Optical-parametric signal-amplification for a high-frequency gravitational-wave detector

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Outline

Introduction

- Optical spring
- Optical parametric amplification (OPA)

Experimental setup at Tokyo Tech.

- Signal recycling Michelson interferometer with OPA

Result

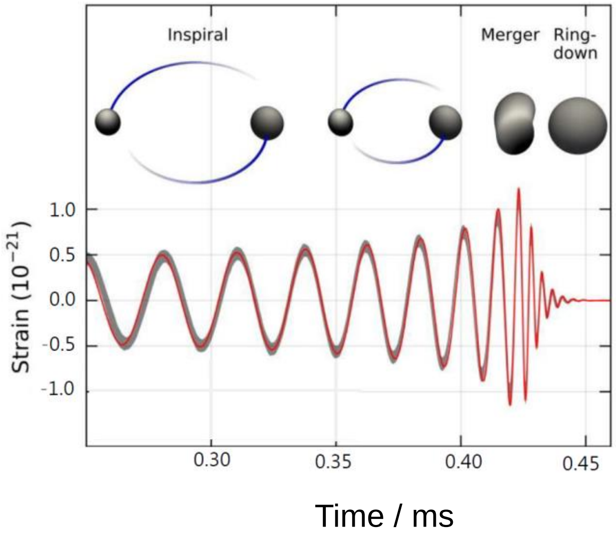
Summary

Introduction

The gravitational wave (GW) sources in a few kHz bands

→ binary neutron star merger, supernova, ….

The high-frequency signal cannot be detected by current GW detectors because of sensitivity degradation due to shot noise.



By improving the sensitivity in the kHz band, we significantly boost our understanding of the universe.

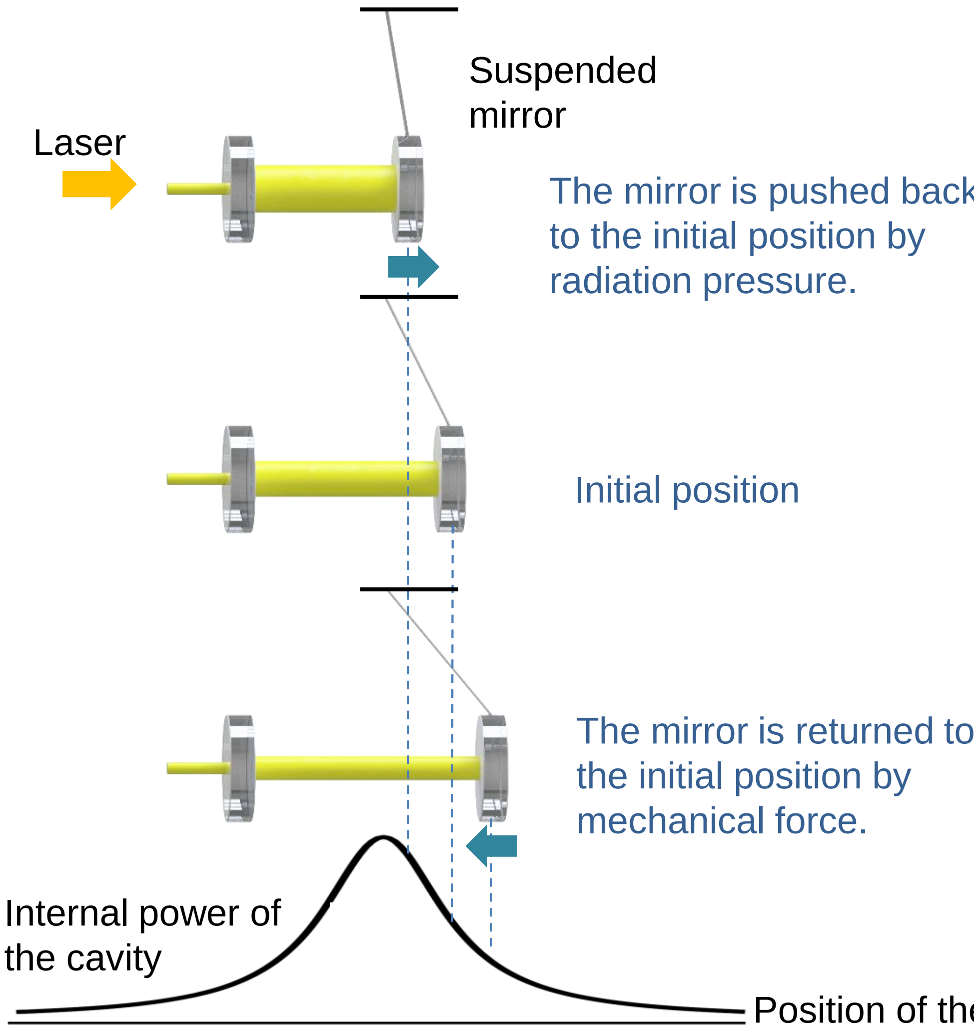
For improving the detection sensitivity,

