High-precision (<1ppb/℃) optical heterodyne interferometric dilatometer for low thermal expansion materials

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Acknowledgement

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Outline

<u>1. Background</u> — CTE characteristics, CTE metrology

<u>2. Goal</u> — Target performance of dilatometer

<u>3. Methodology</u> — Principle & design of the dilatometer

<u>4. Results</u> — Evaluation of the performance of the dilatometer

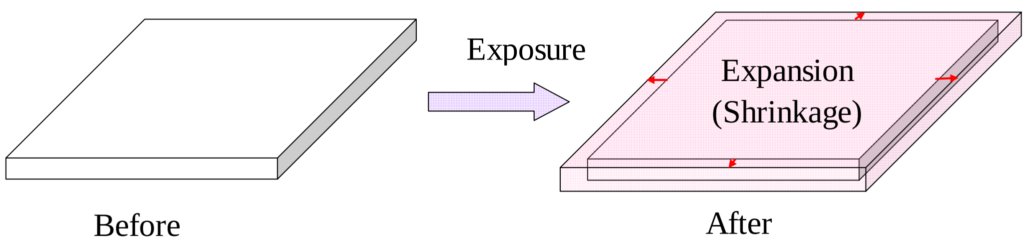
<u>5. Summary</u>

1. Background

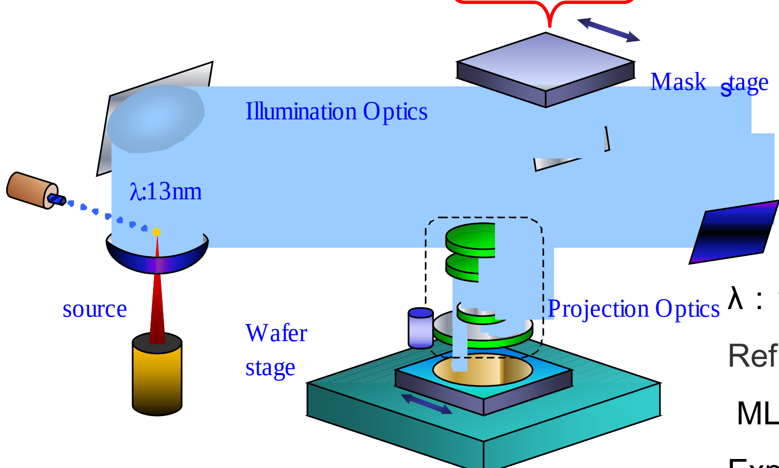
Background (1): CTE of EUVL Mask Substrate

CTE: Coefficient of Thermal Expansion

Exposure deforms mask.



(Change in substrate temperature)



λ : 13.5 nm

Reflective Optics

ML,Reflectance :<70%)

Exposure under vacuum

Configuration of EUVL system

SEMI standards (Class A)

0±5 ppb/°C (19-25°C)

1ppb = 0.1nm (@10cm)

Difficult requirement to meet

⇩

No commercial dilatometer that meets EUVL requirements

⇩

Obstacle to the development of LTEMs

⇩

Strong demand for a metrology that meet EUVL requirement

Background (2): Metrology Development Project

LTEM suppliers

AGC
TOSOH
KYOCERA
NIHON CERATEC
OHARA
Shin-Etsu
TOSHIBA CERAMICS CO., LTD.

LTEM developer

Metrology user

Research organizations

National Institute of Advanced Industrial Science and Technology (AIST)
独立行政法人 産業技術総合研究所

