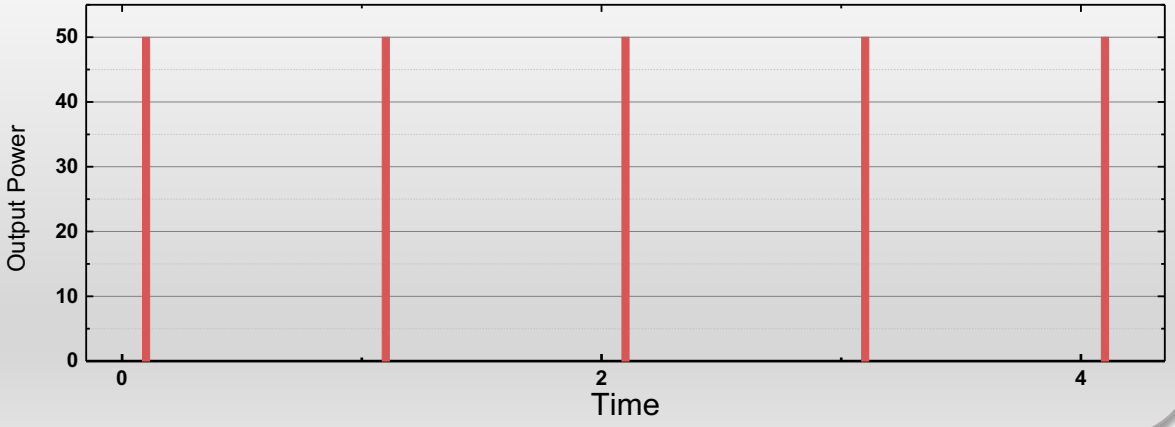
CW (Constant Wave)

시간에 대해서 출력이 일정한 레이저

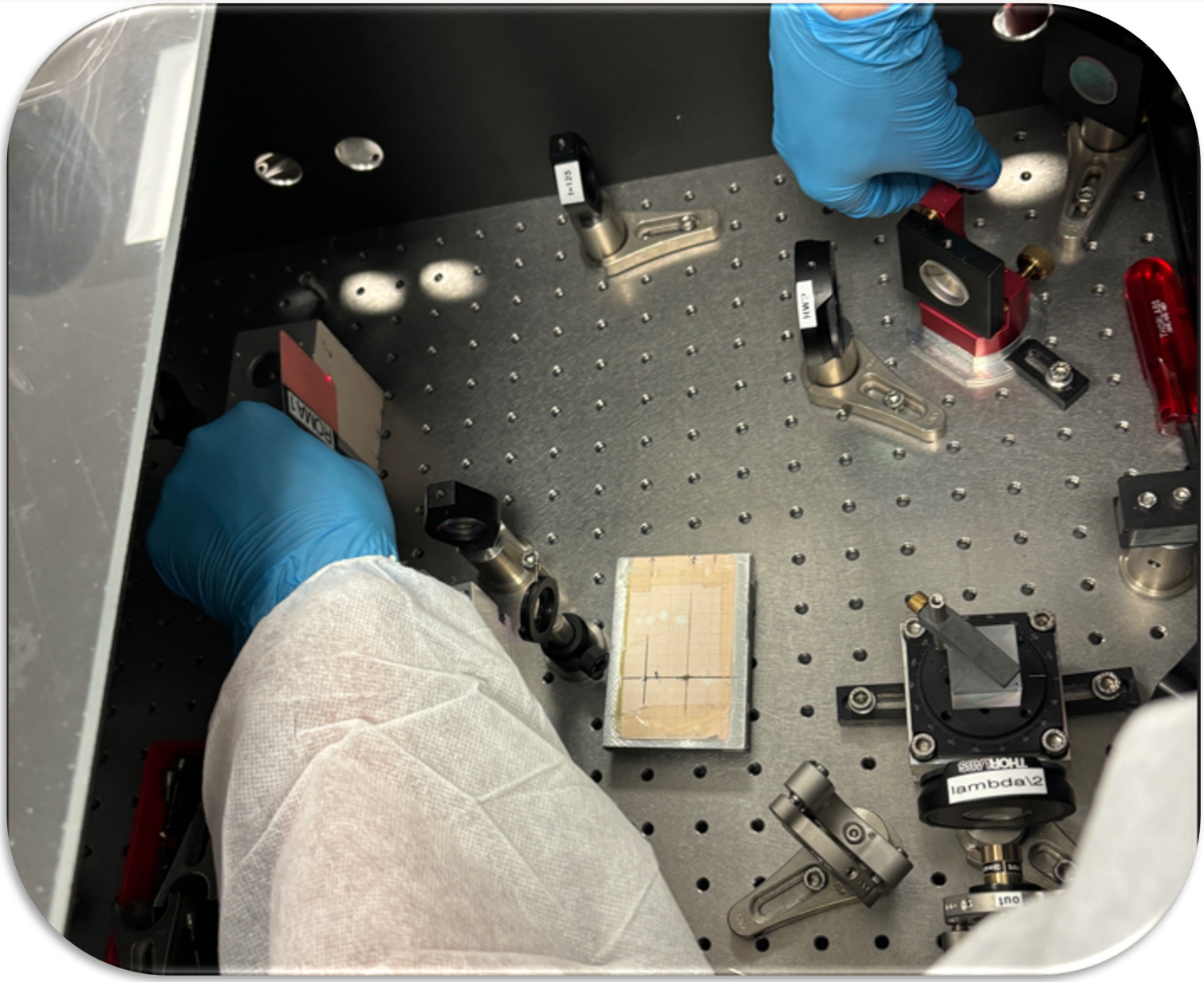


펄스 레이저 (Pulsed Laser)

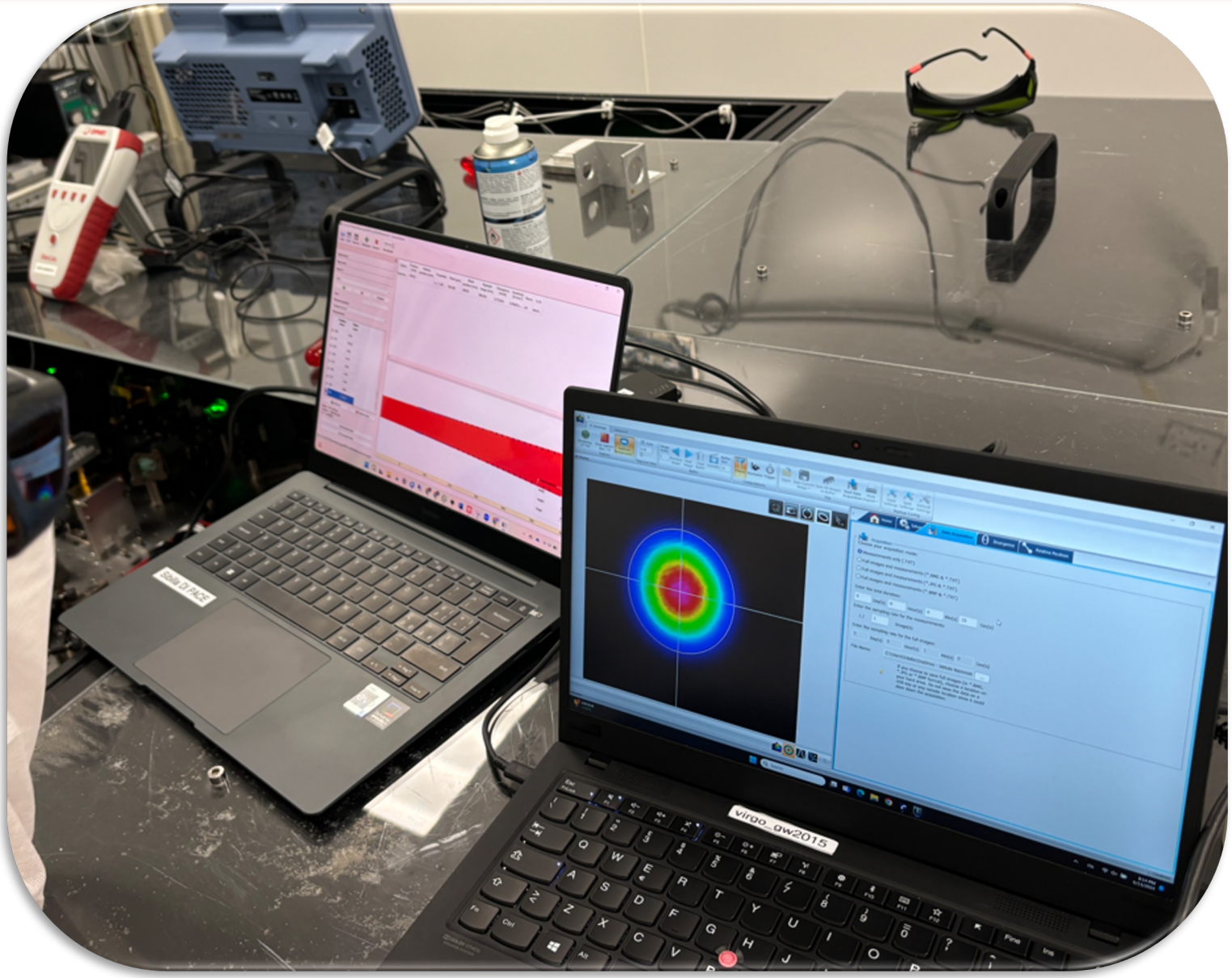
시간에 대해 출력이 일정하지 않고 짧은 시간 안에 에너지가 집약된 레이저



