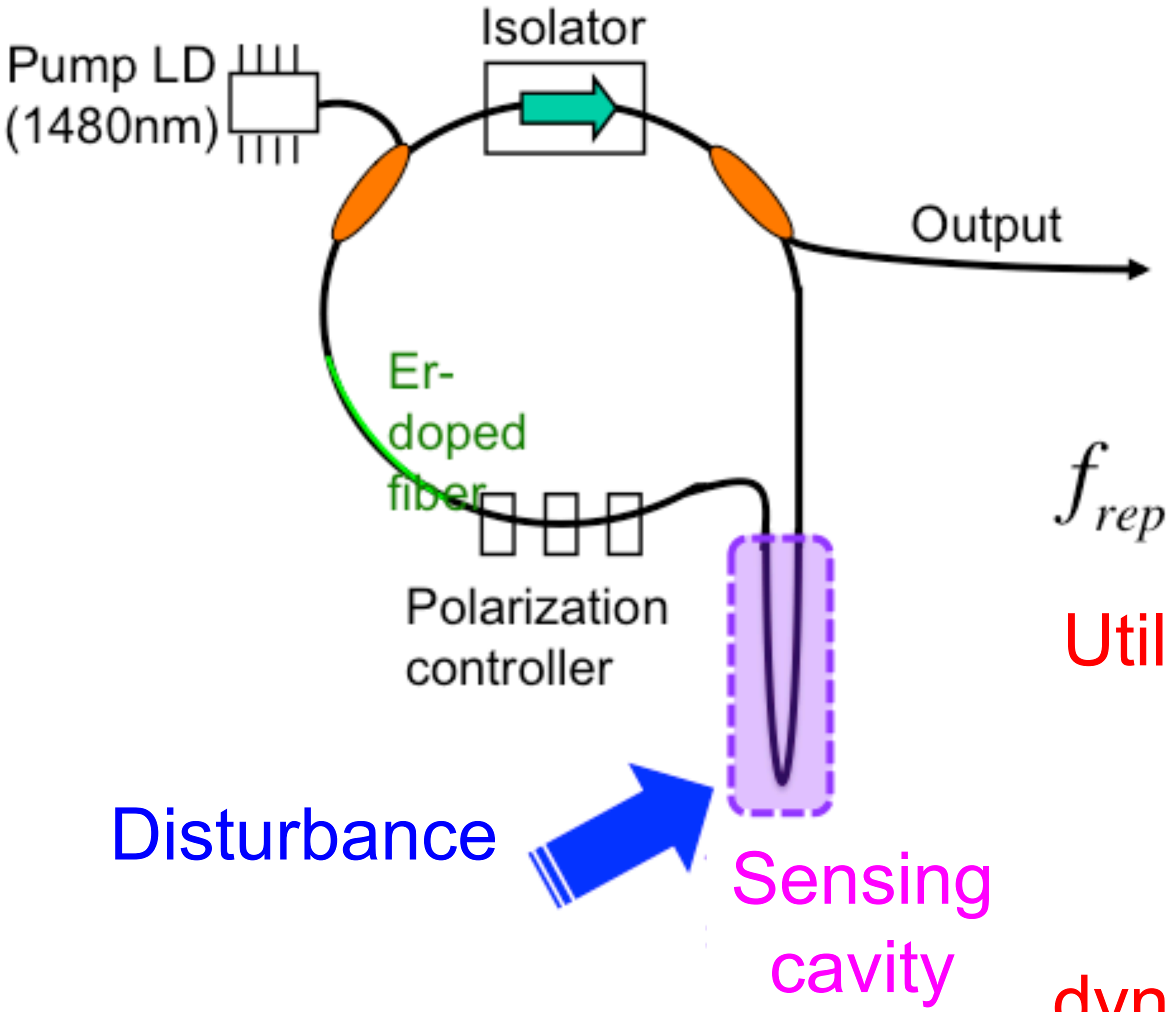
Optical fiber strain sensor

Journal seminar

2015/7/7

M2 Takashi Ogura

Fiber sensing using optical comb cavity



Disturbance/
RFfrequency conversion

$$f_{rep} = \frac{c}{nL}$$

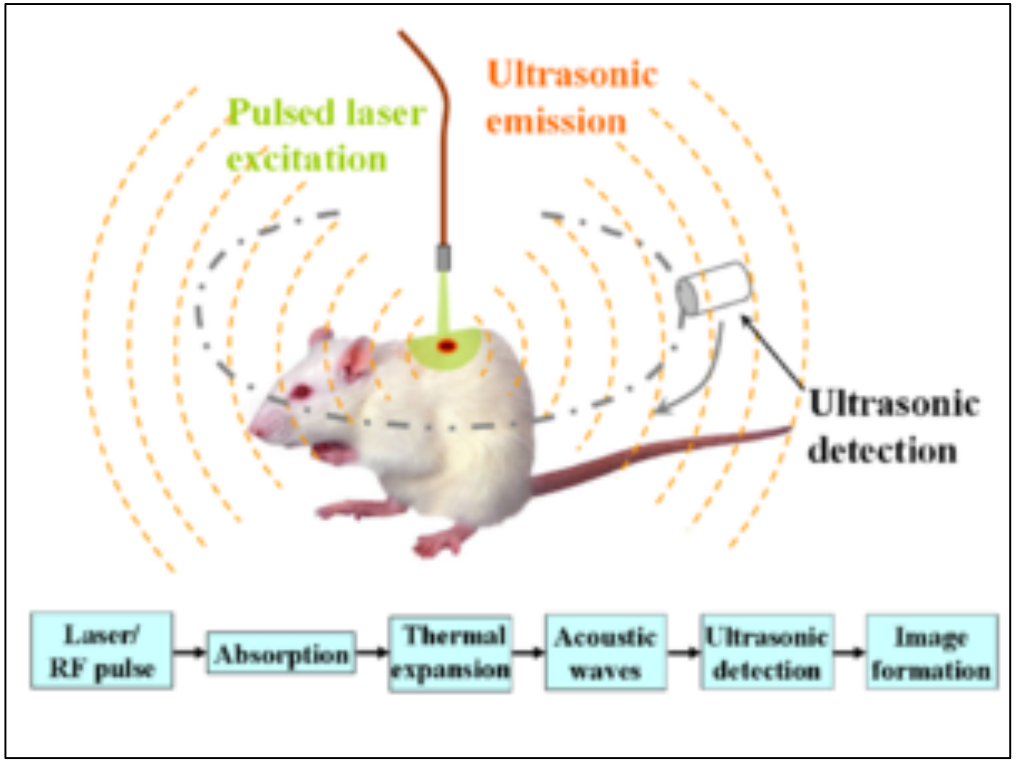
c: light speed
n: group refractive index
L: fiber length