Metrology and patent ownership

ASET

EUVL technology

Equipment design

Development team

Specifications

Performance evaluation

Equipment supplier

uniopt

Optical heterodyne interferometer,
Thermal control technique

Manufacture of equipment

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2. Goal

Goal and targets

Overall Goal

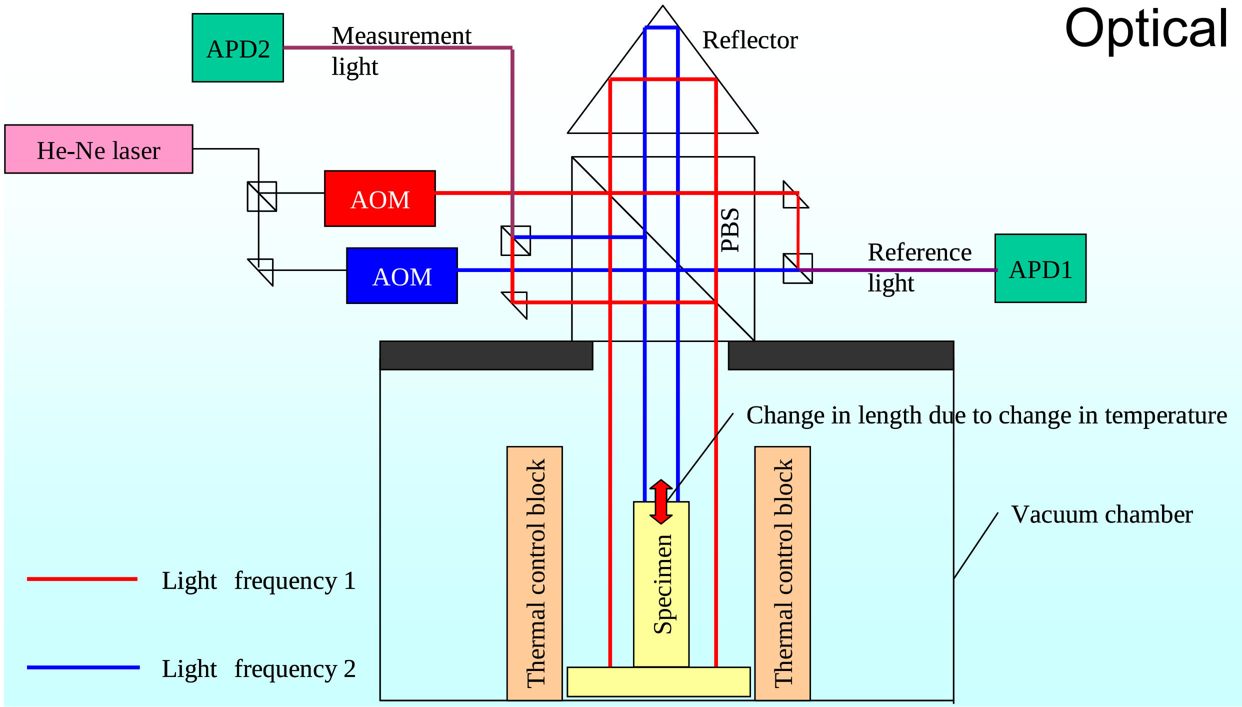
- To establish a CTE metrology tailored to meet EUVL requirements and help bring EUVL closer to the stage of practical use

Target

- Resolution: 1 ppb/° C or less
- Repeatability(σ): 1 ppb/° C or less
- Making practical dilatometer: marketable
- Metrology standardization

3. Methodology

Methodology (1): # Principle of Measurement



Optical heterodyne interferometry

Electric field intensity

$$E_1 = a_1 \cos(2\pi f_1 t + \phi_1)$$

$$E_2 = a_2 \cos(2\pi f_2 t + \phi_2)$$

Intensity of superimposed light

$$I = \langle |E_1 + E_2|^2 \rangle$$

$$= \frac{a_1^2 + a_2^2}{2} + 2a_1 a_2 \cos\{2\pi(f_1 - f_2)t + (\phi_1 - \phi_2)\}$$

$$= \frac{a_1^2 + a_2^2}{2} + 2a_1 a_2 \cos\{2\pi f_b t + \Delta\phi\}$$

Phase difference between APD1 and APD2 at T_1 : $(\varphi_{APD2} - \varphi_{APD1})_{T1}$

Phase difference between APD1 and APD2 at T_2 : $(\varphi_{APD2} - \varphi_{APD1})_{T2}$

Change in phase difference between T_1 and T_2 : $\Delta(\phi_{APD2} - \phi_{APD1}) = \frac{2\pi\Delta L}{\lambda}$

ΔL : Change in length

(Quadruple - sensitivity)