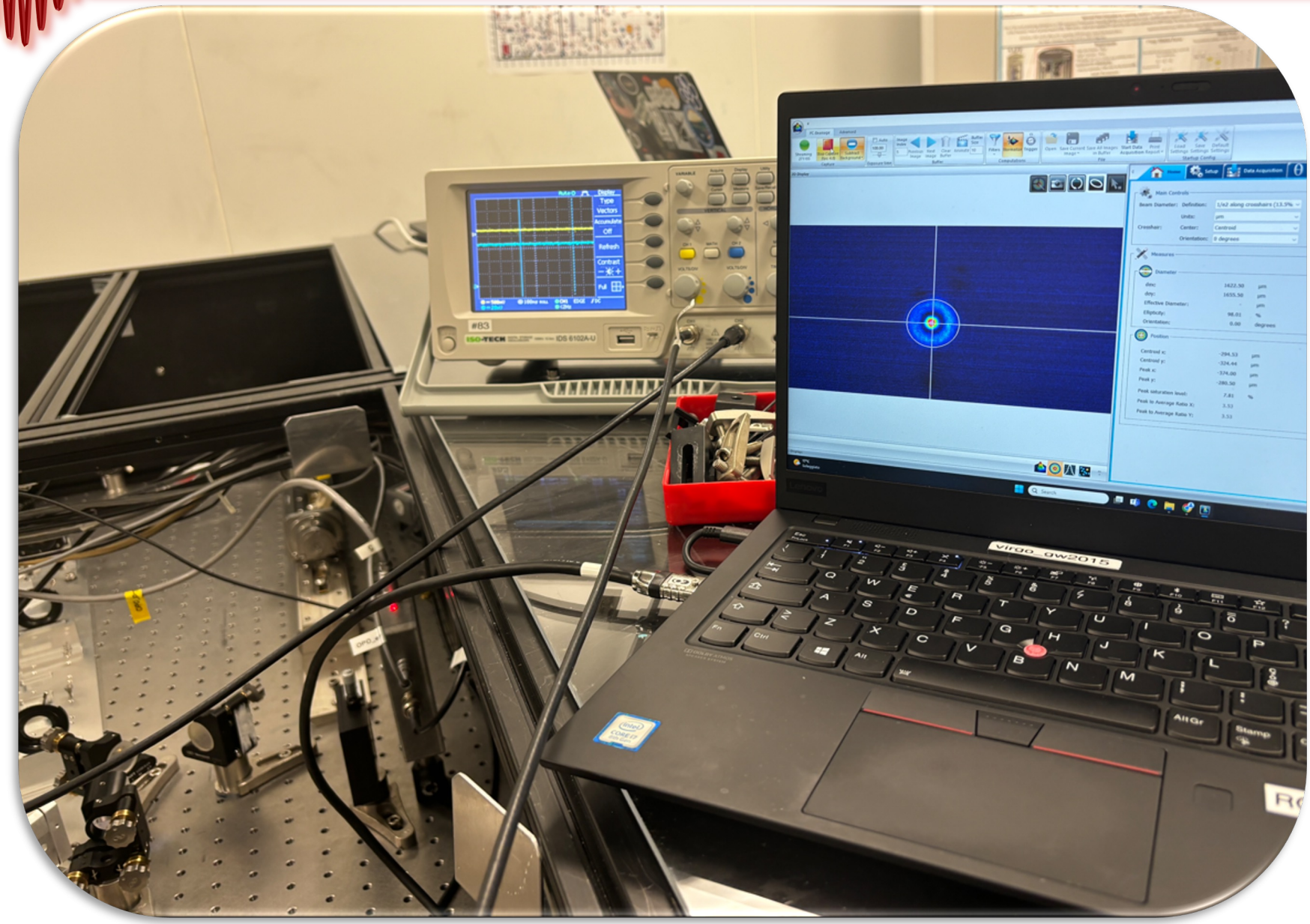
Cascina, Italy



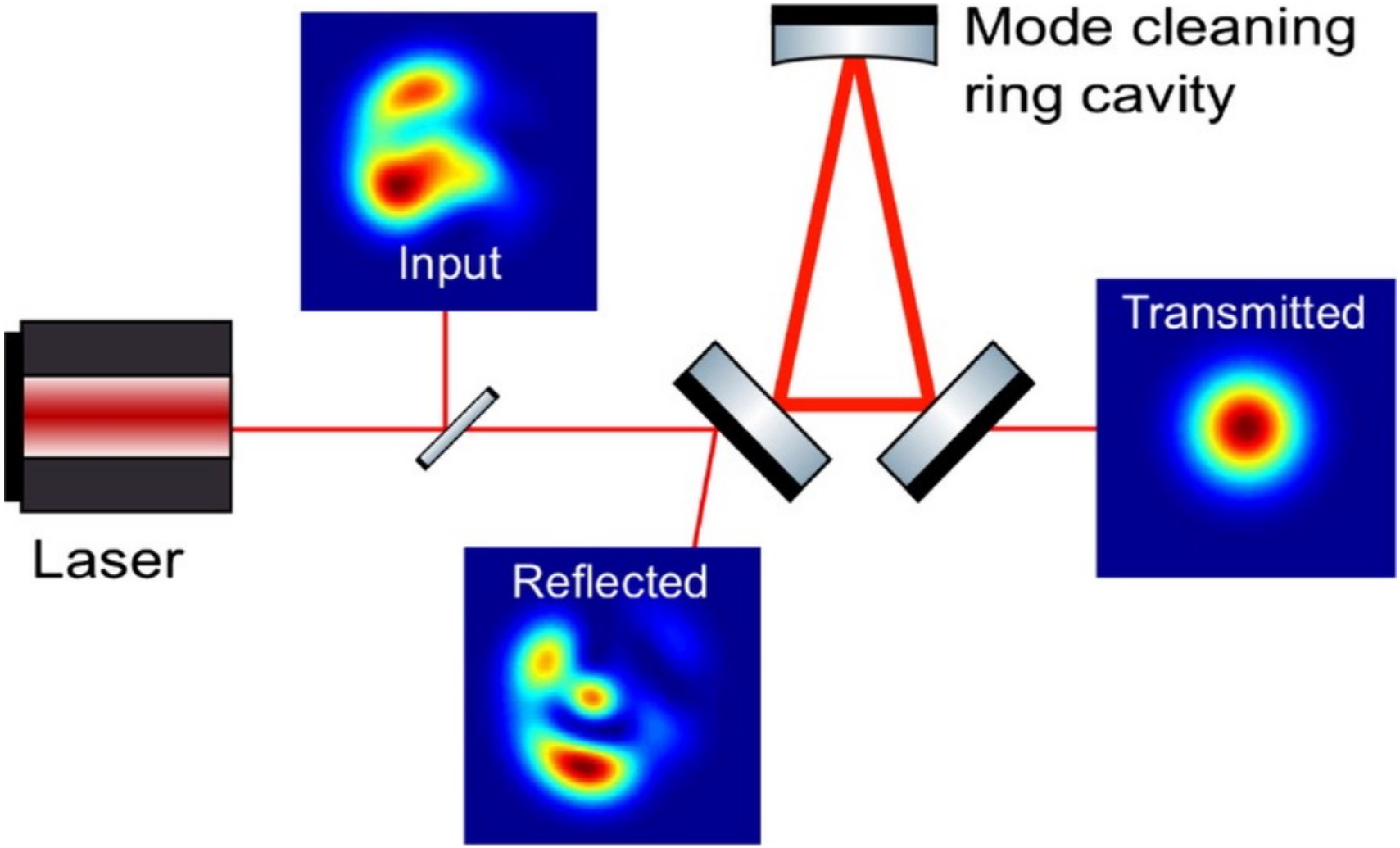
Cascina, Italy



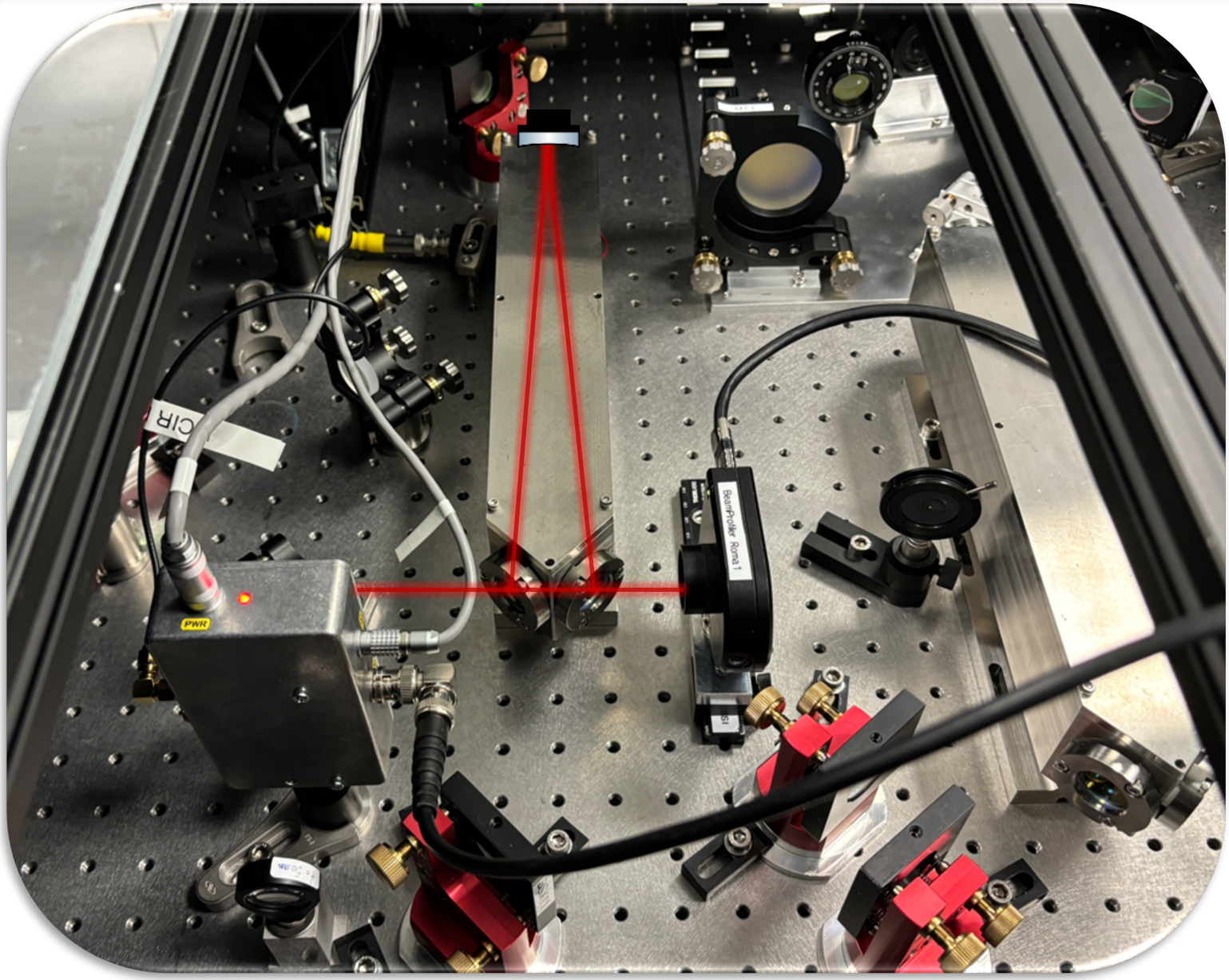
Cascina, Italy



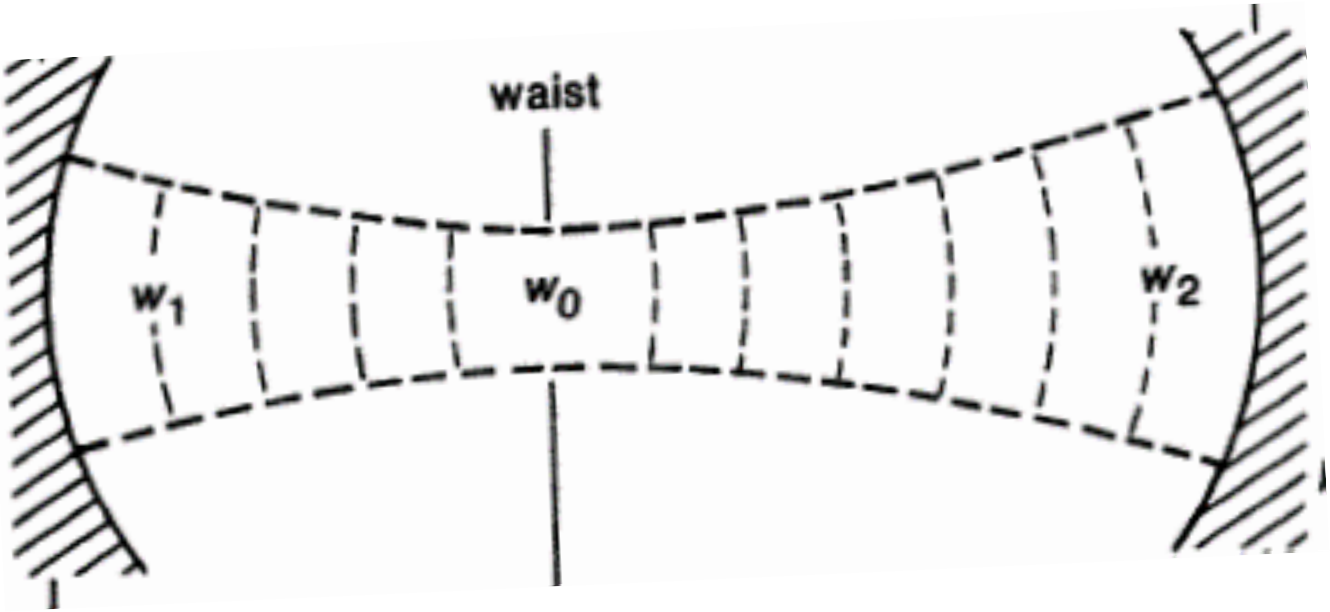
Mode Cleaner



Mode Cleaner



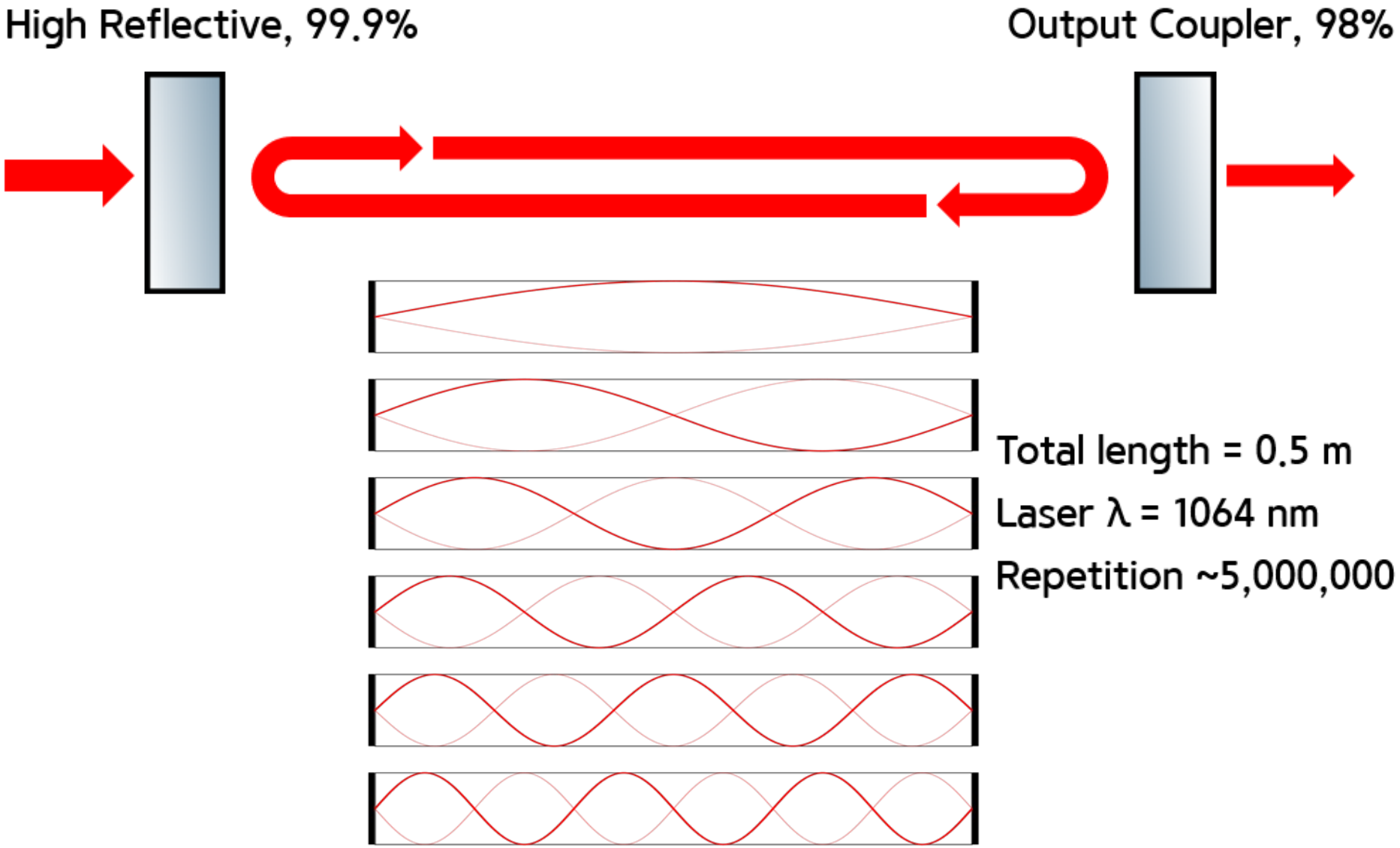
Laser Cavity