Utilize the dynamic range of optical comb

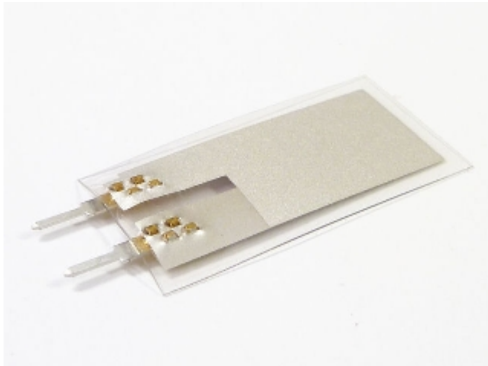
↓

Expansion of the dynamic range of sensing

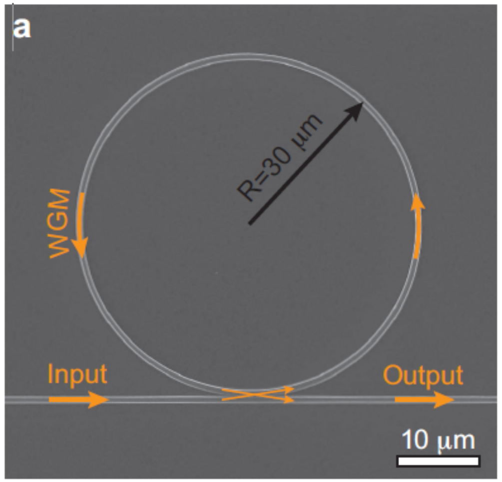
Photoacousitc



Traditional detector for ultrasound



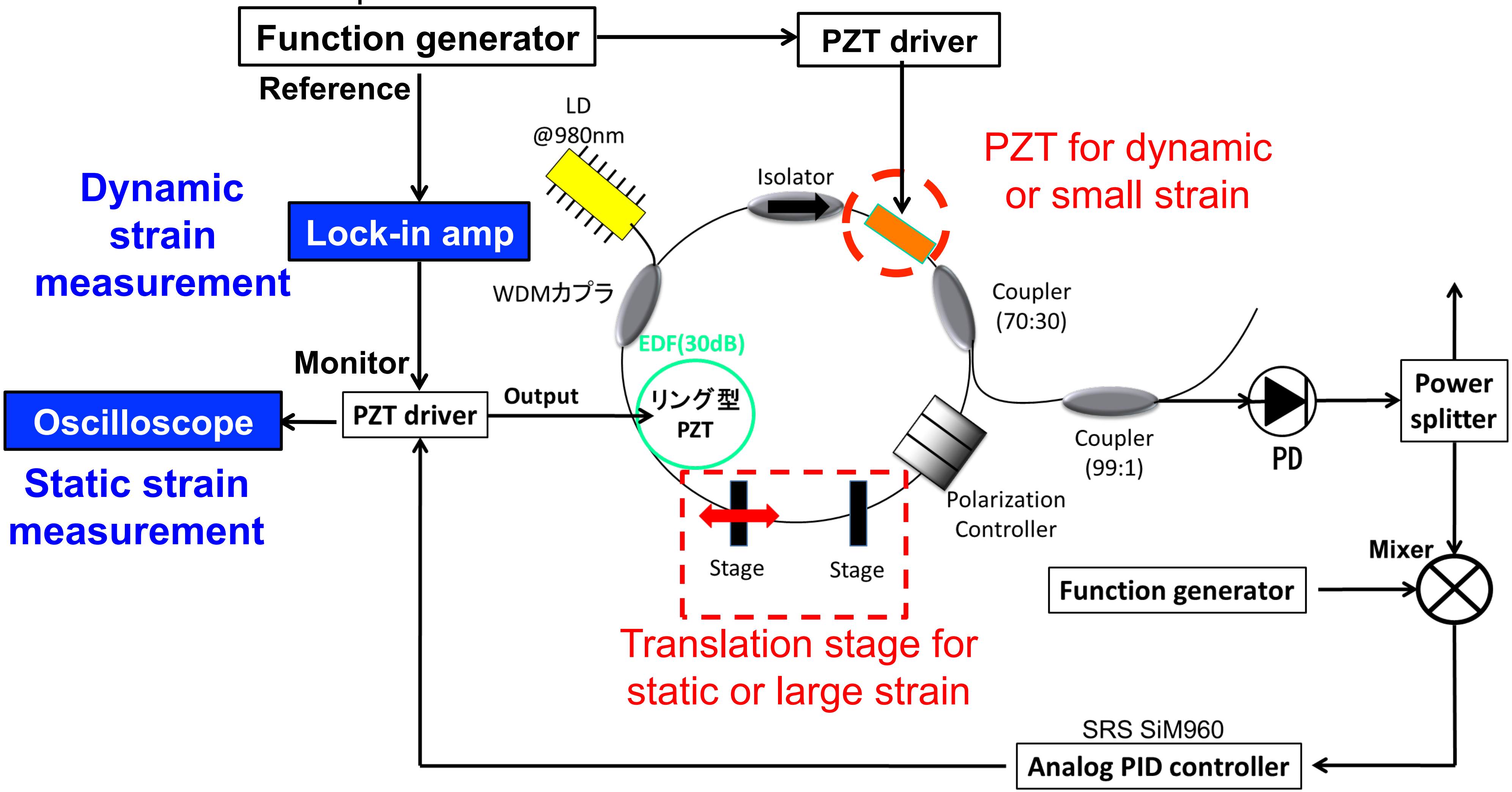
PVDF:Polyvinylidene fluoride



Microring resonator

Strain-sensing fiber comb

(f_{rep} stabilized mode-locked Er:fiber laser)



Experimental results

①Minimum displacement detection=0.036μm
②Maximum displacement detection=36μm
③Cutoff frequeny : f_c=200 Hz

Future plan

①High speed control optical comb
（cutoff frequency>200kHz
②Using for photoacoustic imaging

Consideration

①Comparison with FBG sensor
②Another sensing application and method

In this seminar

①FBG laser Hydrophone
(frequency response=40MHz)
②Strain sensor using optical comb

1. Sien-Ting Lau, *et al*. “Characterization of a 40-MHz Focused Transducer with a Fiber Grating Laser Hydrophone” IEEE Trans Ultrason Ferroelectr Freq Control. **55**, 2714–2718 (2008)

2. Liang Zhang, *et al*. “Optical fiber strain sensor using fiber resonator based on frequency comb Vernier spectroscopy” Opt. Lett. **37**, 13 (2012)

3. Naoya Kuse, *et al*. “Static FBG strain sensor with high resolution and large dynamic range by dual-comb spectroscopy” Opt. Express. **21**, 9(2013)

Sien-Ting Lau, Li-Yang Shao, Helen Lai-Wa Chen,
Hwa-Yaw Tam, Chang-Hong Hu, Hyung-Ham Kim,
Ruibin Liu, Qifa Zhou, and K. kirk Shung.

"Characterization of a 40-MHz Focused Transducer with a Fiber Grating Laser Hydrophone"

IEEE Trans Ultrason Ferroelectr Freq Control. **55**,
2714–2718 (2008)