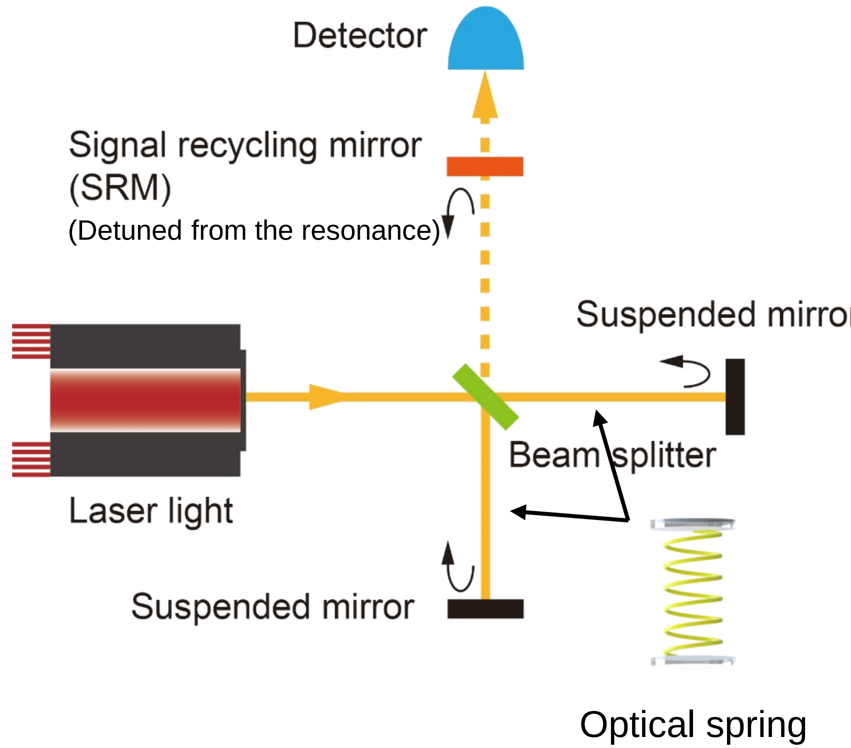
- Squeezed vacuum: Reduce the noise of the sensitivity.
- Optical spring and Optical parametric amplification: Amplify the signal

Optical spring

For improving the detection sensitivity in a high-frequency band,

Optical spring (OS) : Induced by the interaction between electromagnetic radiation and mechanical motion.





OS can modify the dynamics of MI.

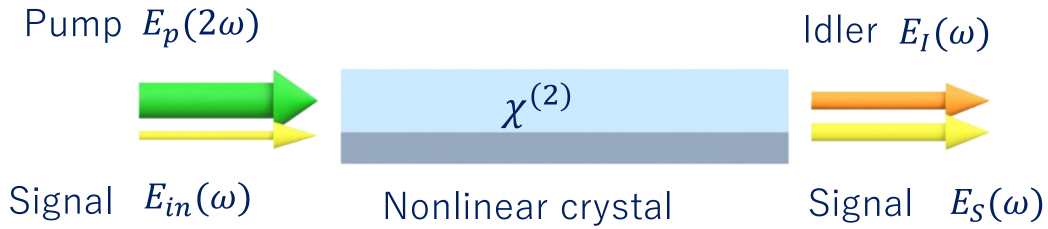
The resonance frequency of OS becomes high by the increase of the radiation pressure.

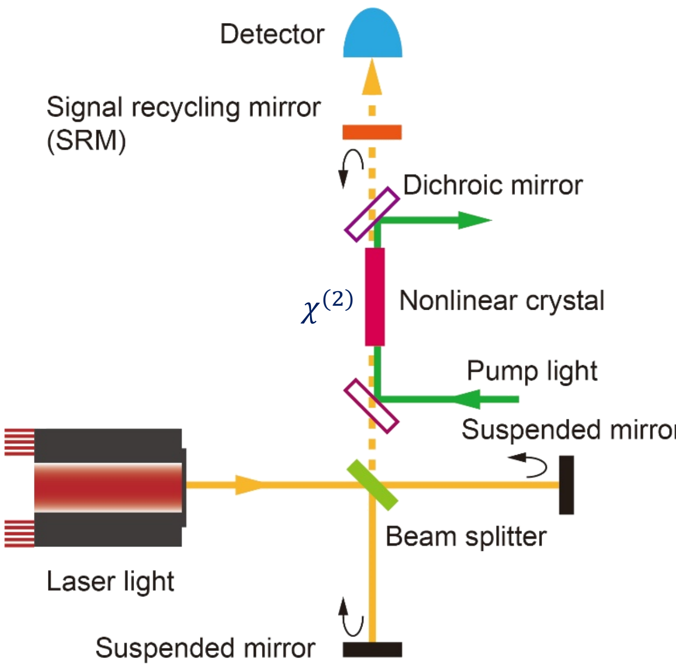
Optical parametric amplification

Optical parametric amplification (OPA)

Amplify the signal intensity.
Convert the wavelength of the light.

A intense pump light and a weak signal light (or without signal) are injected into NLC.





Intracavity OPA

The optical spring becomes stiff.

The resonance frequency of OS is adjusted by detuned phase and pump power.