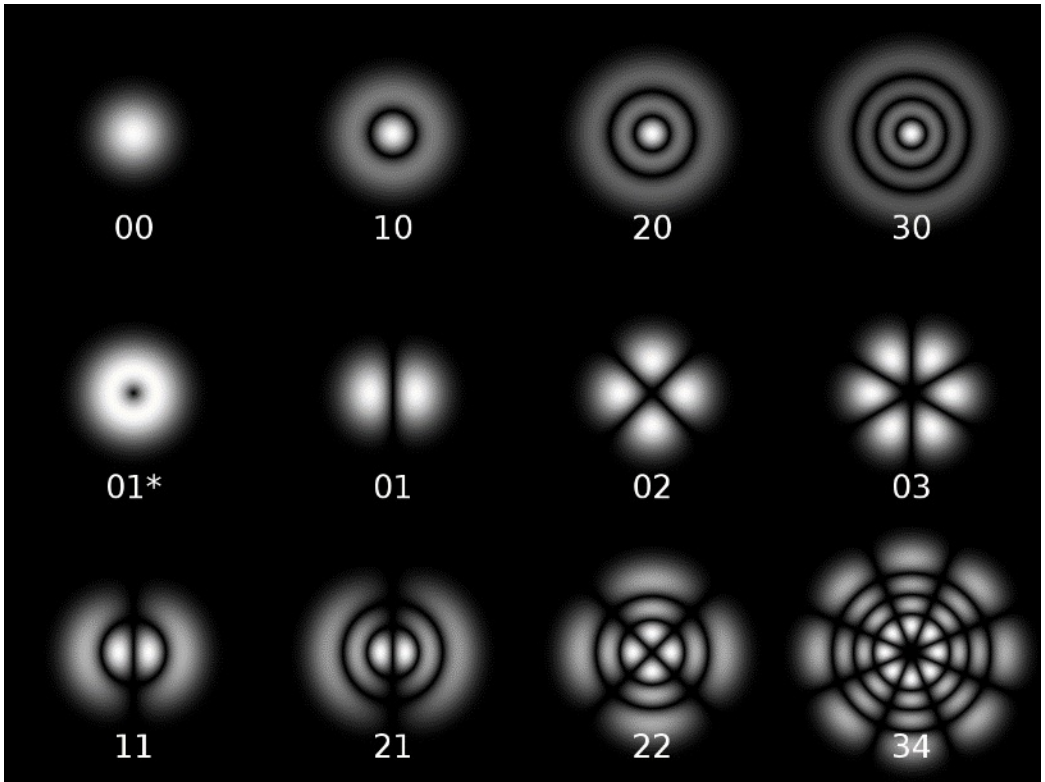
High Reflective, 99.9%

Output Coupler, 98%

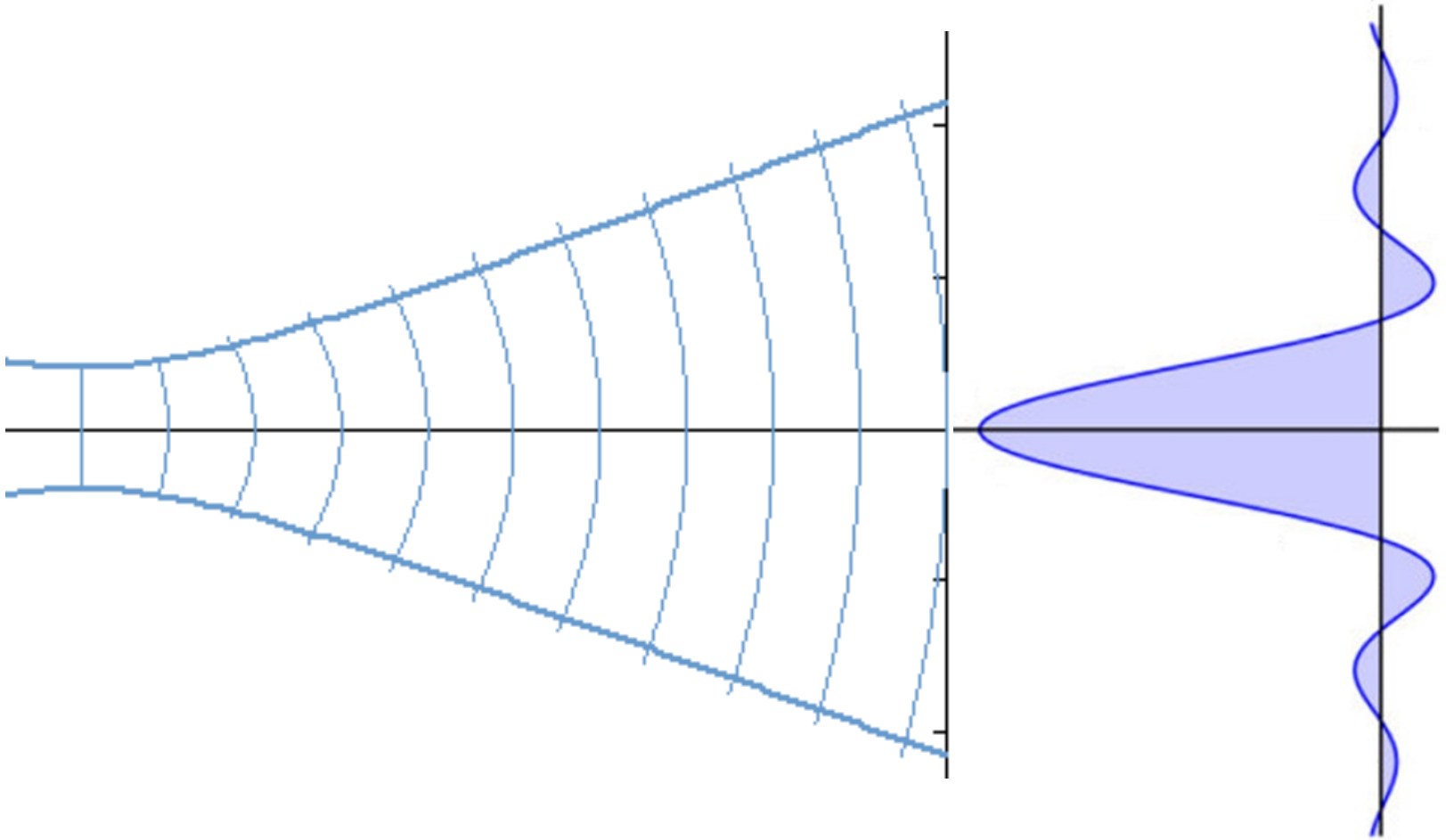
Longitudinal Modes



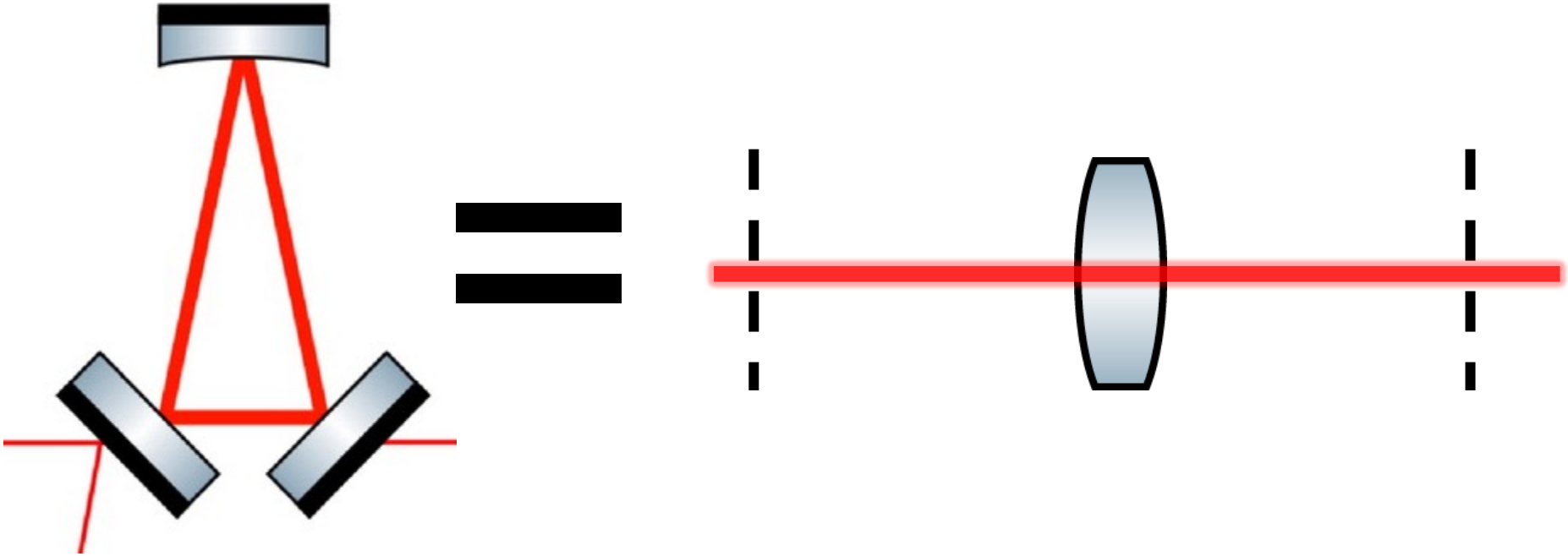
Transverse Modes



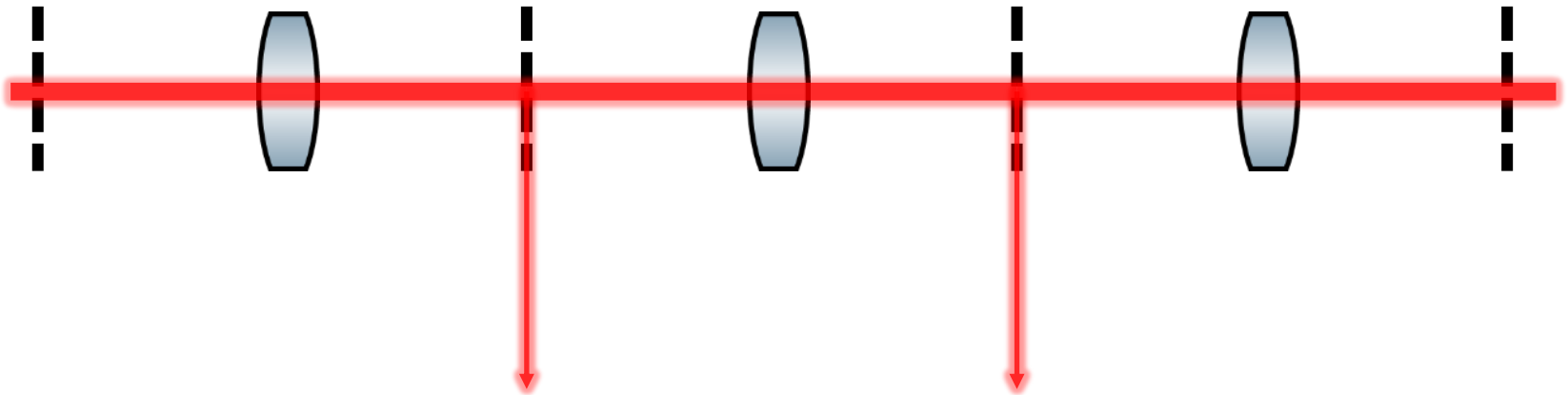
Transverse Modes

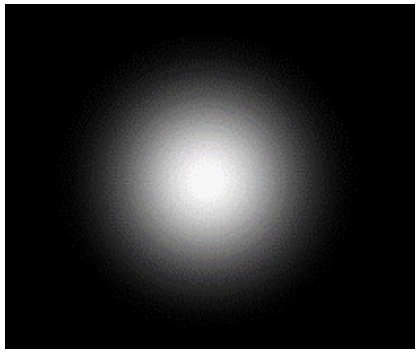