Intoroduction

Ultrasound is frequently used in bioimaging

- clinical imaging
- cardiology
- obstetrics, and gynecology

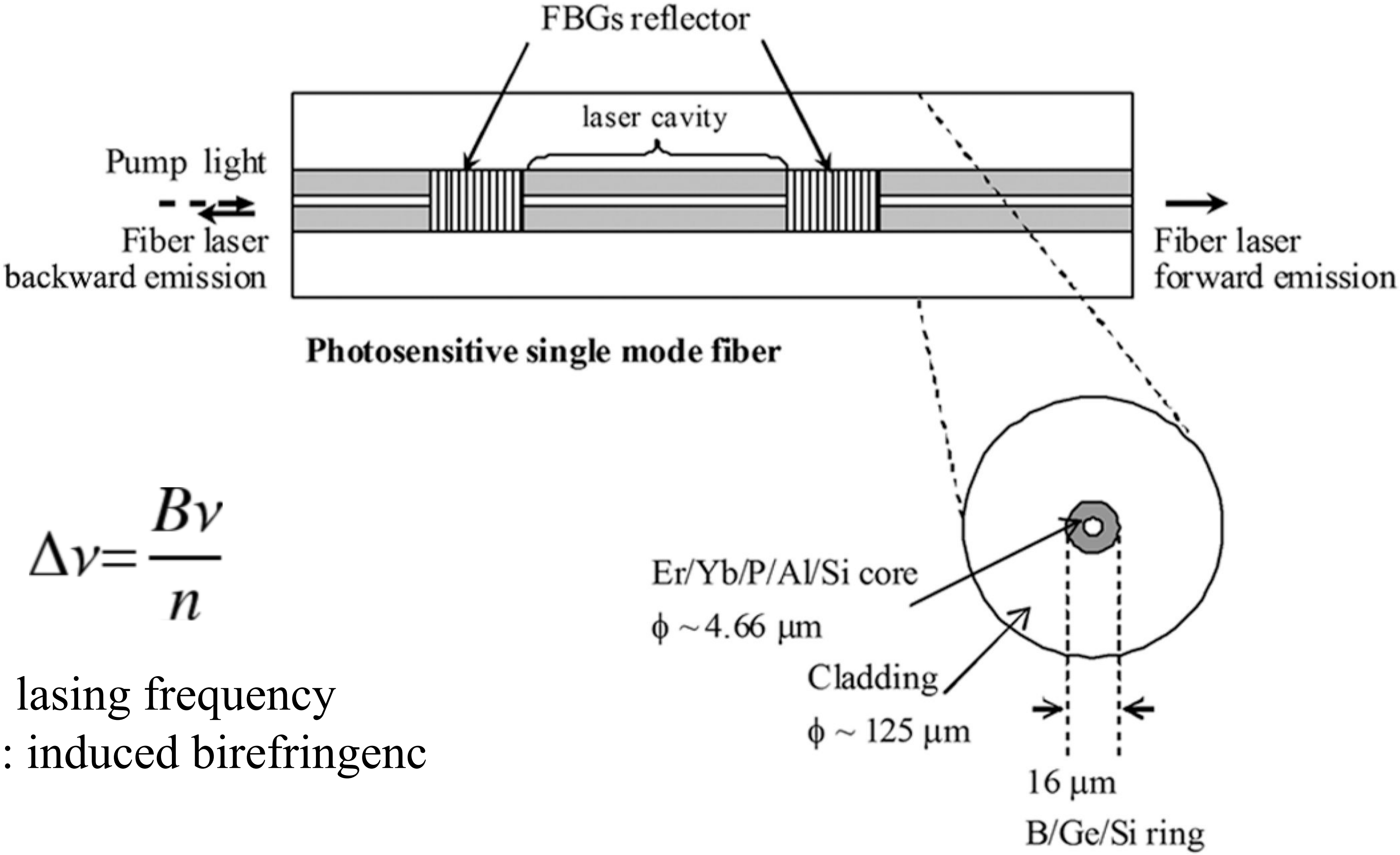
PVDF hydrophones have been widely used in medical ultrasound

□Problem
when the ultrasound frequency is increased,
the size of the hydrophone needs to be decreased.
With the sensing element smaller than afraction of 1 mm, the sensitivity diminishes significantly.

In this letter

- novel fiber-optic hydrophone with a dual polarization distributed Bragg reflector (DBR) fiber laser as the sensing element