Sensitivity estimation

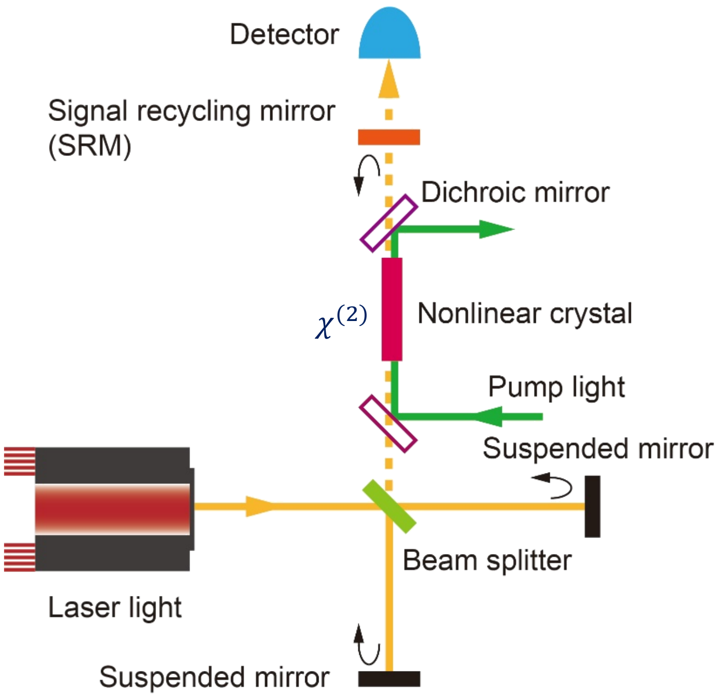
Sensitivity of signal recycling Michelson interferometer (SRMI) with OPA

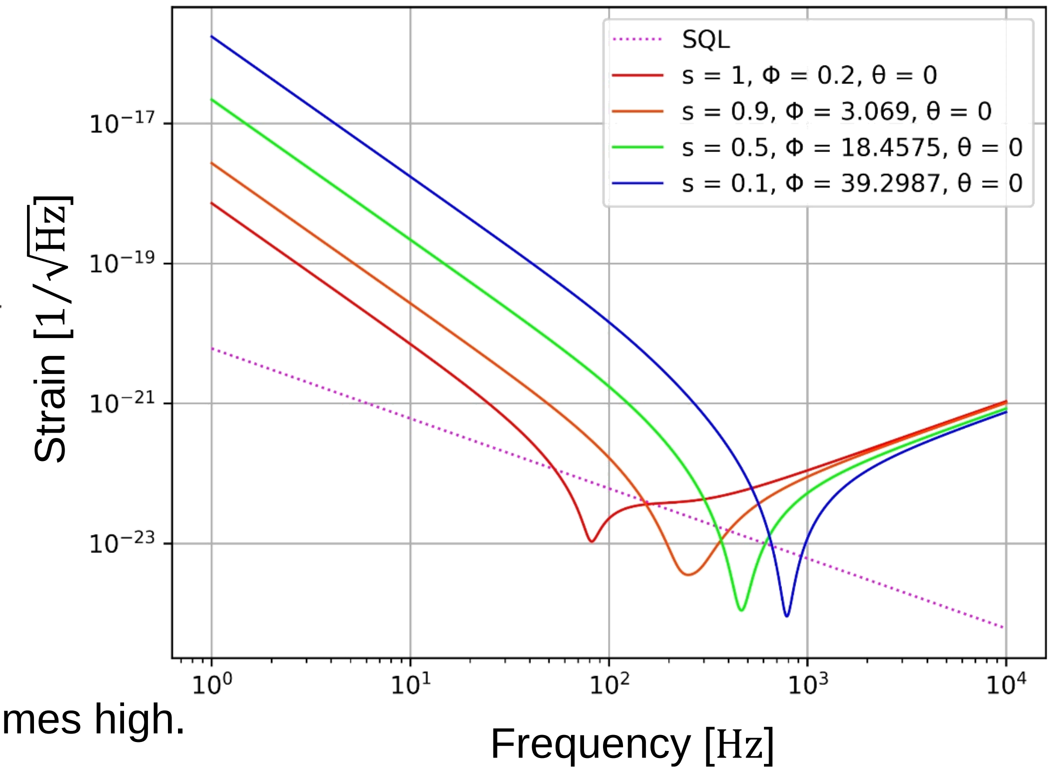
The detuned phase of SRC

→ OS generates.

OPA

→ The resonance frequency of OS is high.

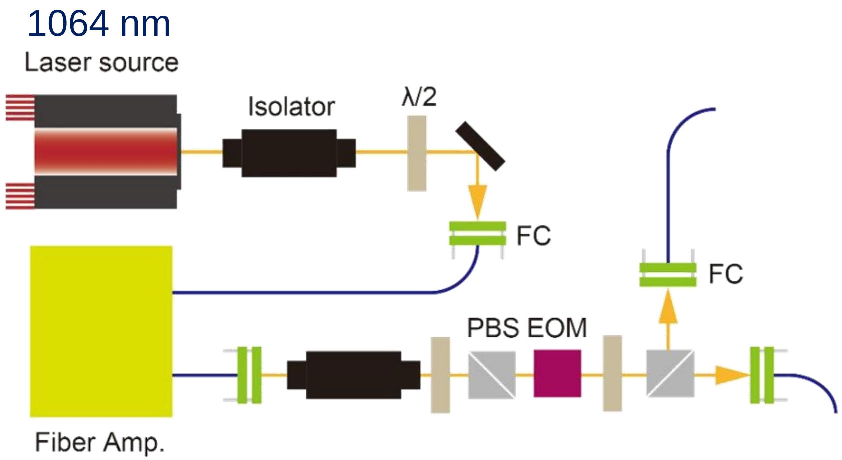


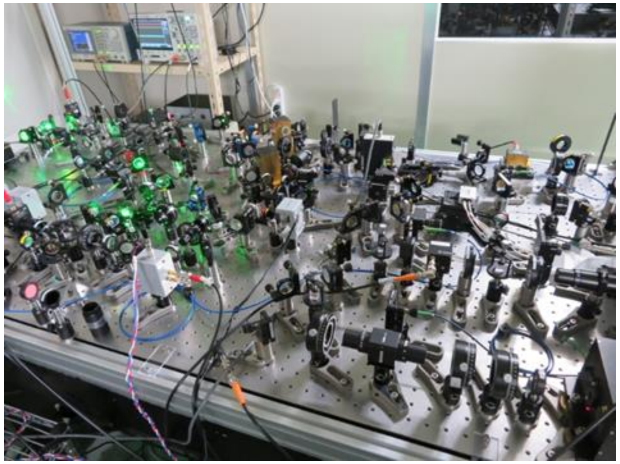


When the pump power is high,
the optical spring frequency becomes high.