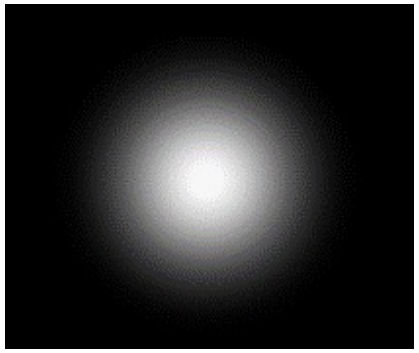
Laser Cavity – Mode Cleaner



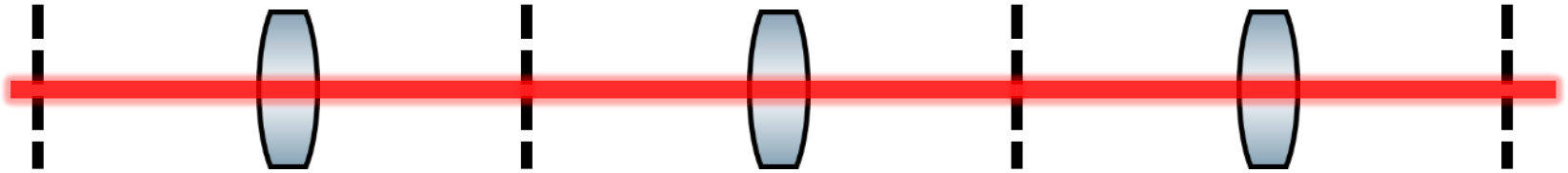
Laser Cavity – Mode Cleaner



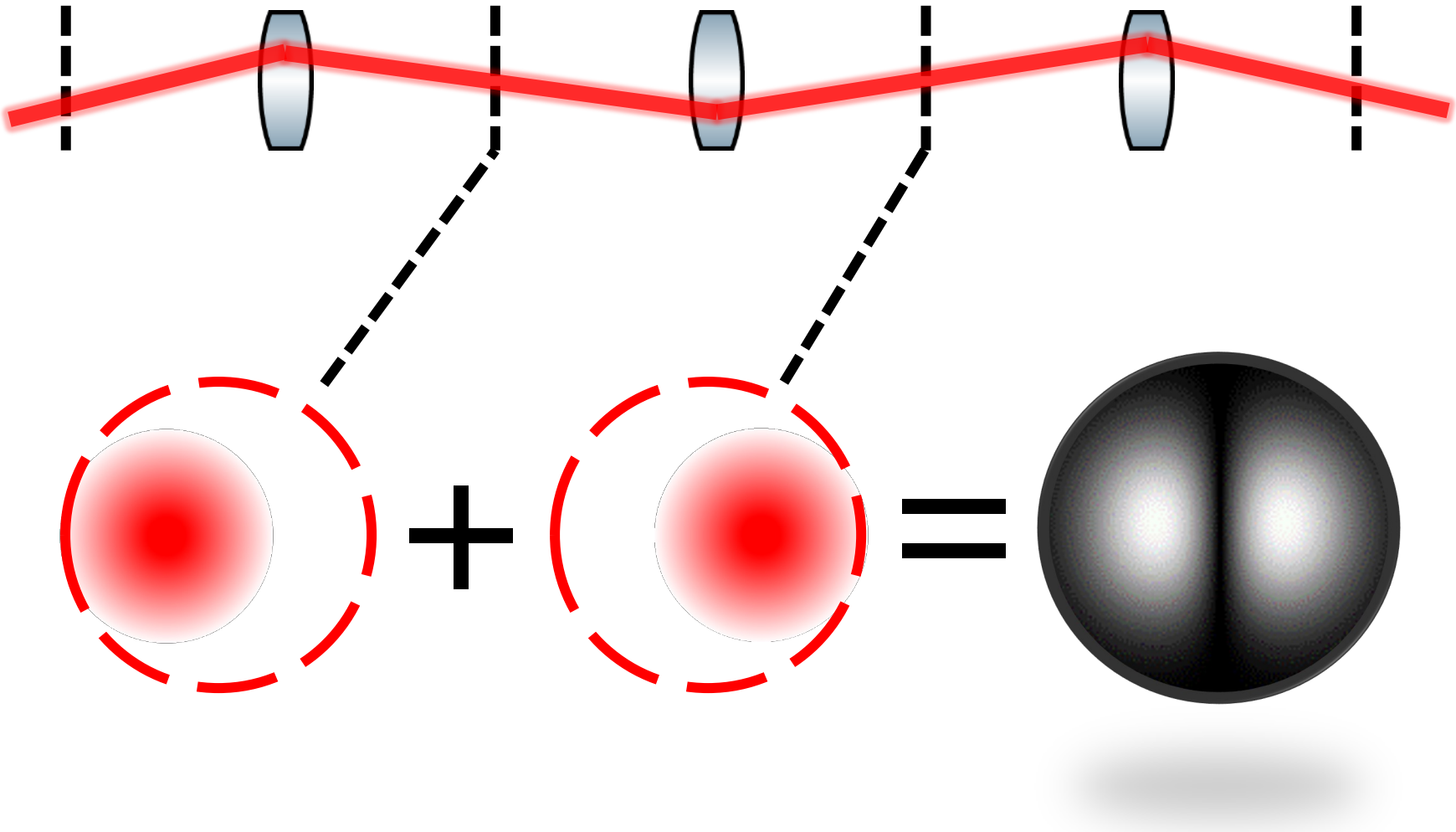




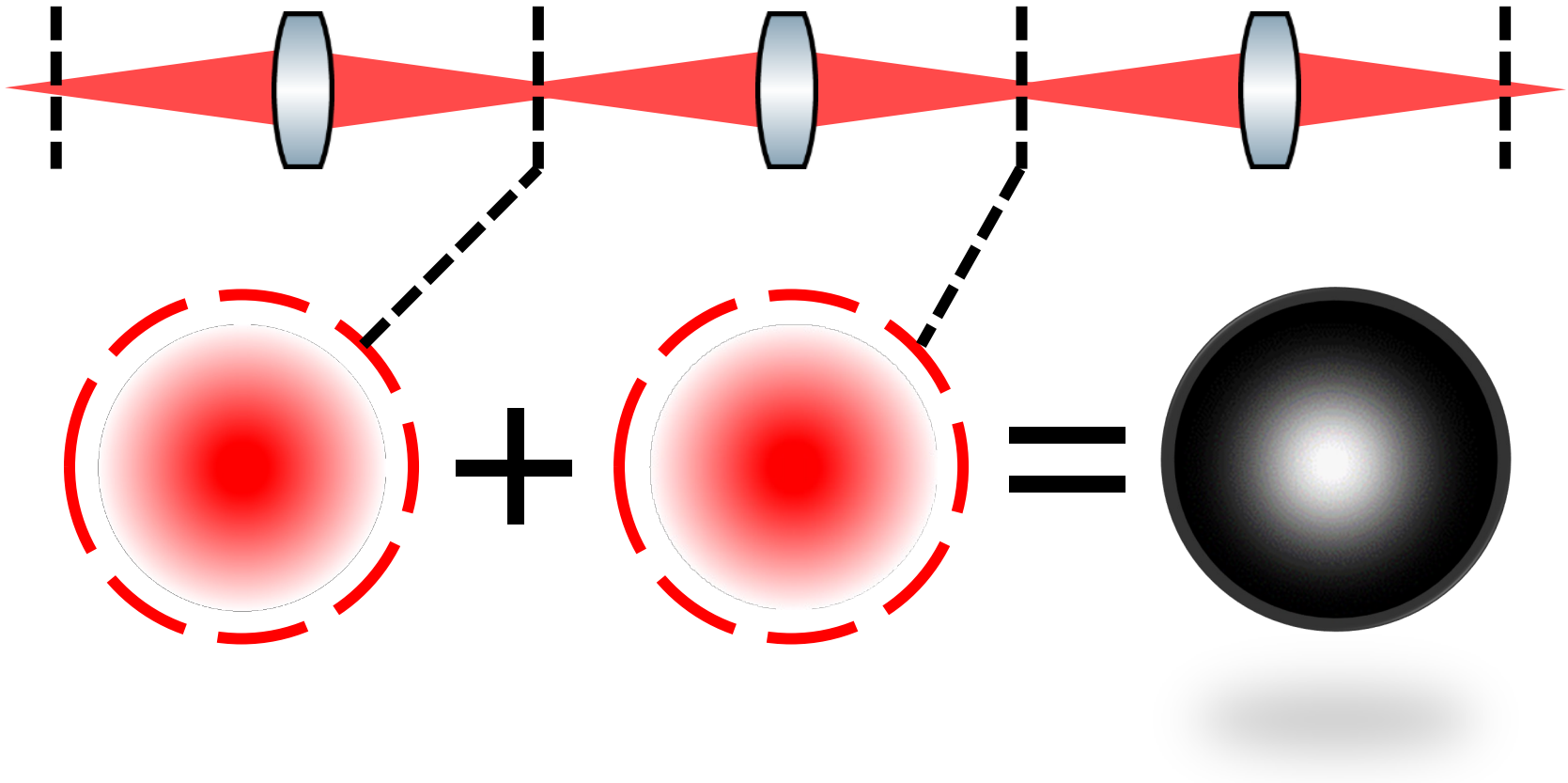
Misalignment



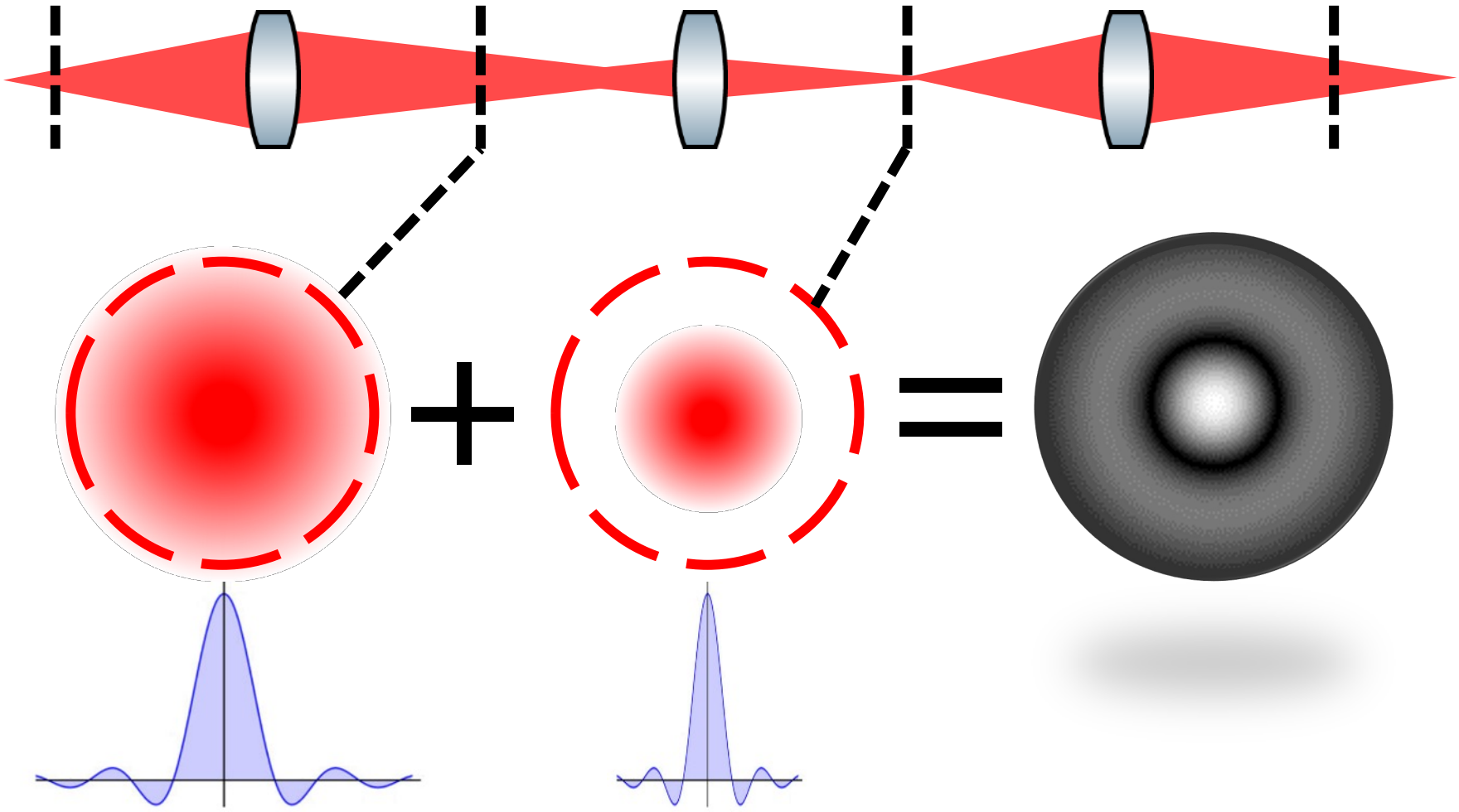