FBGs reflector

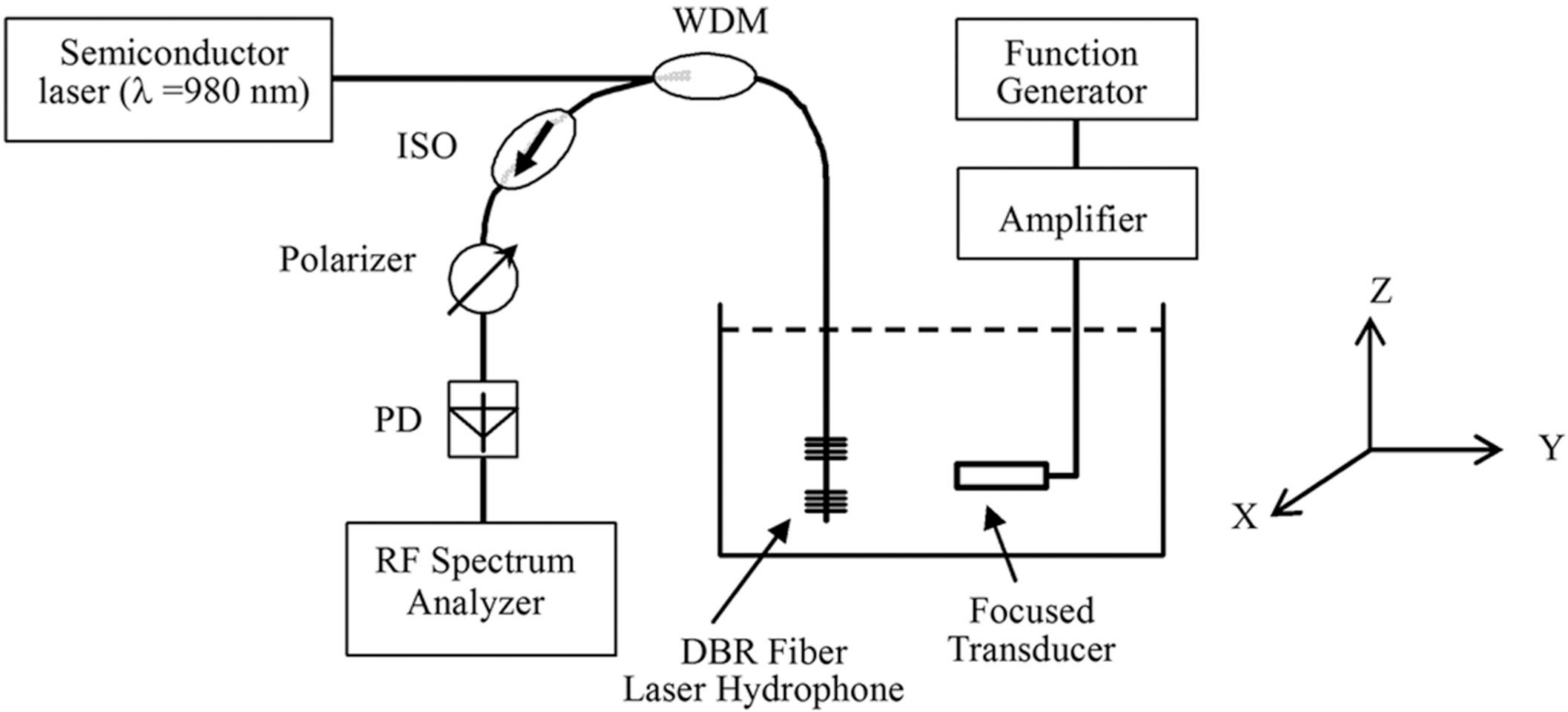


$$\Delta v = \frac{Bv}{n}$$

v: lasing frequency

B: induced birefringenc

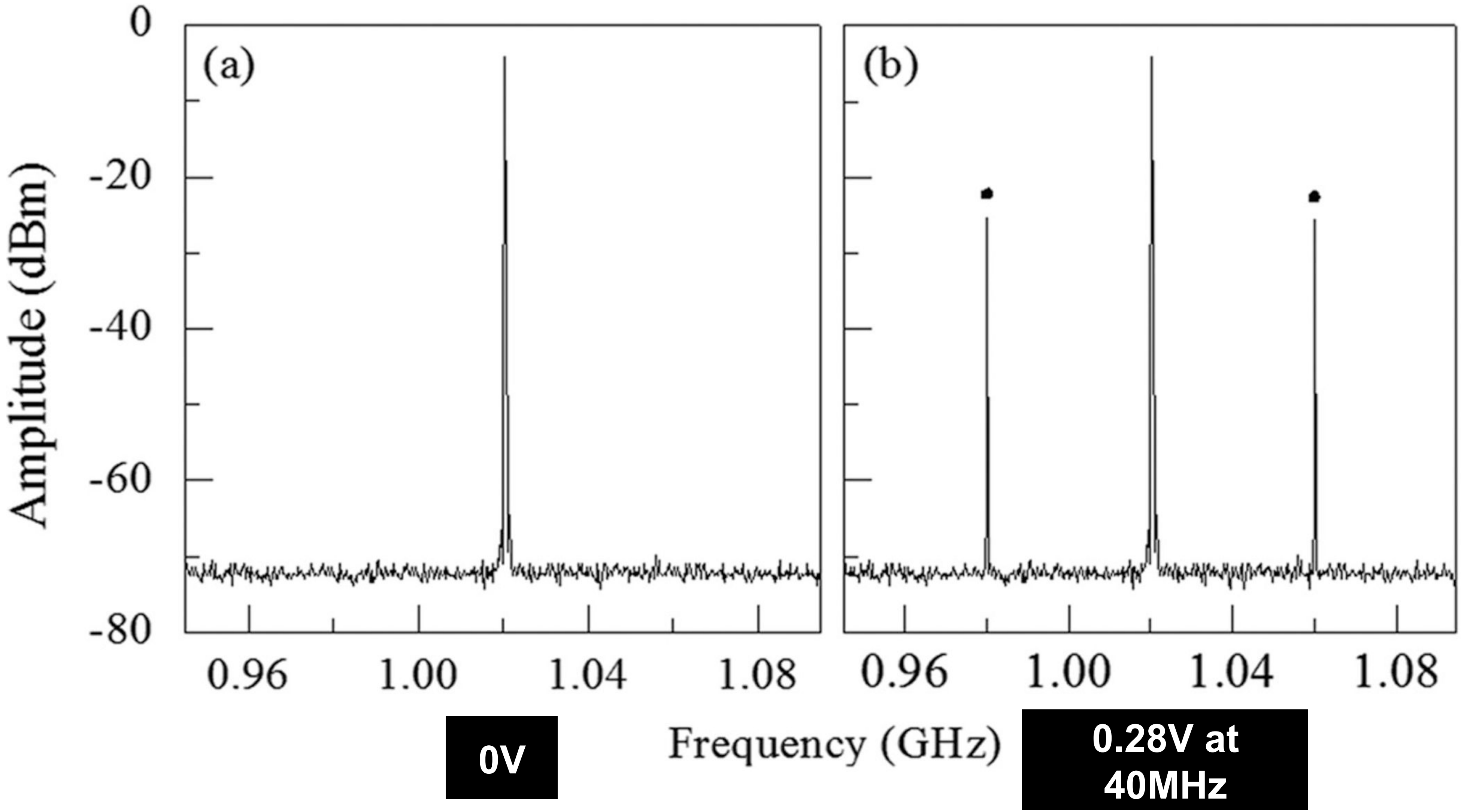
Setup



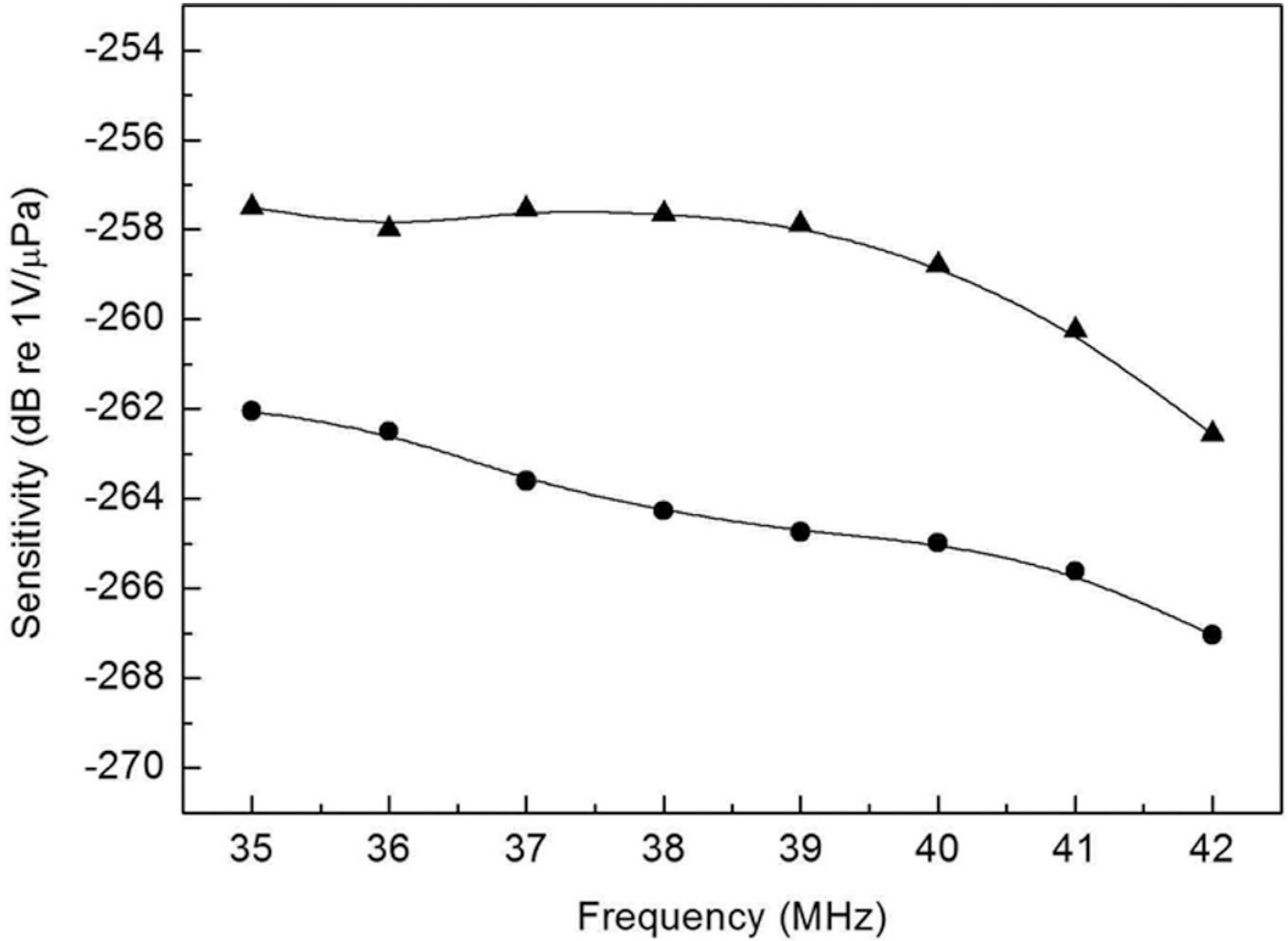
ISO, isolator; PD, photodetector; WDM,wavelength division multiplexer

Experimental results

Beat signal spectra of the DBR laser fiber sensor



Experimental results



Frequency plot of the sensitivity of the fiber hydrophone (▲) and needle-type PVDF hydrophone (●).

Summary

- **A thinned fiber-optic acoustic pressure sensor that employed a dual polarization short-cavity fiber laser has been demonstrated.**

- **Based on the modulation of the birefringence of the in-fiber laser by acoustic pressure, the sensor is capable of detecting ultrasound up to a frequency of 42 M Hz with good sensitivity (approximate −259 dB re 1V/μPa).**

Liang Zhang, Ping Lu,Li Chen, Chaoran Huang,
Deming Liu, and Shibin Jiang

"Optical fiber strain sensor using fiber resonator based on frequency comb Vernier spectroscopy"

Opt. Lett. **37**, 13 (2012)