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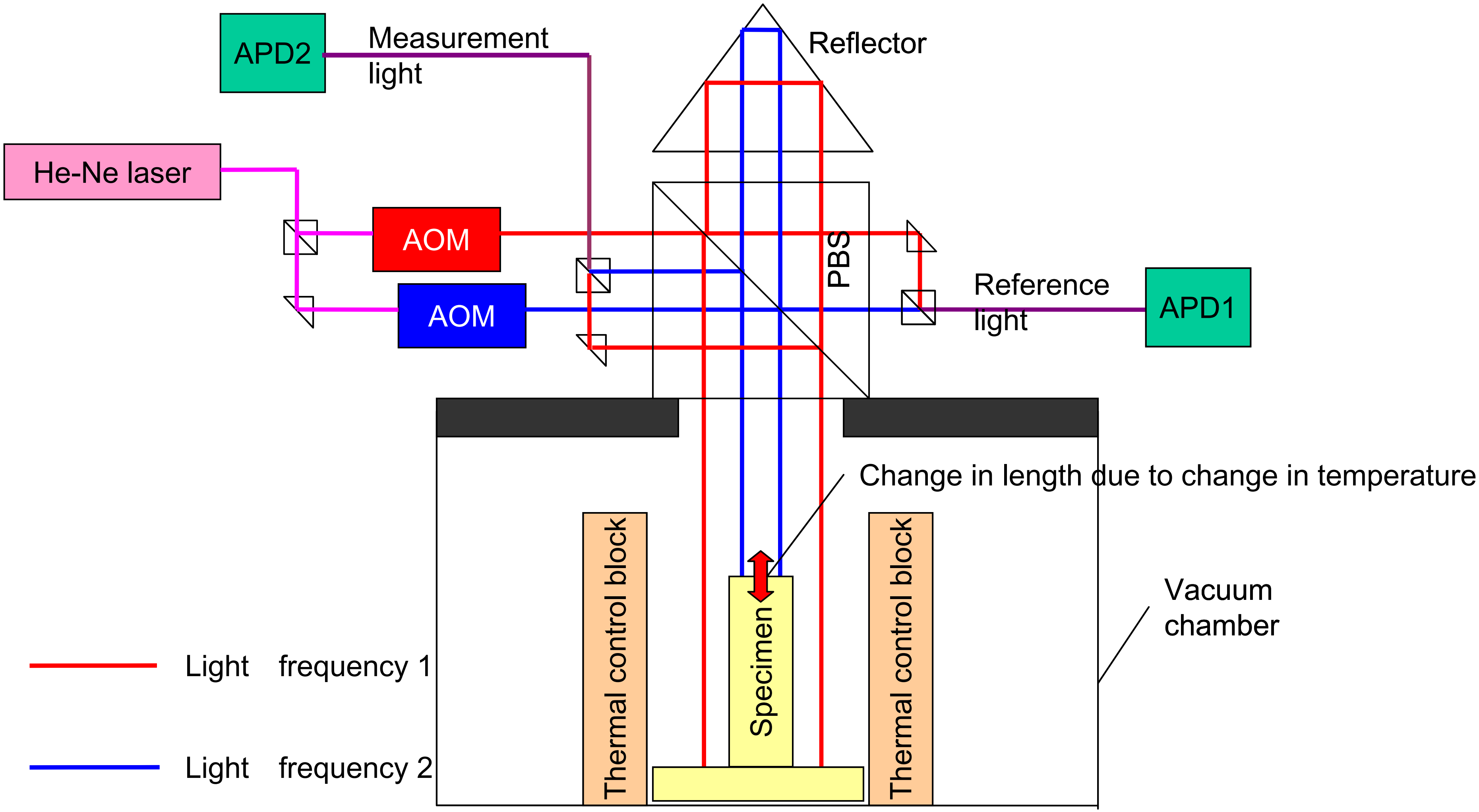