Misalignment



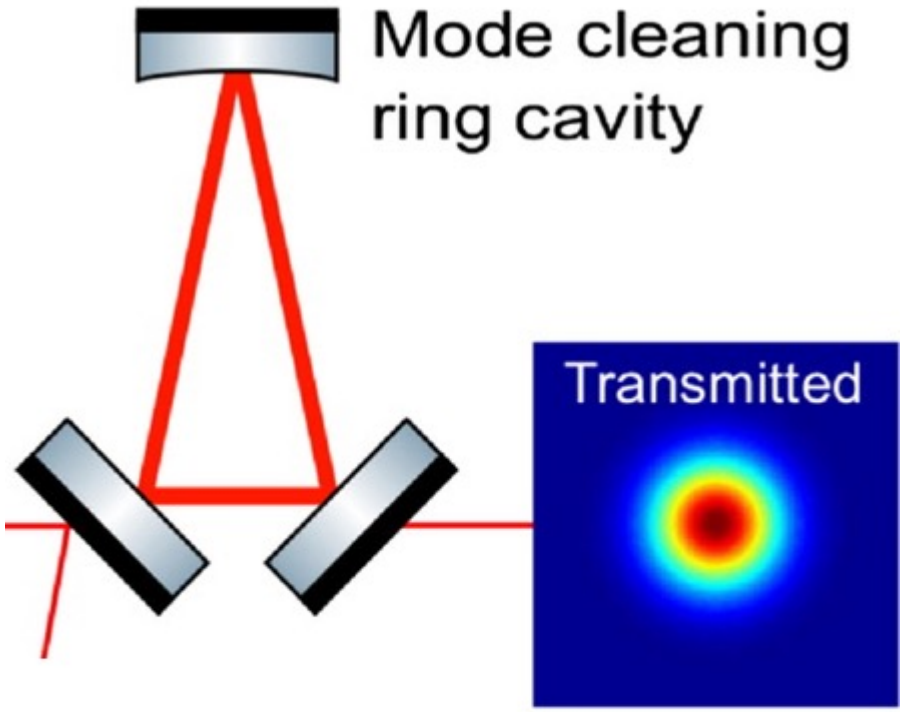
Misalignment

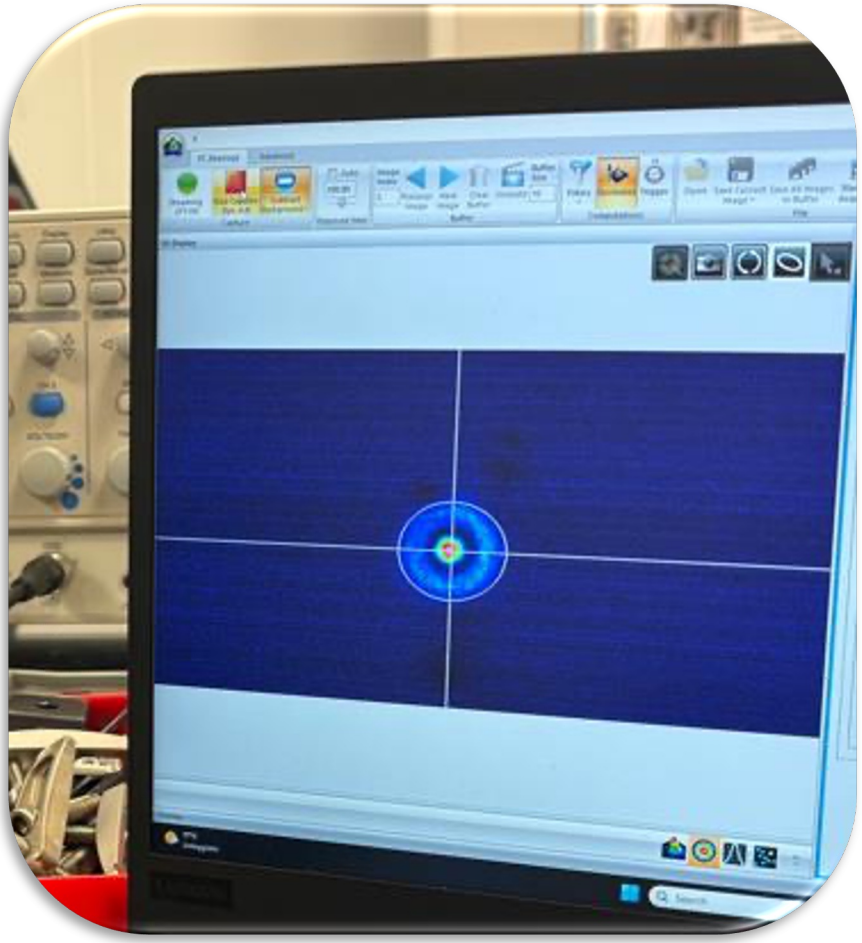


Misalignment

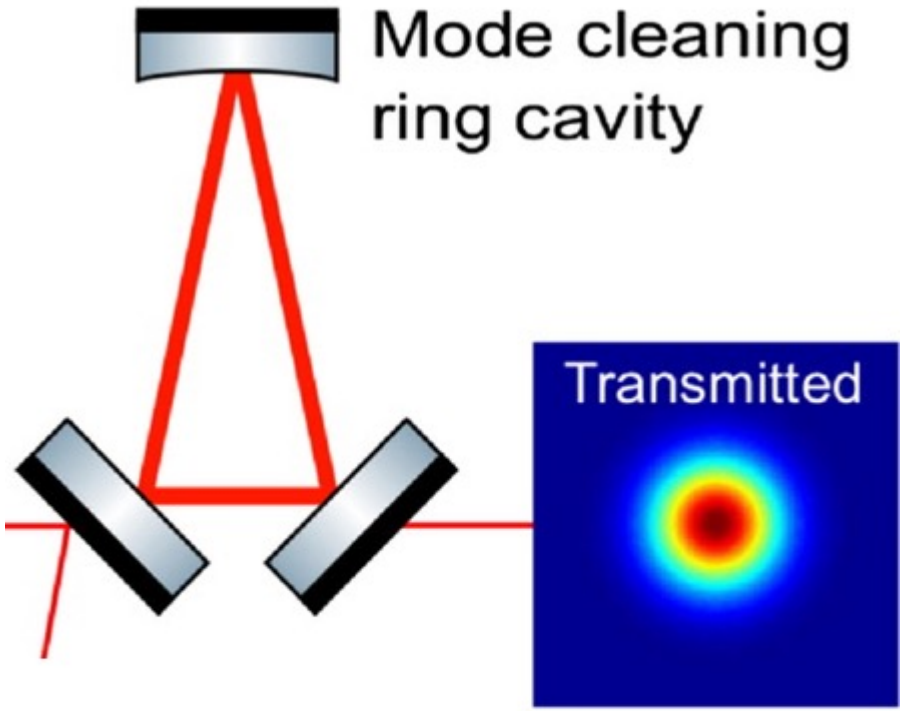


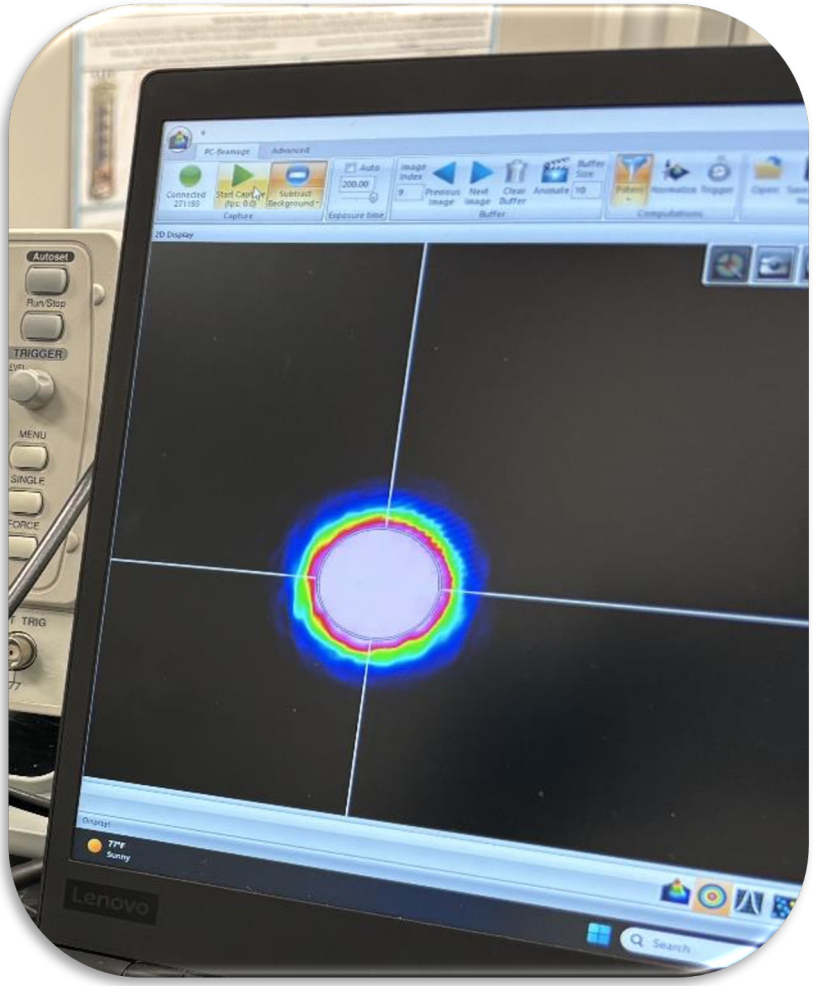
Mode Cleaner



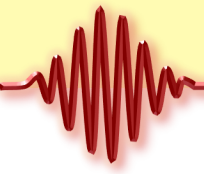


Mode Cleaner

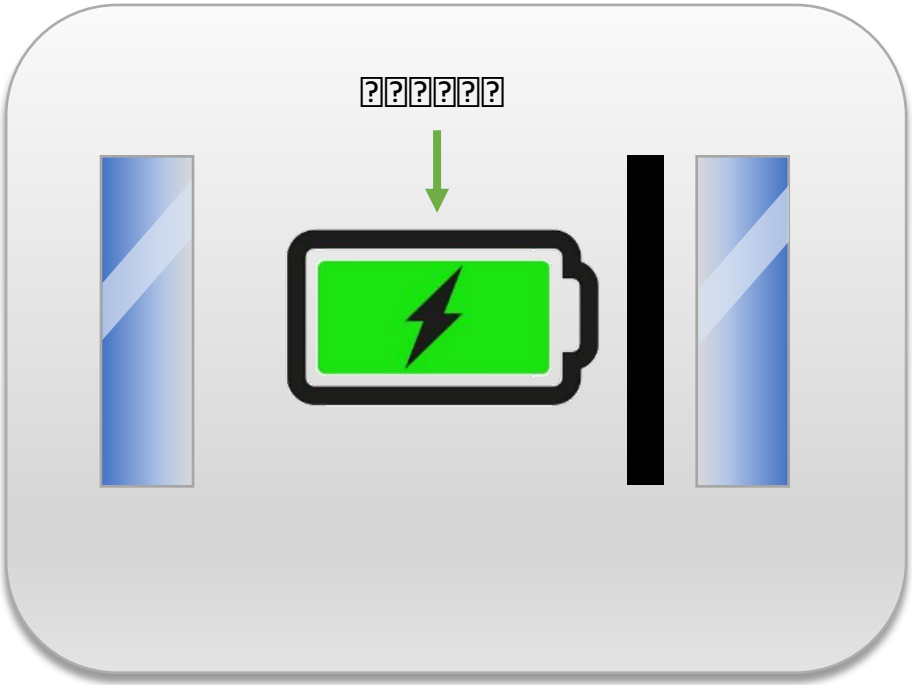