Intoroduction

Fiber Bragg gratings have been used as sensitive strain sensors

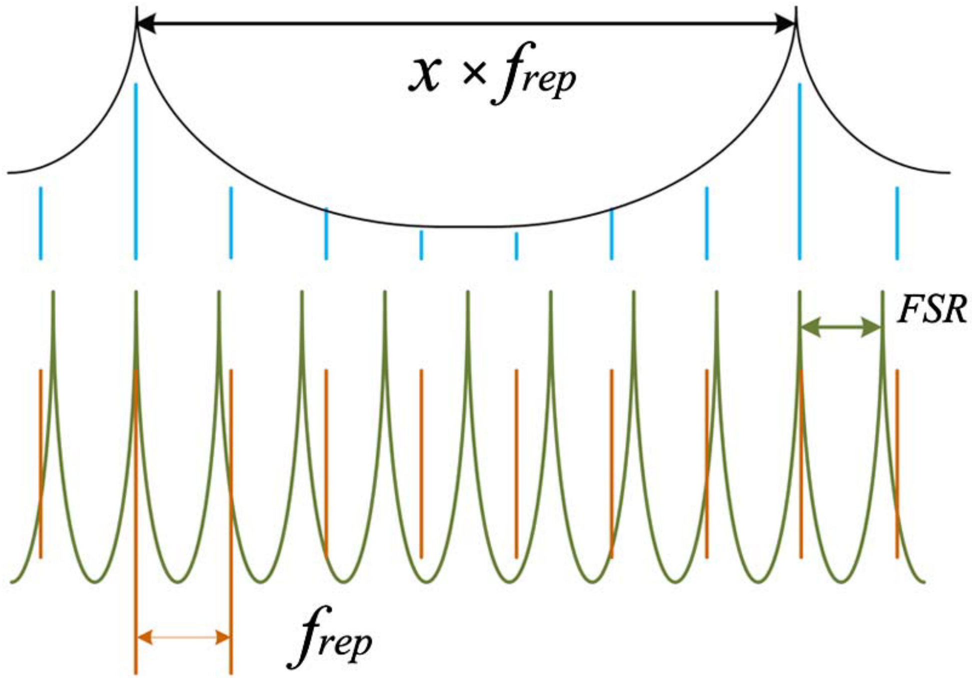
□Advantages
・cost effective
・small
・immune to electromagnetic interference

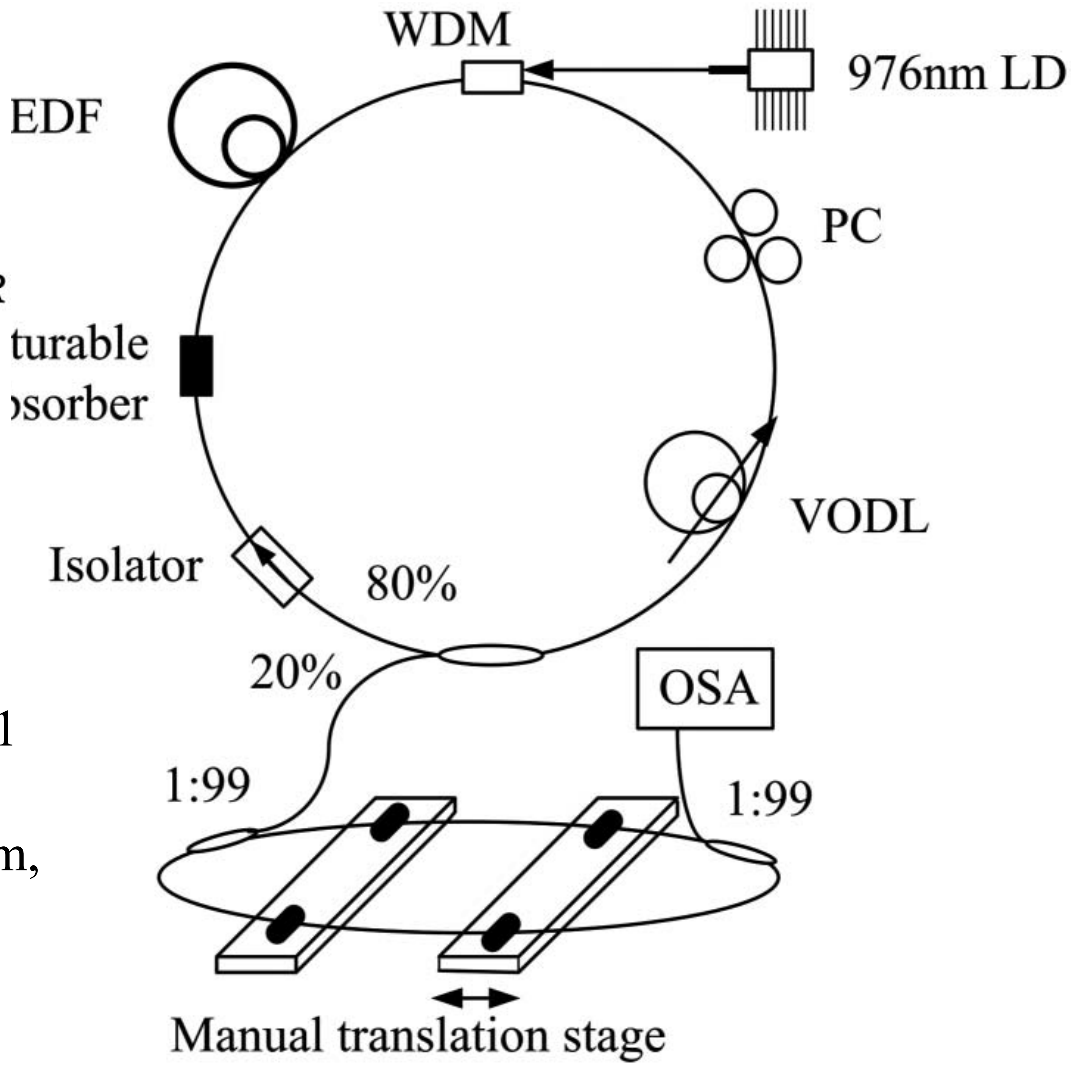
Frequency comb Vernier spectroscopy

□Problem
However, the aforementioned techniques are implemented in mirror-based cavities, whose difficult alignment limits their application in strain sensing.

In this letter
・ **alternative scheme for strain sensing using a fiber ring resonator based on frequency comb Vernier spectroscopy,**