Experimental setup

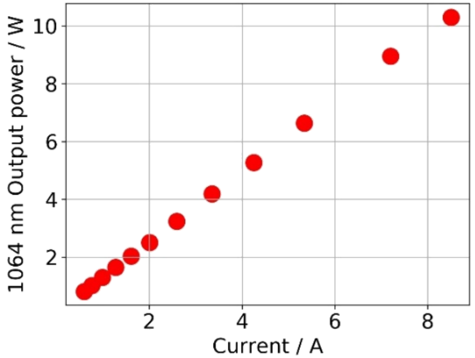
Laser sources





λ/2: Half-wave plate
EOM: Electro-optic modulator
FC: Fiber coupler
PBS: Polarizing beam splitter

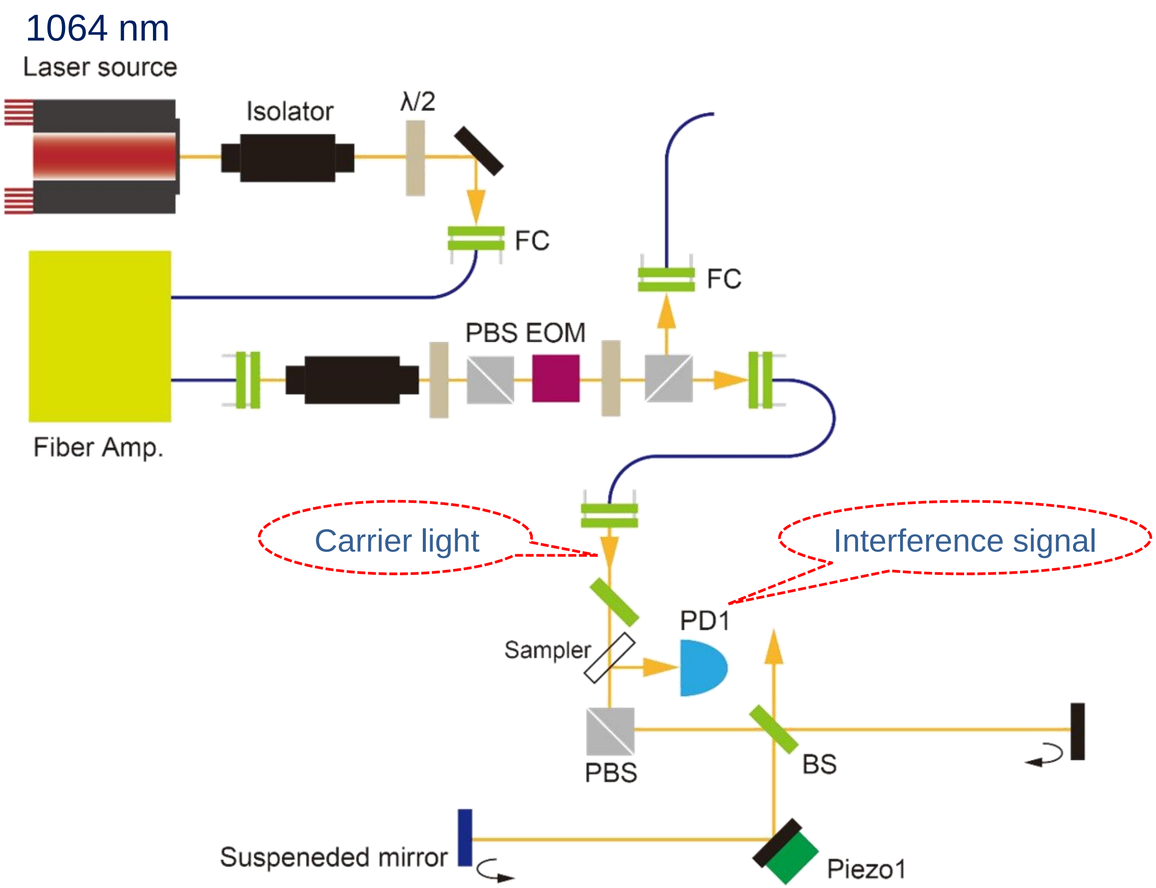
Output power after the fiber amp.