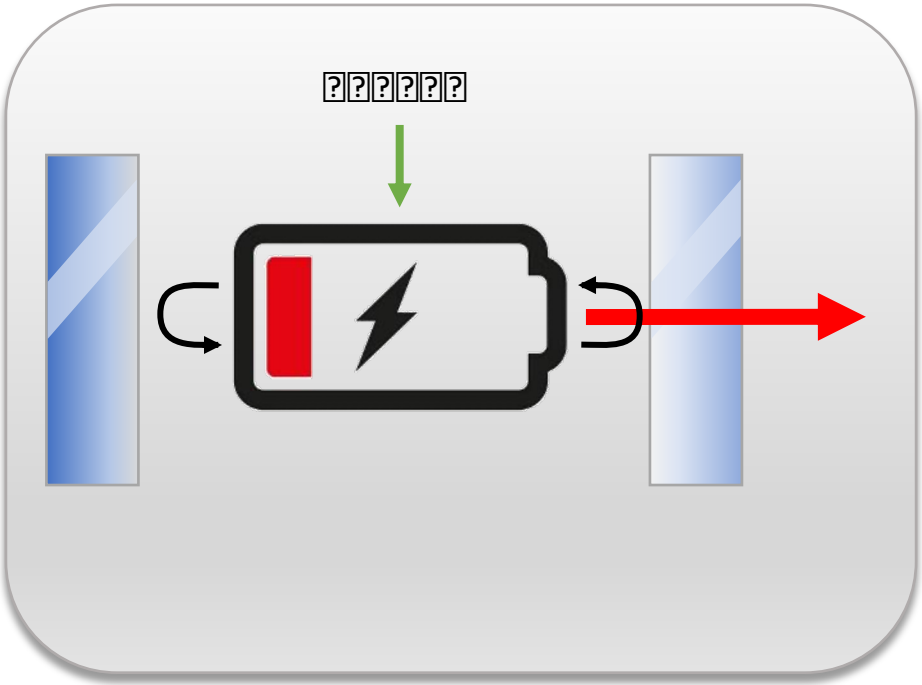


QnA

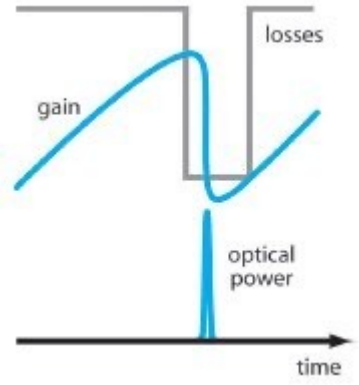


펄스 레이저는 어떻게 나와요?

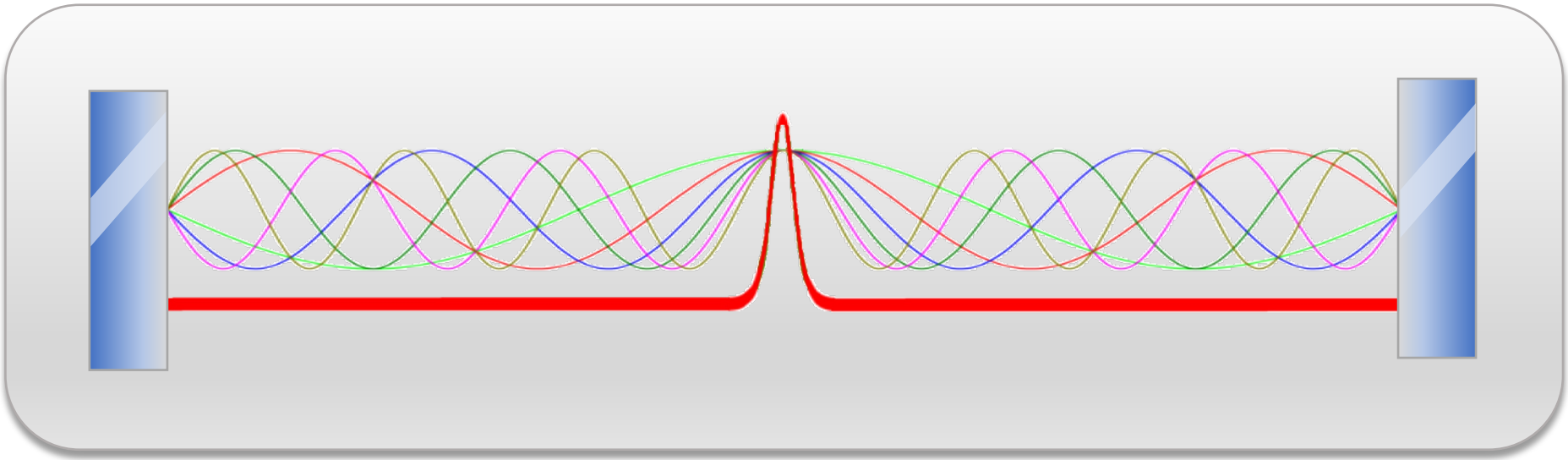




Q-switching : Charge up the gain, then suddenly use up the energy.



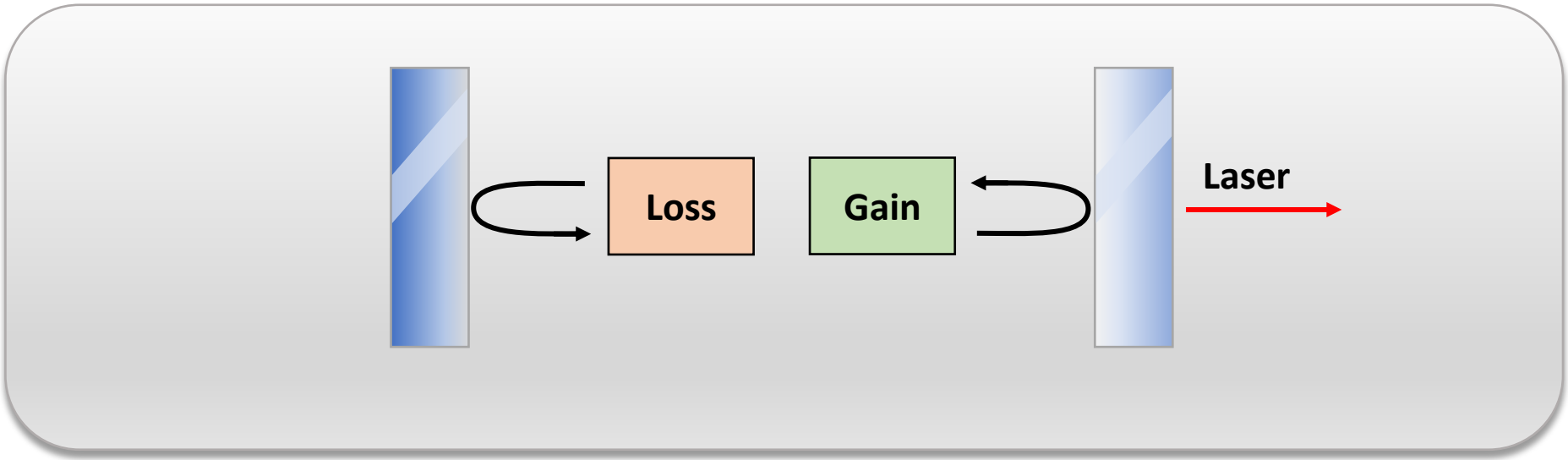
펄스 레이저는 어떻게 나와요?