Principle&Setup



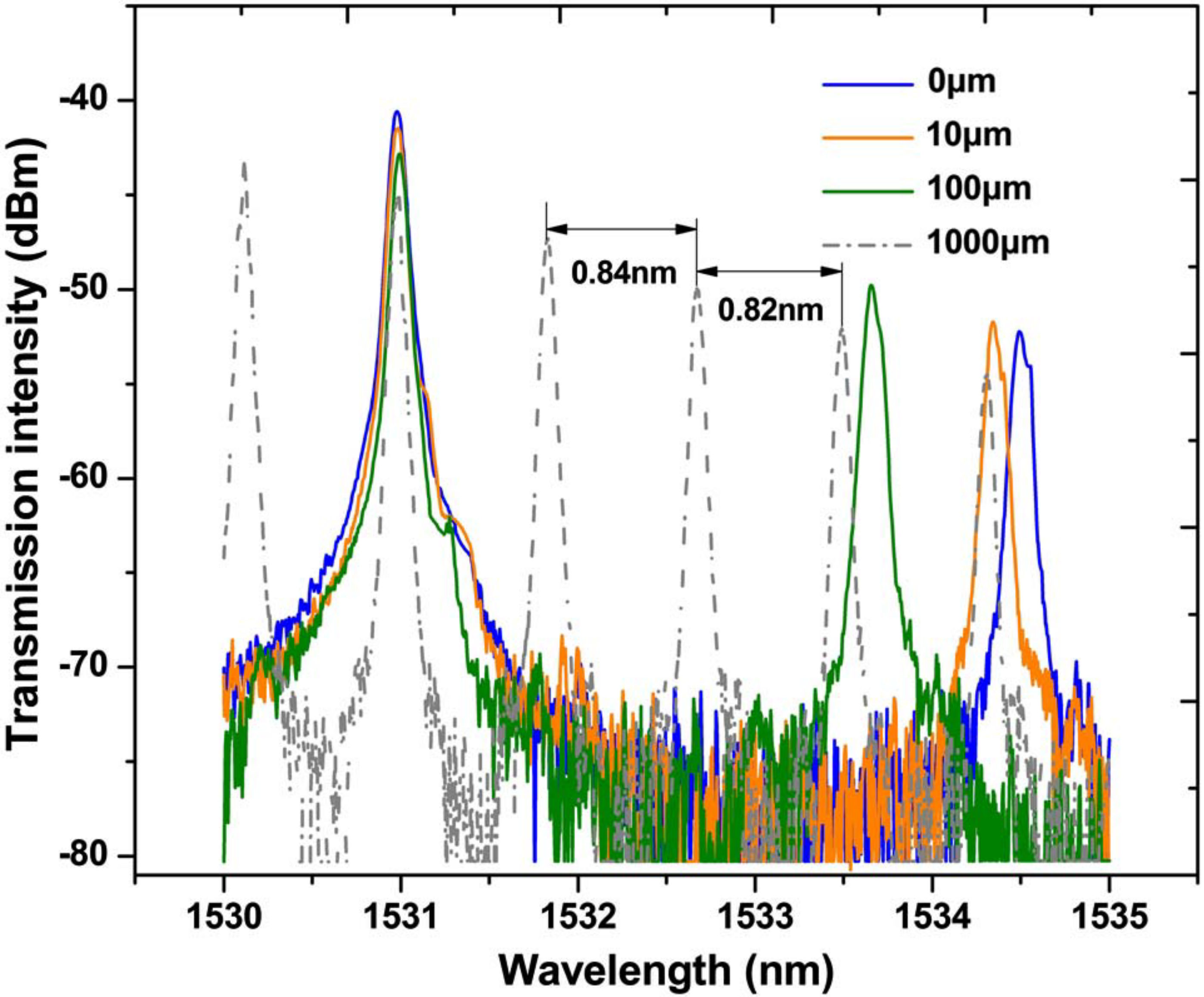


・The length of the laser cavity was about 11 m, corresponding to the f rep of 18.8 MHz

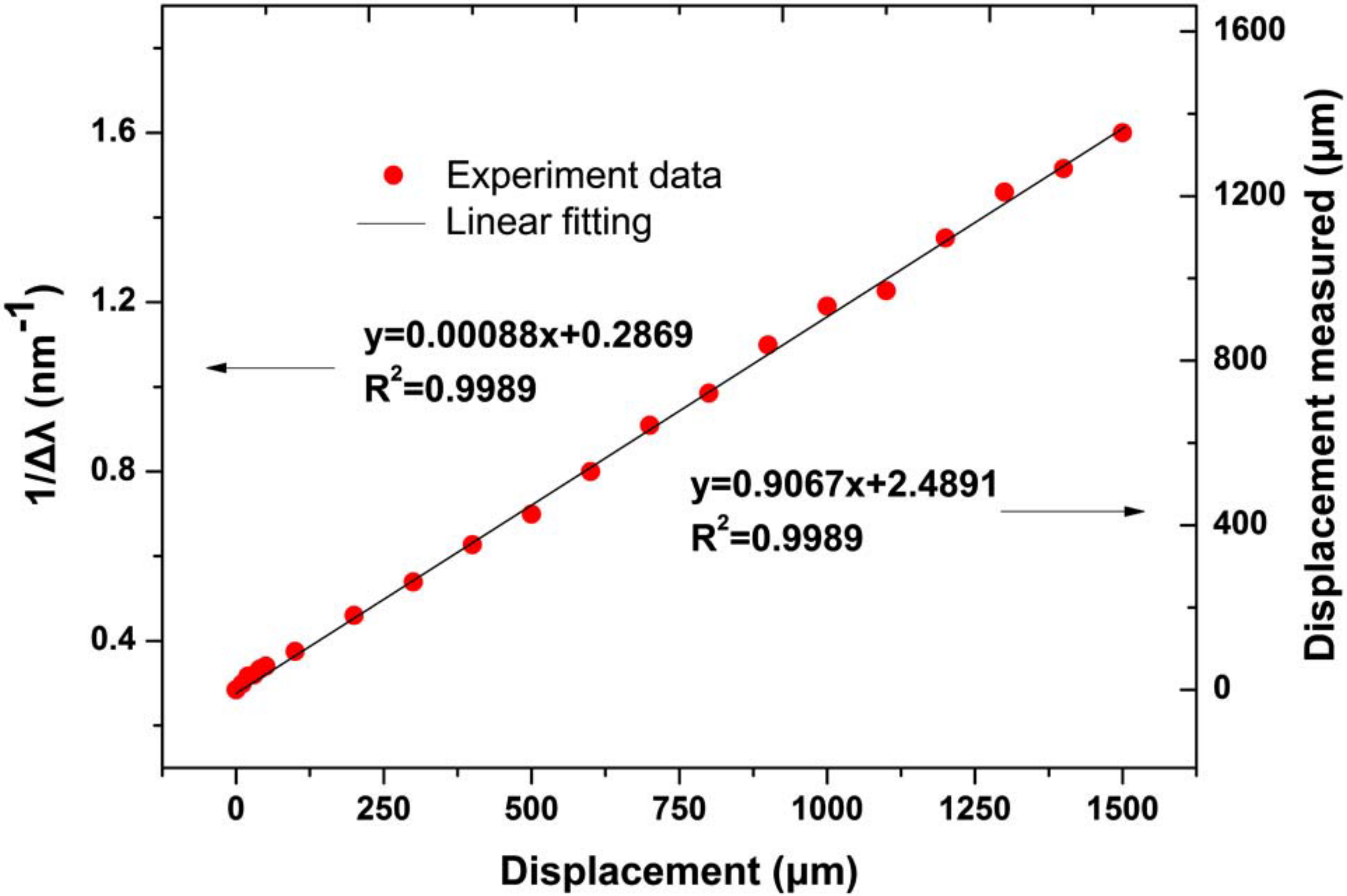
・The length of the resonator was about 11 m, corresponding to FSR of 19 MHz

・Two sections of optical fibers of about 5 m as sensing heads

Experimental results



Experimental results(strain)



Summary

- **They have proposed and experimentally demonstrateda novel (to our best knowledge) optical fiberstrain sensor using a fiber ring resonator based on frequency comb Vernier spectroscopy.**
- **The transmission spectrum demonstrates high sensitivities better than 40 pm/με within the range of 0 to 10 με.**

Naoya, Kuse, Akira Ozawa, and Yohei Kobayash
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“Static FBG strain sensor with high resolution and large dynamic range by dual-comb spectroscopy”

Opt. Express. **21**, 9(2013)