Experimental setup

Michelson interferometer (MI)

Piezo1: Stabilize the MI system



λ/2: Half-wave plate
EOM: Electro-optic modulator
FC: Fiber coupler
PBS: Polarizing beam splitter
BS: Beam splitter
PD: Photodetector

Suspended mirror

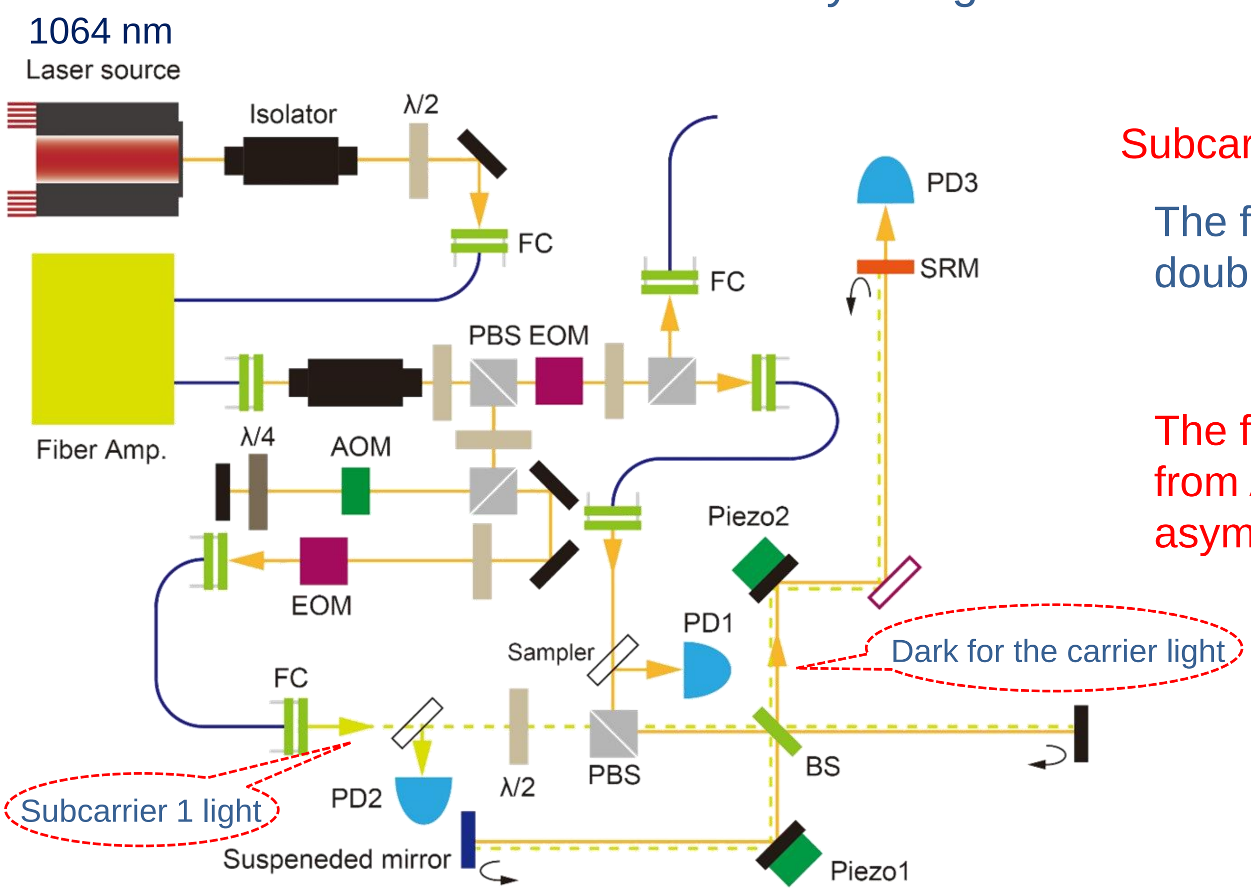
Diameter: 6 mm
Weight: 0.2 g
Resonant frequency: 11 Hz
Mount made of polyester

Experimental setup

Signal recycling cavity (SRC)

Piezo1: Stabilize the MI system

Piezo2: Stabilize SRC
by using the subcarrier 1 light



Carrier frequency

$\omega_{\mathrm{sub1}} = 2\omega_{\mathrm{AOM}}$

Subcarrier 1 ($\omega + \omega_{\mathrm{sub1}}$)

The frequency-shifted by the double-pass configuration of AOM.