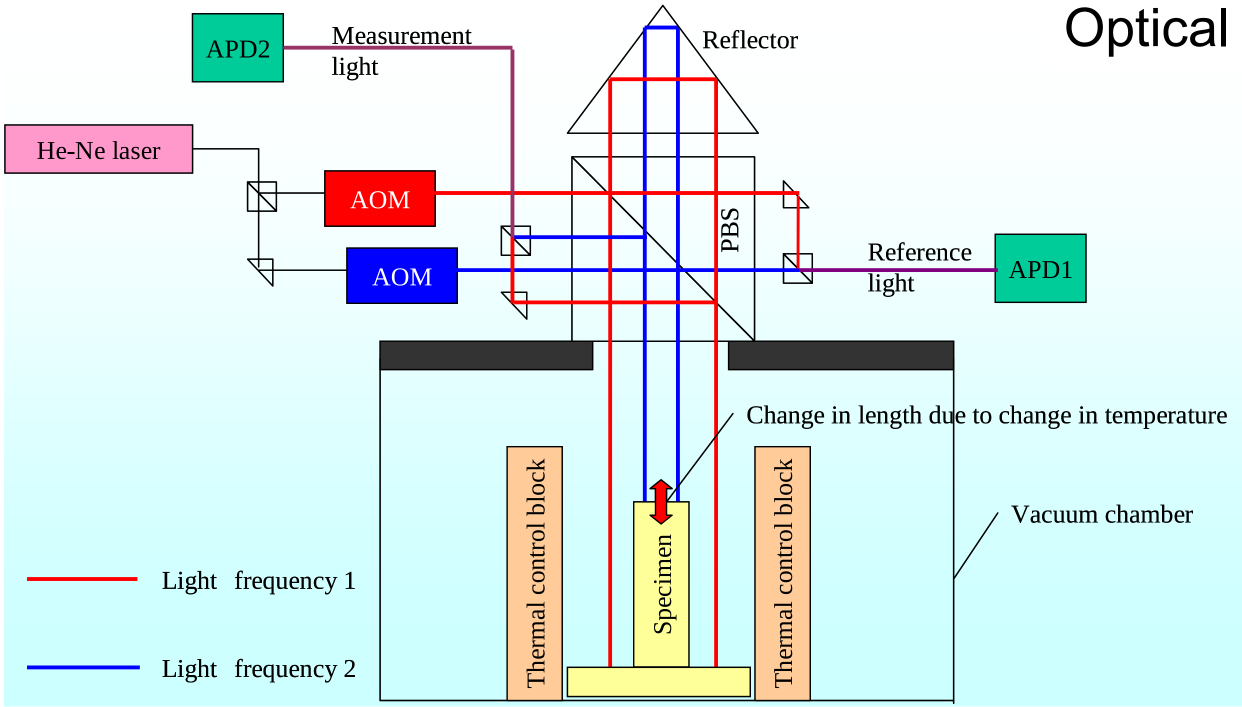
Methodology (1): Optical Path of the Dilatometer