Intoroduction

Fiber Bragg gratings have been used as sensitive strain sensors

□Advantages
・cost effective
・small
・immune to electromagnetic interference

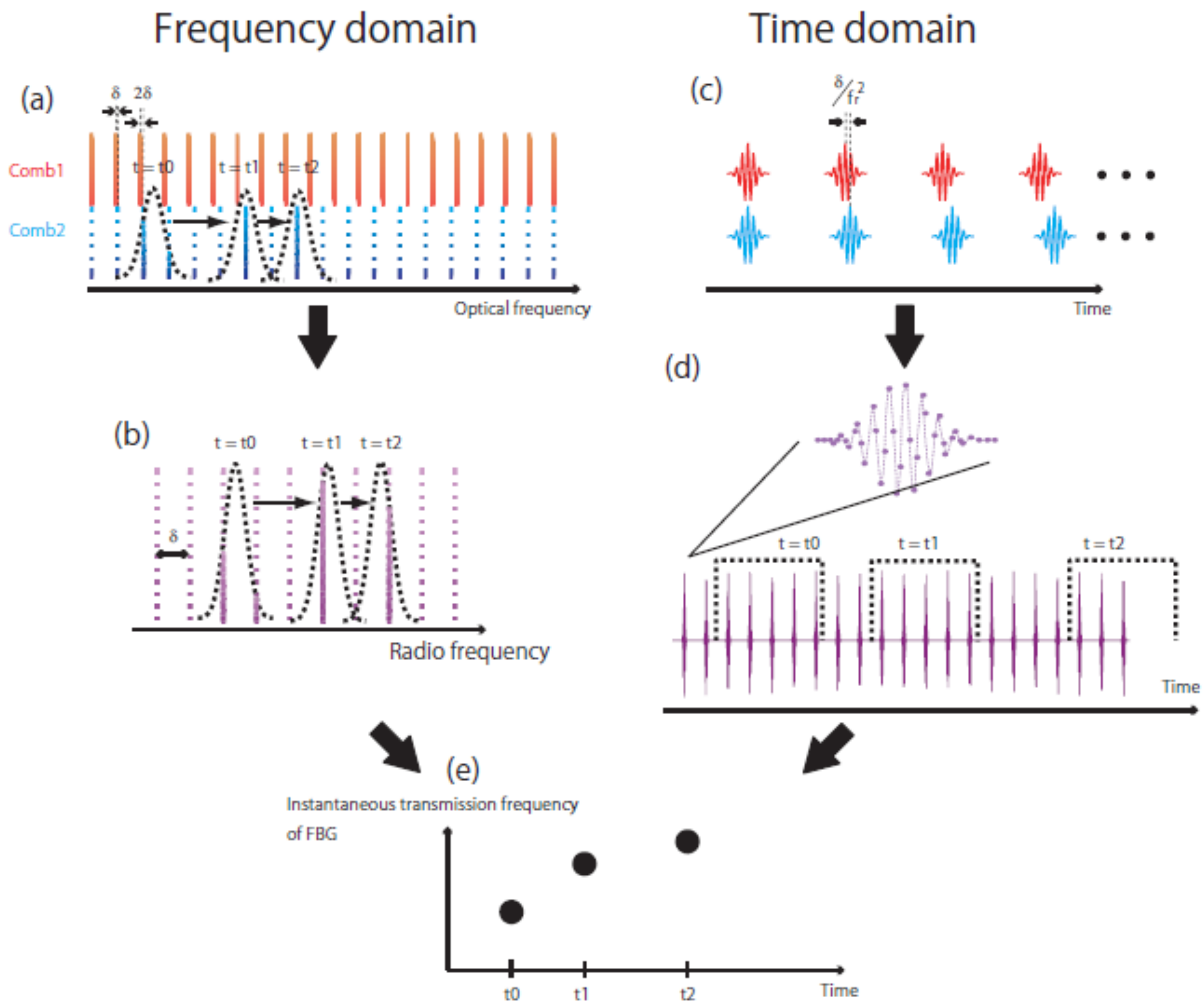
Single-longitudinal-mode continuous-wave (CW) lasers are often used to detect the spectral shift of FBGs with high resolution

□Problems
the resolution is limited by the frequency noise of the laser source.

In this letter

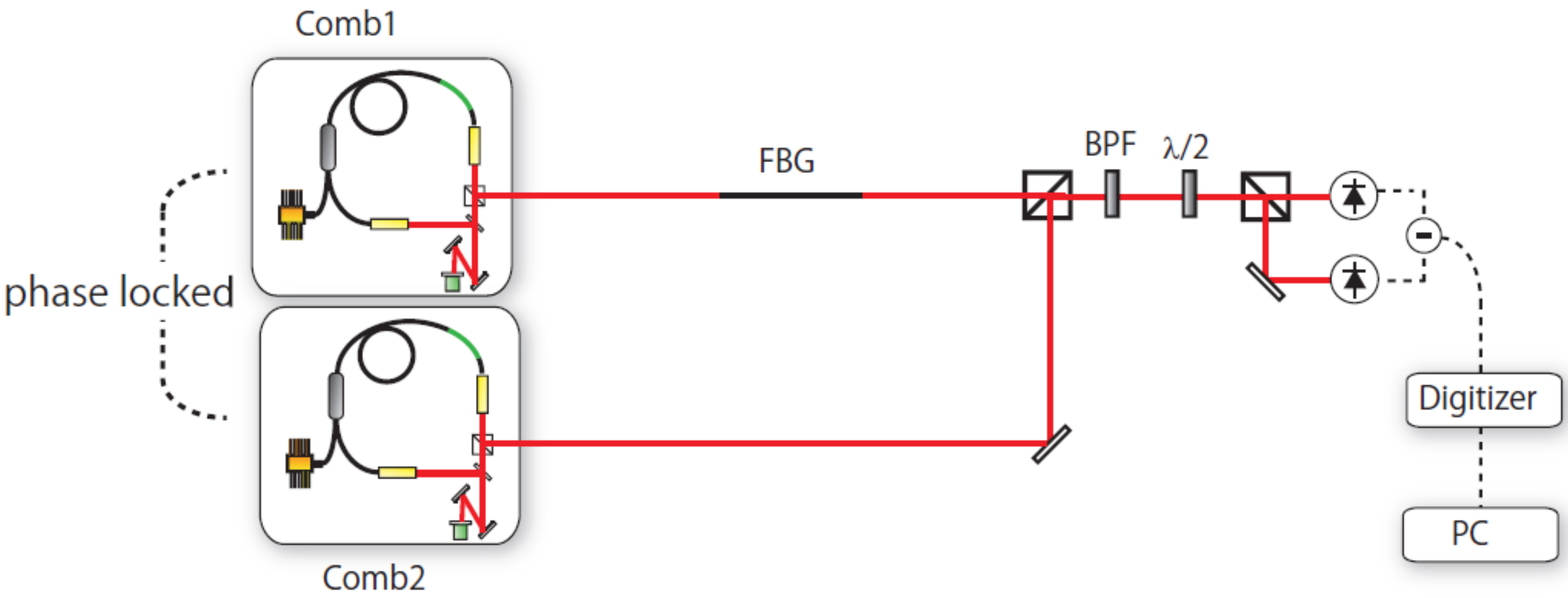
・ we propose and demonstrate a precise and broadband characterization of FBG sensors by employing dual-comb spectroscopy,

Principle



Frequency domain
Time domain
(a)
δ
2δ
Comb1
Comb2
t = t0
t = t1
t = t2
Optical frequency
(b)
t = t0
t = t1
t = t2
δ
Radio frequency
(c)
Time
(d)
t = t0
t = t1
t = t2
Time
(e)
Instantaneous transmission frequency
of FBG
t0
t1
t2
Time

Experimental setup



Experimental results

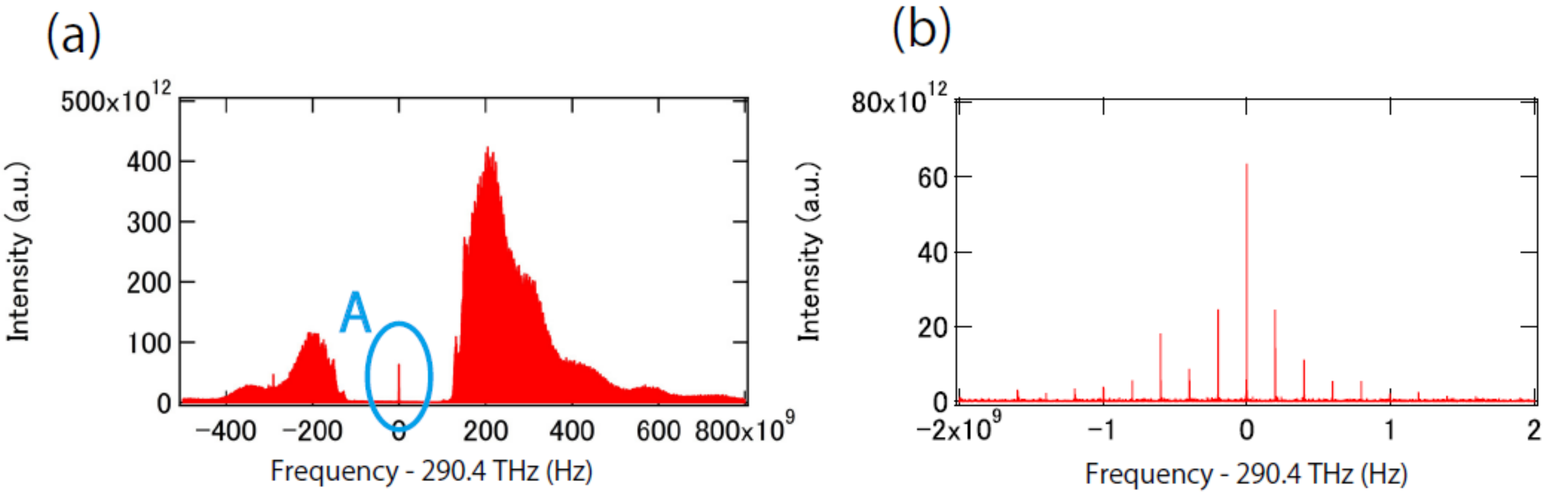
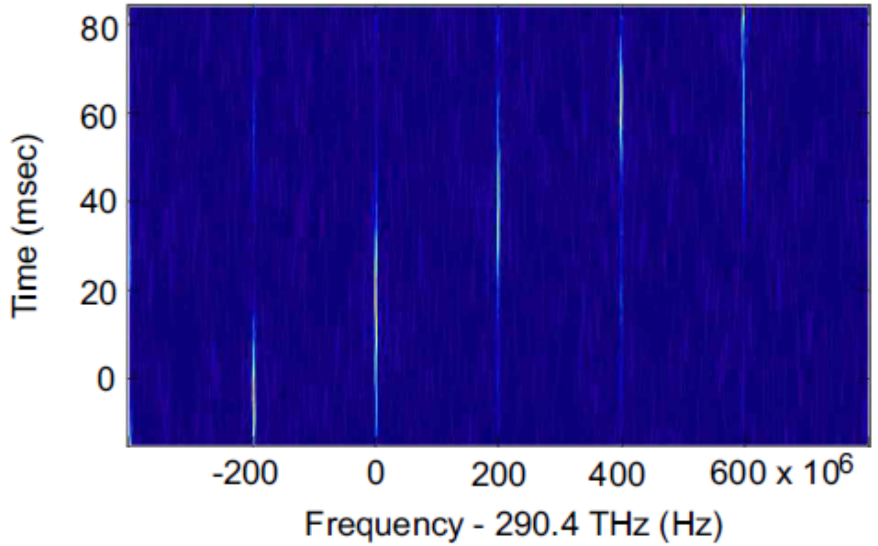