$$\omega_{\mathrm{AOM}} = 40\ \mathrm{MHz}$$

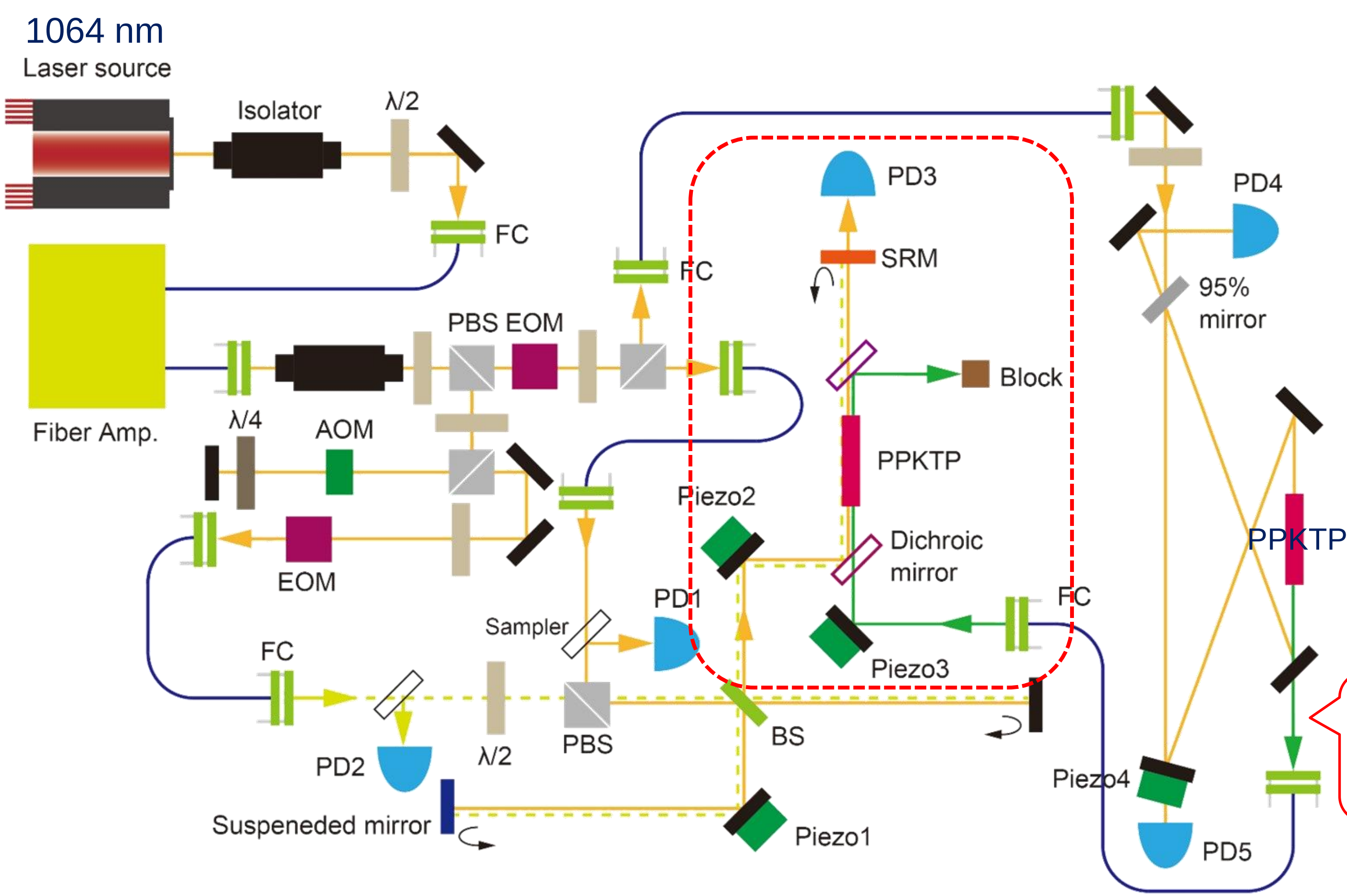
The frequency-shifted light is leaked from AS port because of the asymmetry of arm lengths of MI.

EOM: Electro-optic modulator
AOM: Acousto-optic modulator
FC: Fiber coupler
λ/2: Half-wave plate
λ/4: Quarter-wave plate
BS: Beam splitter
PBS: Polarizing beam splitter
PD: Photodetector
SRM: Signal recycling mirror

Experimental setup

Second harmonic generation (SHG)

Bow-tie cavity: Generate 532 nm light by SHG.
Stabilized by the Pound-Drever-Hall (PDH) method.



Cavity length: 1.2 m

PPKTP:
Periodically Poled KTiOPO4
(1 × 2 × 10 mm)
Temperature controlled by an oven

Transmission loss of the crystal: 1%

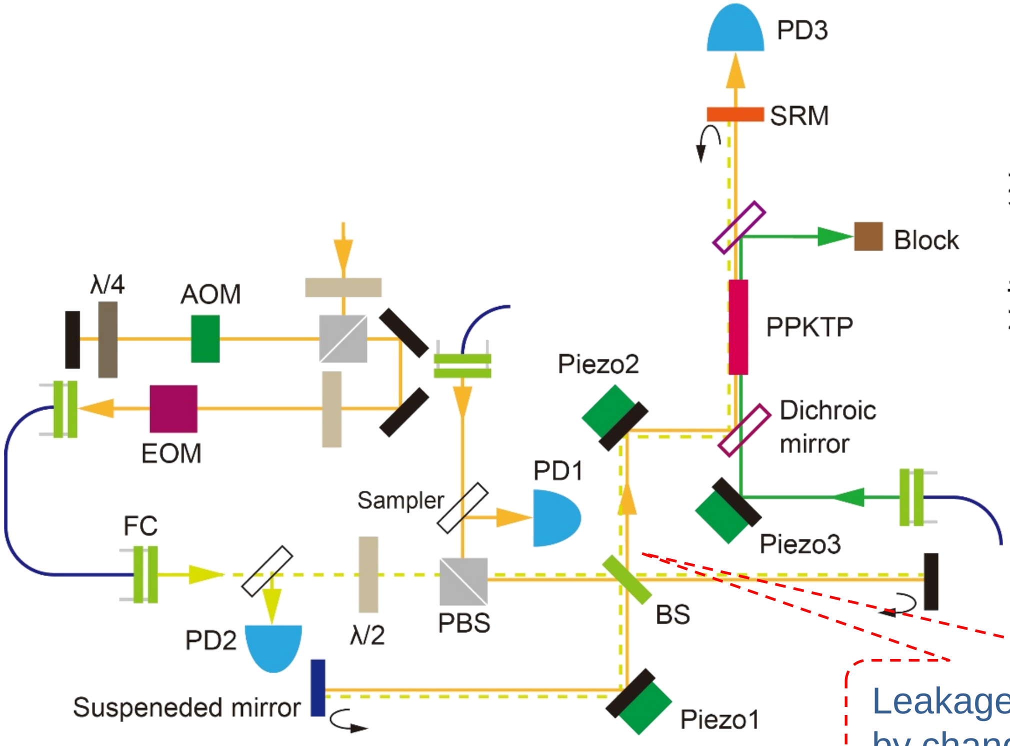
Maximum output pump power (532 nm): 500 mW