모드 록킹 : 레이저 공진기의 내부에서 여러 파장의 빛이 공진할 때, 그 파장들의 위상을 맞추어서 중첩된 전기장의 형태를 조정하는 방법.

Mode-locking : Fix multiple modes' phase in time. The final electric field of overlapped modes forms in a pulse.

펄스 레이저는 어떻게 나와요?



Loss − Gain = Net Gain

일반적인 레이저 시스템에서는 가장 이득율이 가장 큰 광선 한 개만이 증폭된다.

Any beam of the greatest net gain dominates all other beams and oscillate.

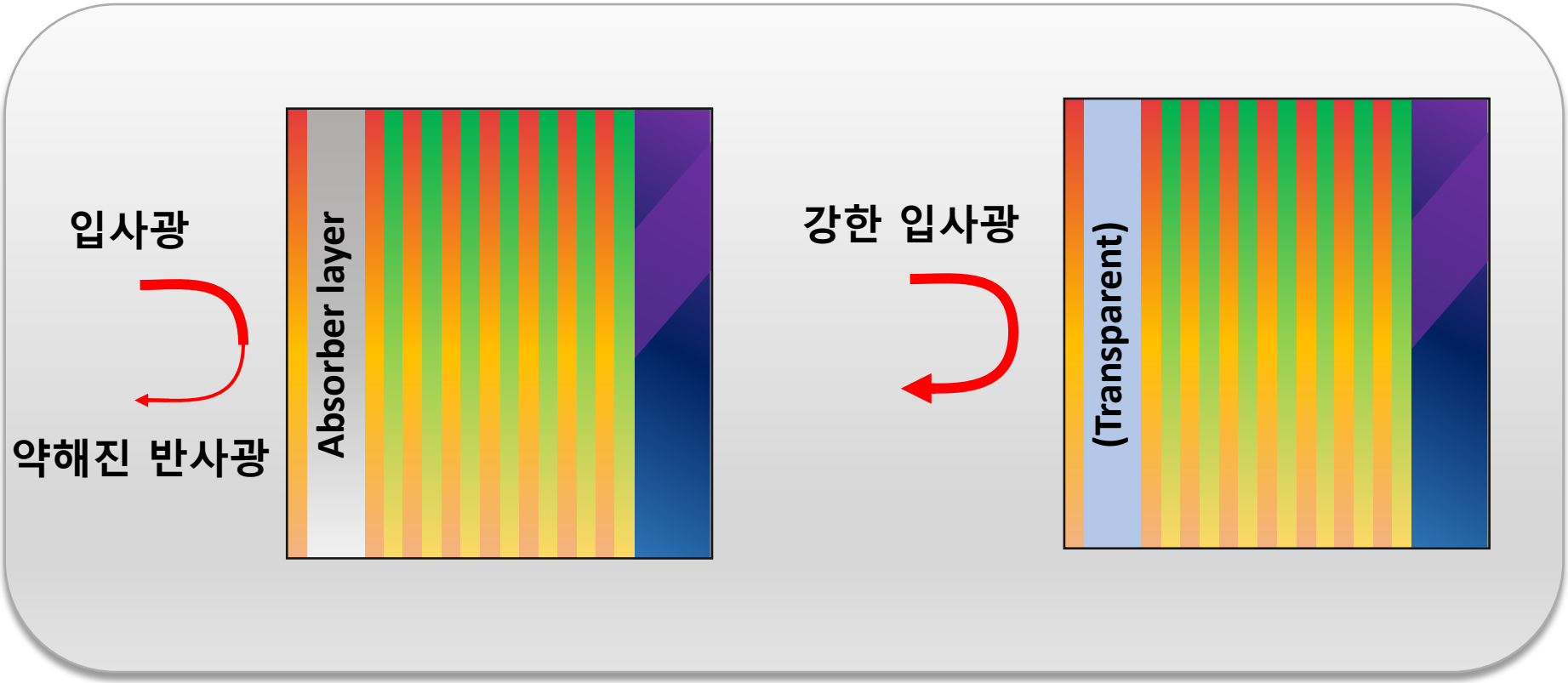
SESAM

SEmiconductor **S**aturable **A**bsorber **M**irror

- 반도체 기판 위에 브래그 반사판을 올리고 그 중간에 포화 흡수체 층을 쌓은 특수 거울
- 공진기 내부 파워에 따라서 반사율이 바뀐다.
- 브래그 반사층은 다중반사의 효과로 매우 고반사율을 띈다.

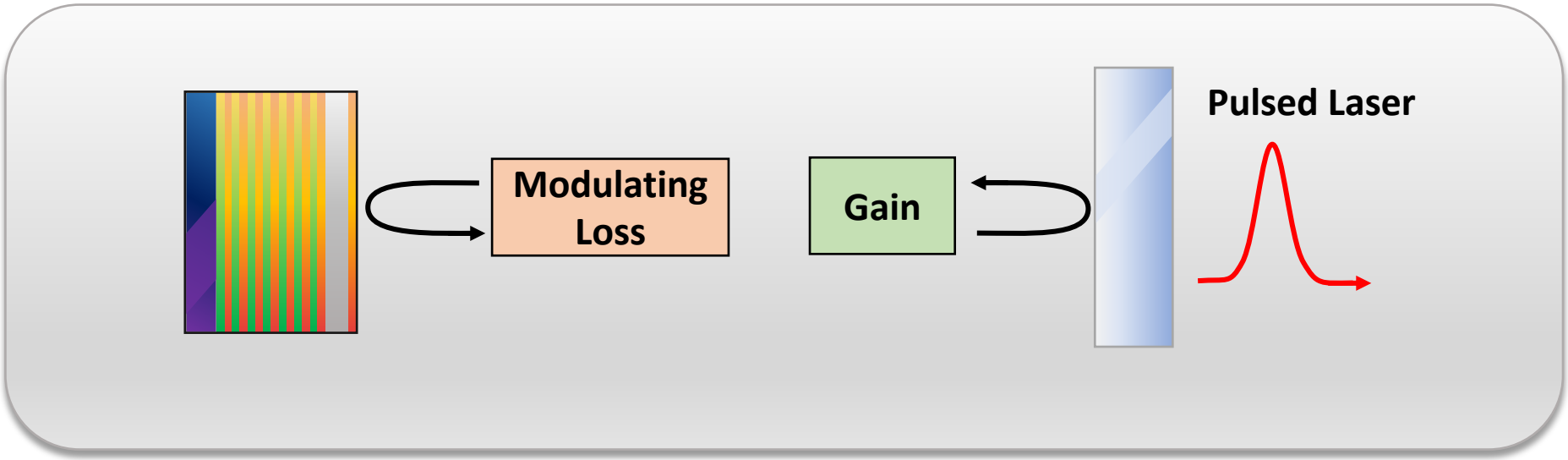
- A structure of integrated Bragg-reflector, which contains a saturable absorber layer in it, on a semiconductor substrate.
- It has diverging reflectance by cavity power.
- Bragg mirrors have large bandgap that makes no absorption occur.
- Position of the absorber layer determines the modulation depth and saturation fluence.

SESAM



Incoming weak beam experiences more loss than intense beam.

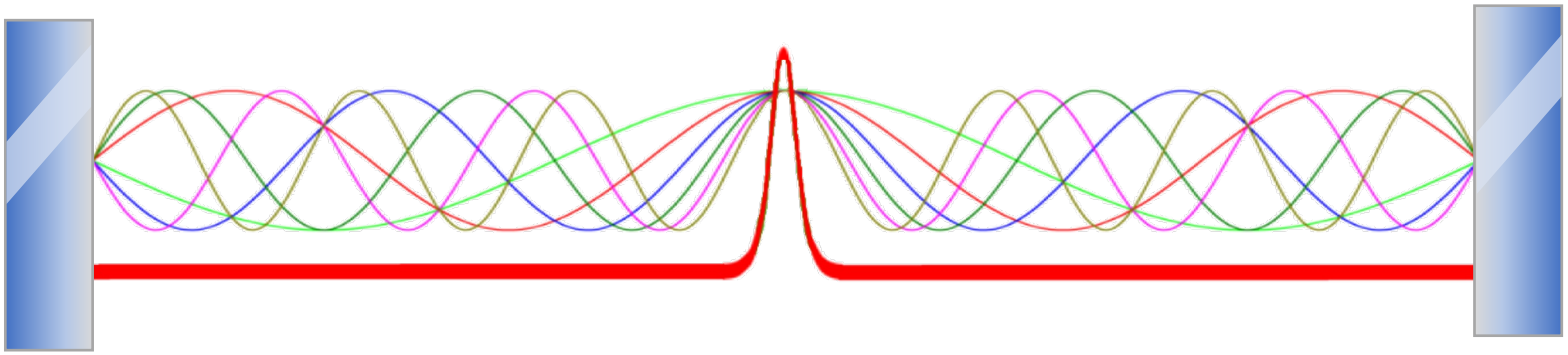
SESAM



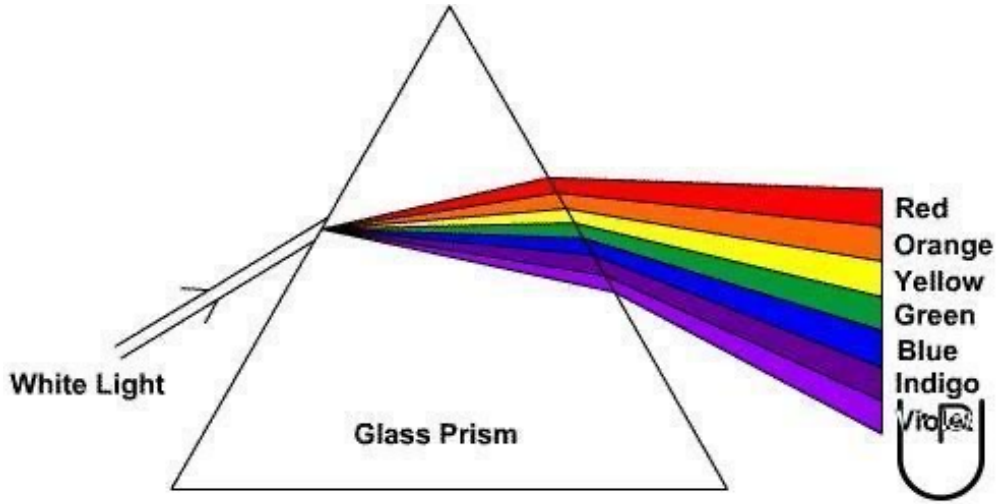
입사광에 따라 바뀌는 손실율은 CW 레이저는 억누르고
펄스 레이저를 증폭해주어 펄스 출력을 얻어낼 수 있게 해준다.