Methodology (1): # Principle of Measurement



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(Quadruple - sensitivity)

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Methodology (2): # To Meet EUVL Requirement

$$\alpha = \frac{\Delta L}{L_0} \cdot \frac{1}{\Delta T}$$

α : low

Consideration of uncertainty factors

$$\delta\alpha_{total} = \left(\frac{\delta L_0}{L_0}\right)_{sp} \alpha + \left[\frac{\delta(\Delta L)}{L_0}\right]_L \frac{1}{\Delta T} + \left[\frac{\delta(\Delta T)}{\Delta T}\right]_T \alpha$$

Determination of sample length

Determination of change in sample length due to thermal expansion

Stability of thermo control and determination of temperature

This term has little influence.

This term has a large influence.

This term has little influence.

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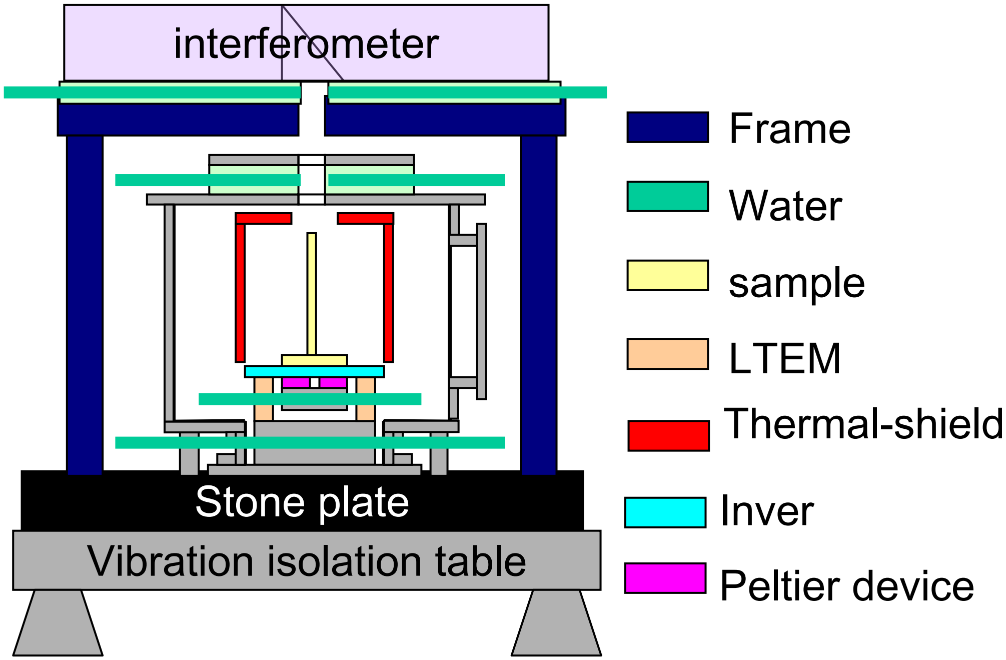
Methodology (3): KEY Design Consideration

How to reduce magnitude of uncertainty factors affecting ΔL measurement



Structure of dilatometer

Design guidelines

Compact interferometer

Frequency-stabilized laser

Sample inclination prevention

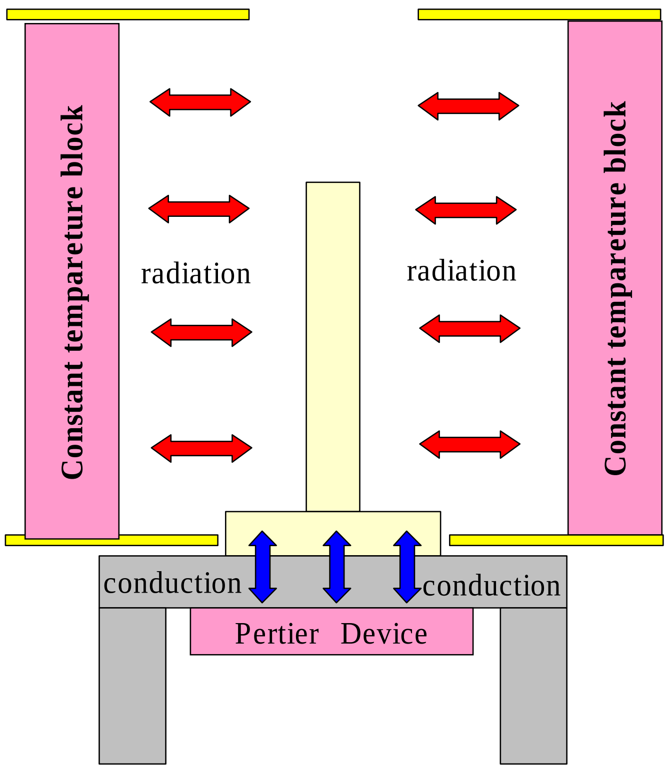
- Thermal isolation
- Thermal control
- LTEM pedestal