Result

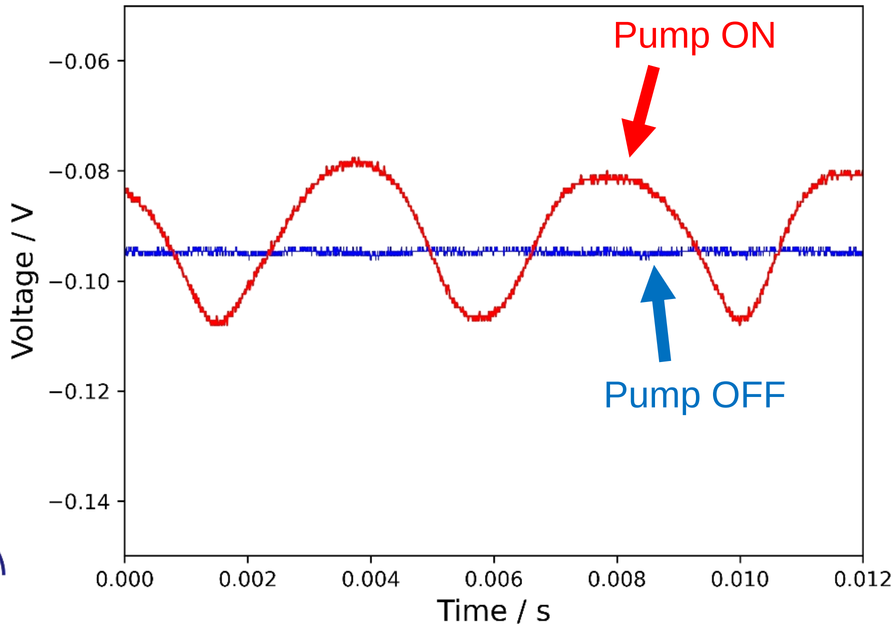
Observation of the signal amplification of the 1064 nm light

Carrier power (1064 nm): 30 mW

Pump power (532 nm): 450 mW



Detected by PD3



(Change of the relative phase by piezo 3.)

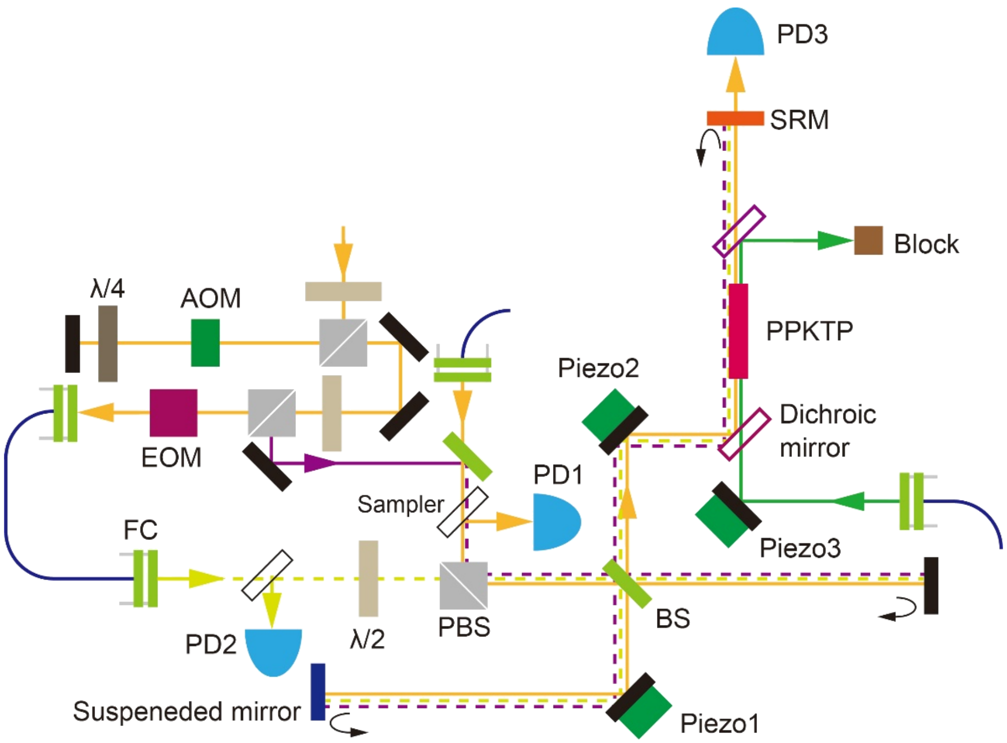
Leakage of the carrier light from MI by changing the offset

We confirmed the signal amplification by OPA.

Subcarrier 2

Subcarrier 2: Stabilize the relative phase between the carrier and pump.

Employ the coherent control (CC) method reported in Phys. Rev. Lett. 97, 011101 (2006).



Subcarrier 2 ($\omega + \omega_{\mathrm{sub2}}$)

The frequency is identical to subcarrier 1.

$$\omega_{\mathrm{sub2}} = \omega_{\mathrm{sub1}} = 2\omega_{\mathrm{AOM}}$$

The polarization is the identical to the carrier light.

The frequency-shifted light is leaked from AS port because of the asymmetry of arm lengths of MI.

The beat signal between $\omega + \omega_{\mathrm{sub2}}$ and $\omega - \omega_{\mathrm{sub2}}$ generates by OPA.