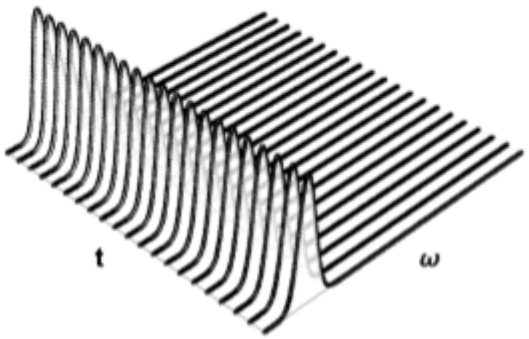
Net gain of oscillating pulse is higher than the CW beam.
It is more beneficial to oscillate in pulse form than CW form!

펄스 레이저는 어떻게 나와요?



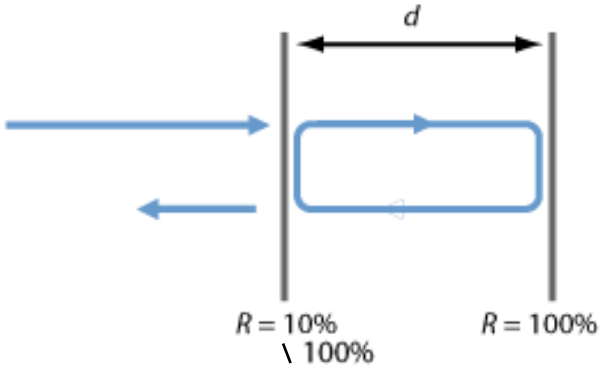
펄스 레이저는 어떻게 나와요?



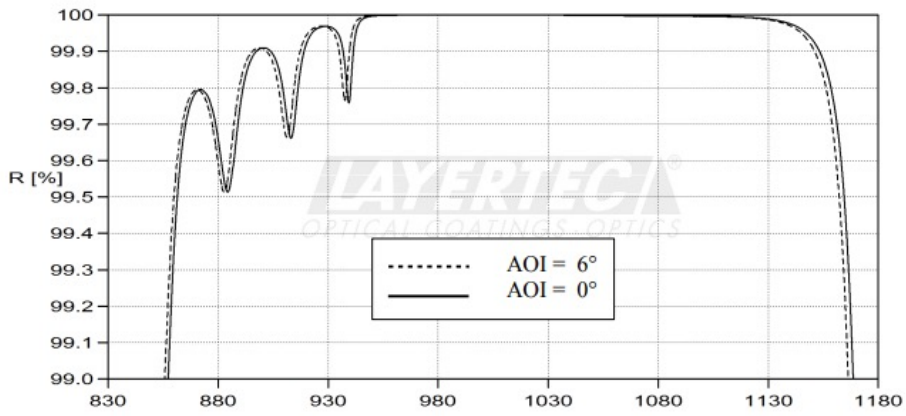


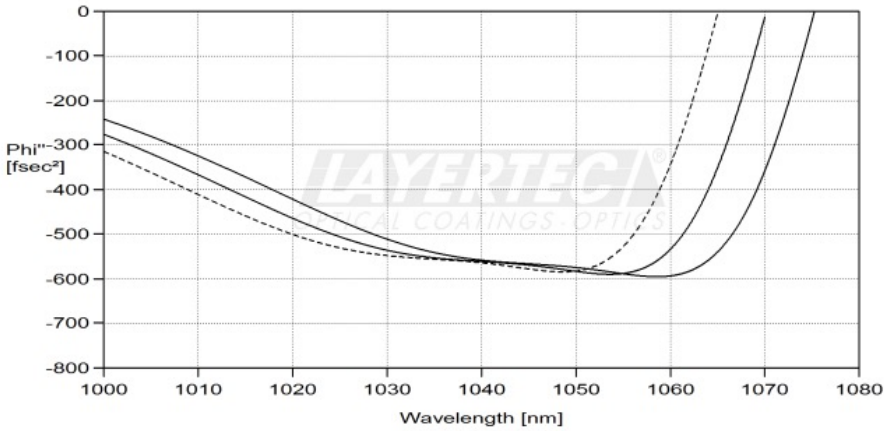
펄스 레이저는 어떻게 나와요?

GTI 미러 : GTI 미러는 특수 코팅 된 거울로, 입사광과 반사광의 위상차이가 파장에 따라서 달라지는 거울이다. 이를 잘 이용하면 마치 음의 굴절률 매질을 통과 하는것과 같다.

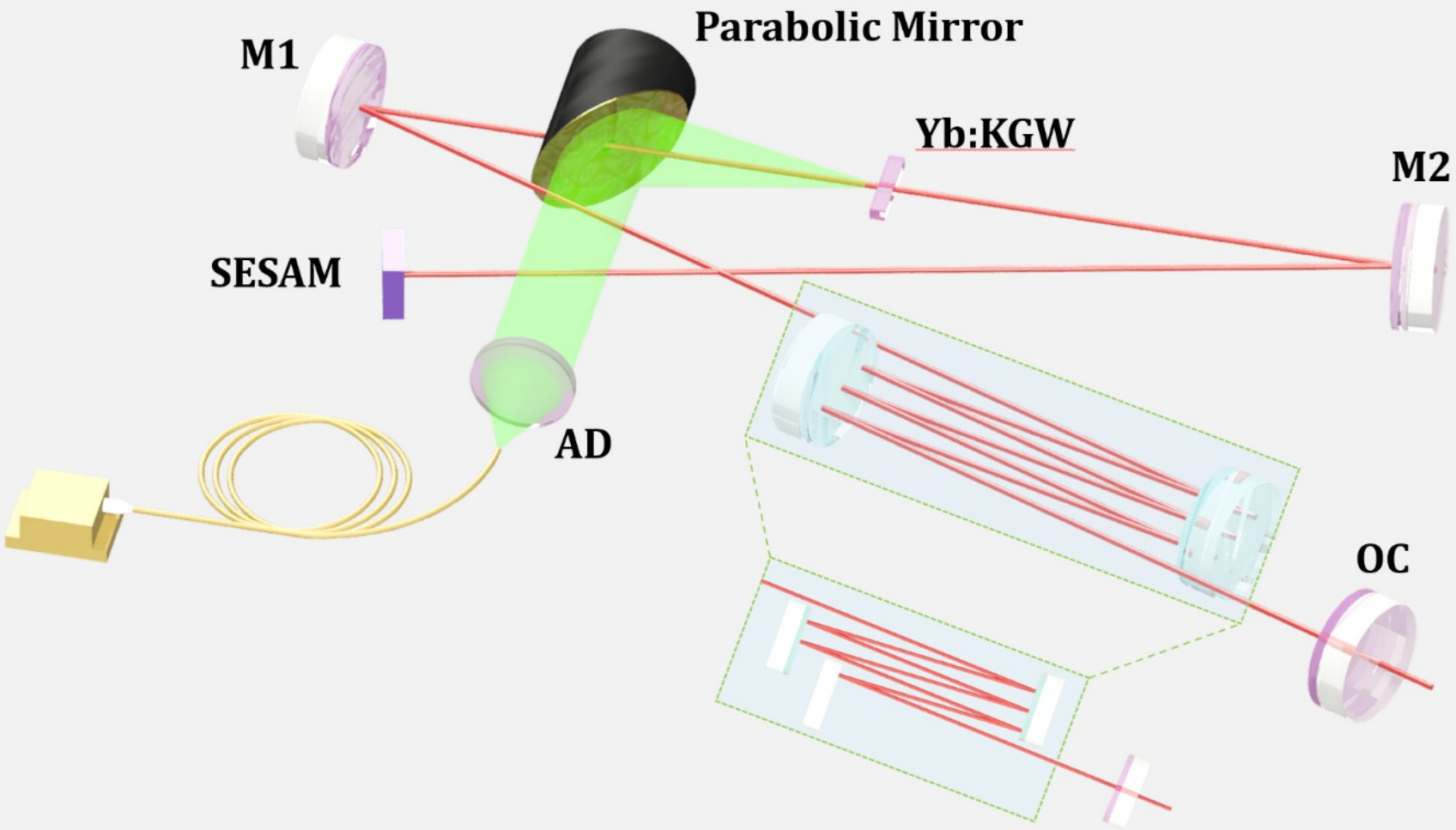


GTI Mirror is a sort of Fabry-Perot interferometer cavity. It can provide chromatic dispersion. So negative dispersions
can be served inside the cavity.

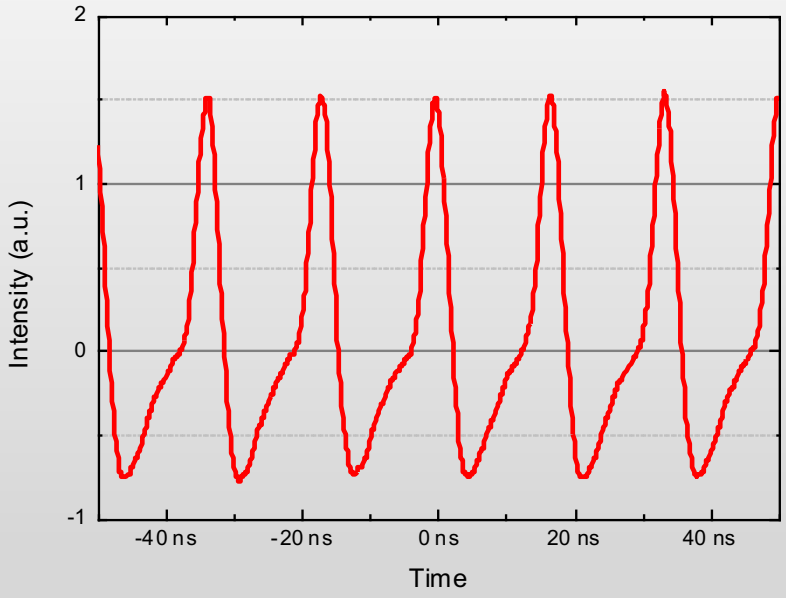


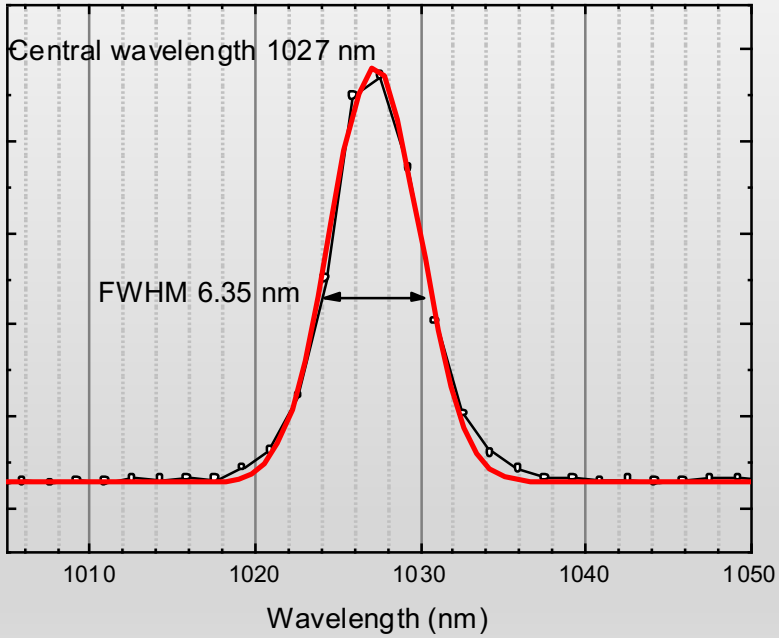


셋업



결과


2
1
0
-1
Intensity (a.u.)
-40 ns
-20 ns
0 ns
20 ns
40 ns
Time


Central wavelength 1027 nm
FWHM 6.35 nm
1010
1020
1030
1040
1050
Wavelength (nm)

결과

Average output power	7.14 W
Threshold power (Pump)	4.56 W
Cavity length	2.42 m
Repetition rate	62.7 MHz
Energy per pulse	113 nJ

Pulse width (FWHM)	170 fs
Wavelength bandwidth (FWHM)	6.35 nm
Central wavelength	1027 nm
Slope efficiency	32.5 %