Fig. 3. Transmitted spectrum of FBG sensor without applying strain, 150-ms time window was used for Fourier transformation of time-domain interferogram. The result is shown in spans of approximately 1 THz (a), and in approximately 4 GHz (b), which is an expansion of gAh in (a).

Experimental results

(a)



(b)

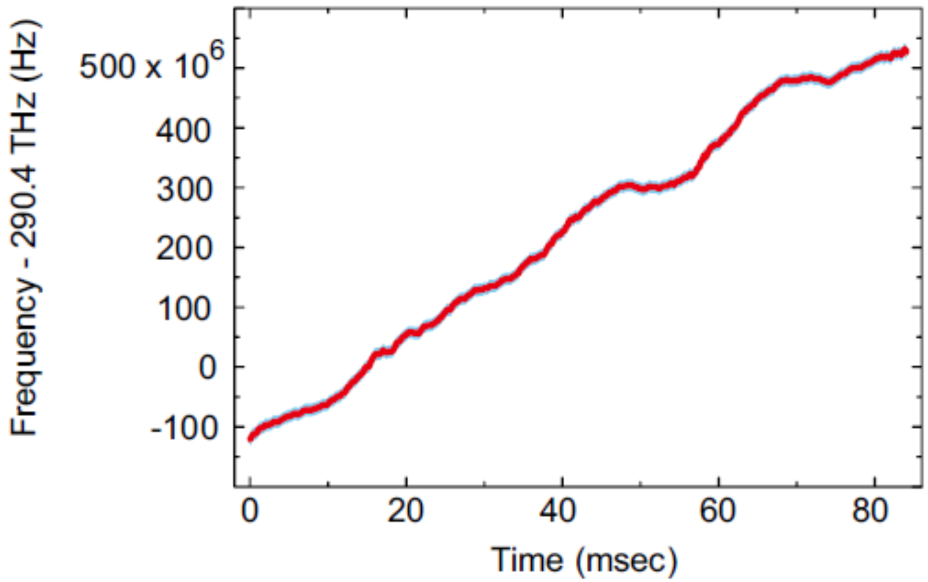


Fig. 4. (a) Instantaneous transmission spectra of FBG when linearly increasing strain is applied. The result is shown in a span of approximately 1 GHz, which corresponds to region gAh in Fig 3(a). (b) Retrieved instantaneous transmission frequency of FBG.

Summary

- **They have demonstrated a quasi-static FBG strain sensor with 34 nε -resolution and 1-THz bandwidthby dual-comb spectroscopy. This high-resolution, broad-bandwidth FBG sensor has apotential as a tool for geophysics applications.**

Carbon NanoTube

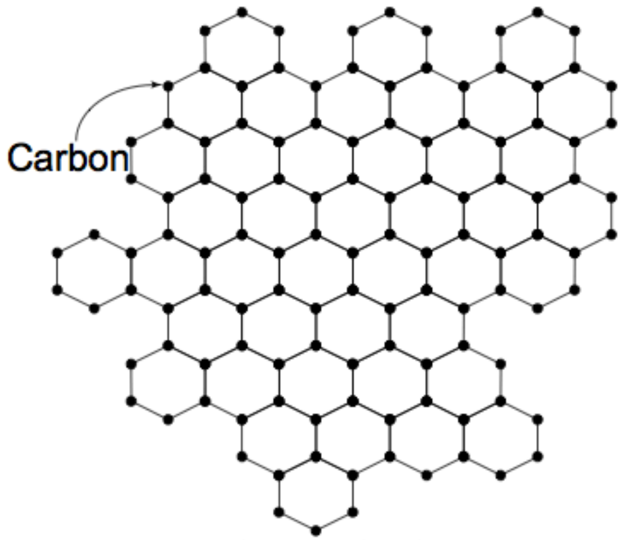
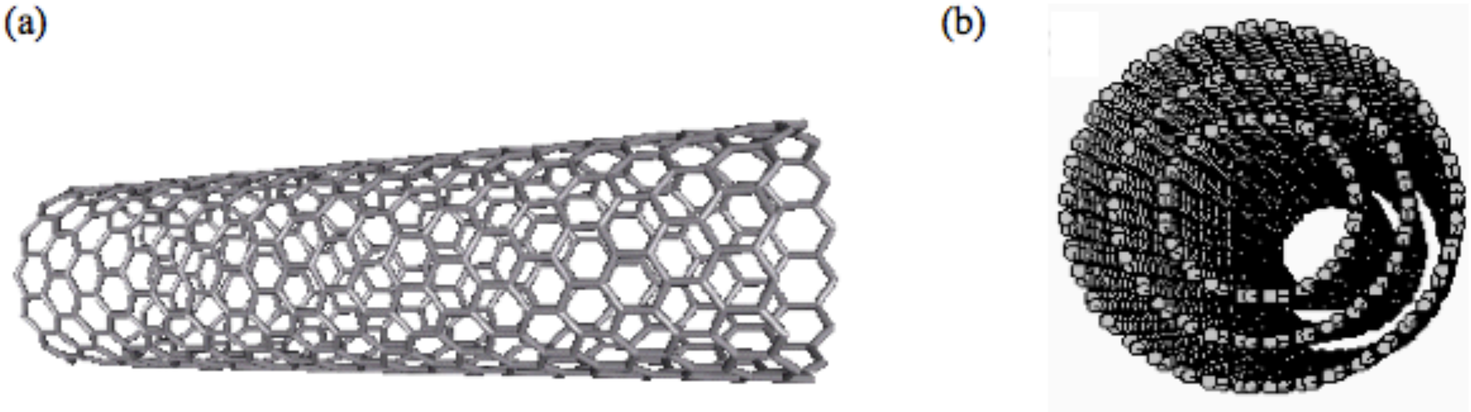


Fig.2.1 Graphen sheet

(a) (b)



(a) SWNT:Single-Walled NanoTube (b)MWNT:Multi-Walled NanoTube

Fig.2.2 Configuration of Carbon NanoTube