The error signal I_{err} can be obtained by demodulating $2 \times \omega_{\mathrm{sub2}}$.

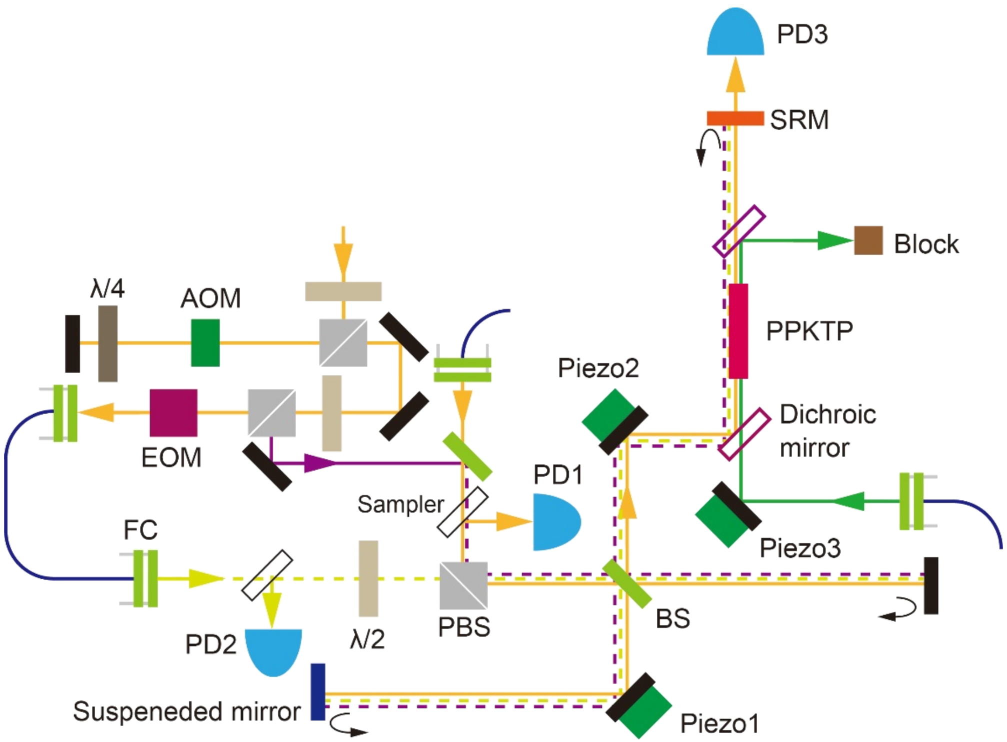
$I_{\mathrm{err}} \propto \sin\theta$ θ: relative phase

Subcarrier 2

Observation of OPA by subcarrier 2

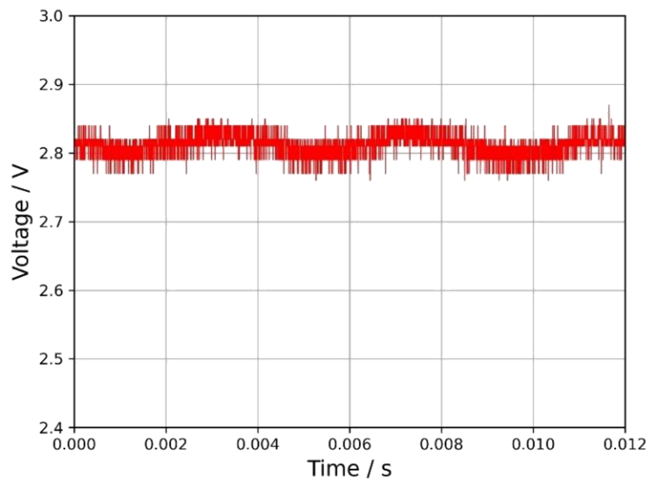
Subcarrier 2 power (1064 nm): 8 mW

Pump power (532 nm): 450 mW



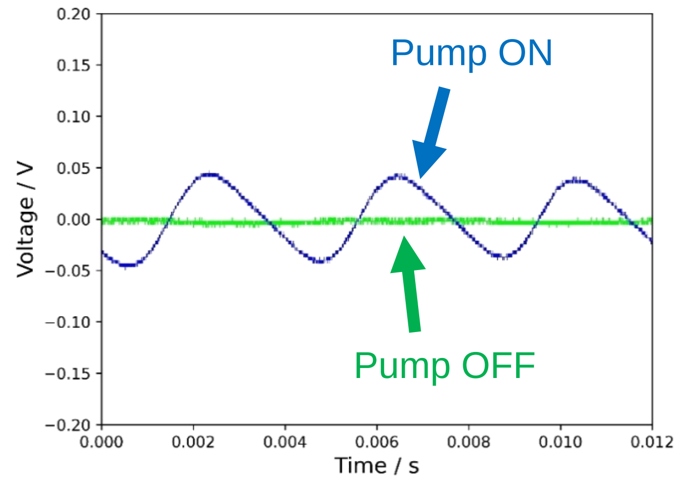
We obtained the error signal using the subcarrier 2.

Subcarrier 2 intensity detected by PD3



Demodulated by $2\omega_{\mathrm{sub2}}$

Error signal



(Change of the relative phase by piezo 3)

Summary

Observed OPA in SRMI.

Obtained the error signal using subcarrier 2.

Future plans

Improvement of the OPA signal

Observation of the frequency shift of OS by OPA

Thank you for your attention!