Vibration isolation

- Stone plate
- Vibration isolation table

Methodology (4): **Design Guideline**

How to reduce magnitude of uncertainty factors affecting ΔT measurement



To achieve uniform temperature distribution in sample

- Employment of two heat sources

Efficiency: Constant temp. blocks

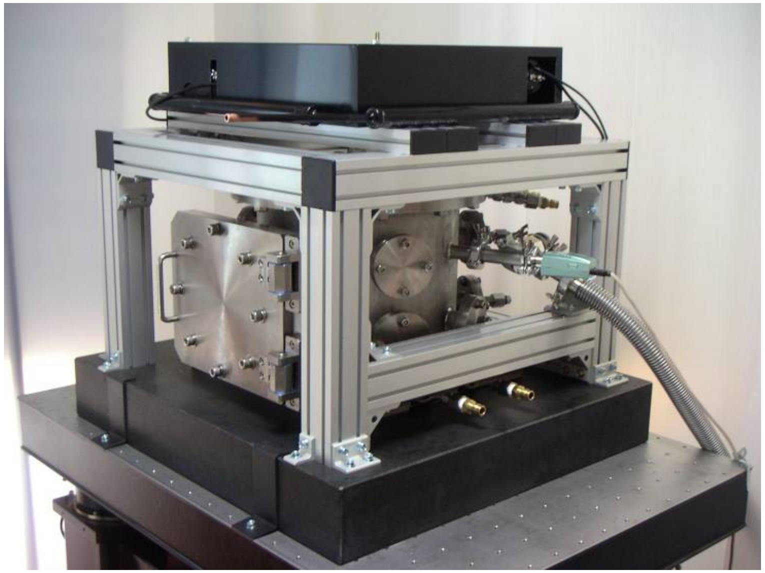
Uniformity: Peltier device

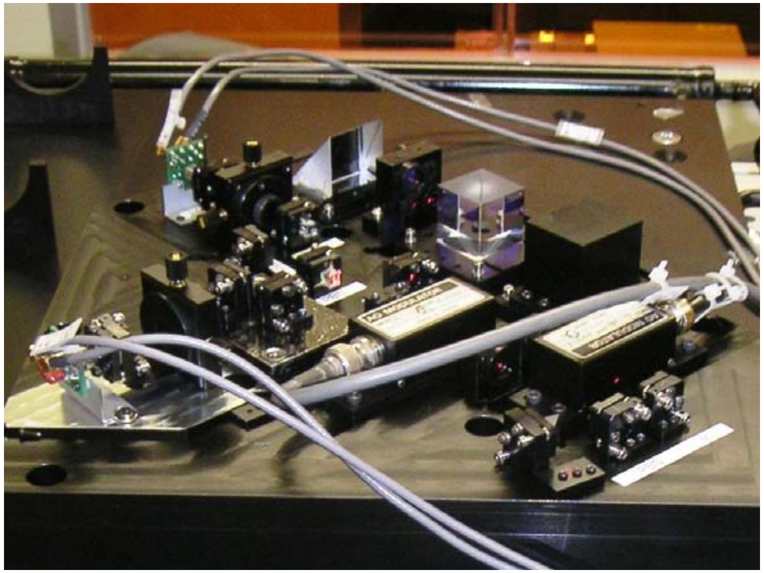
Configuration of thermo-control system

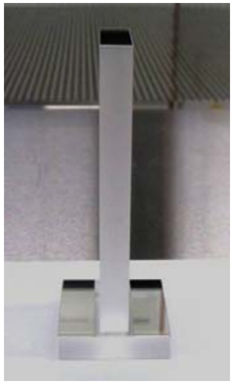
Methodology (5): Practical Dilatometer, Sample

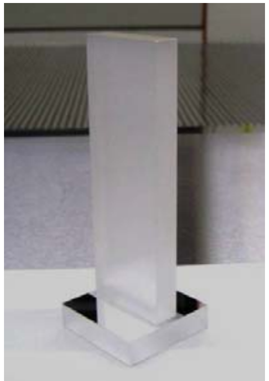
CTE-01

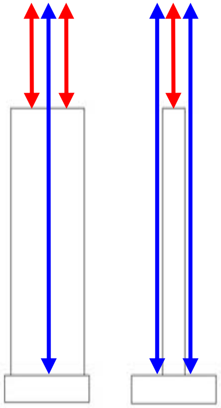
Equipment supplier uniopt







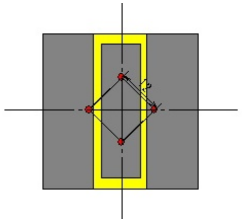




Optical path

Reference

Displacement



Arrangement of laser spot

4. Results

Evaluation Items

- Determination of measurable range of CTE and types of materials that could be measured

- Reproducibility

  Repeatability (Static) :

  Reproducibility obtainable from measurements of the same sample without moving it .

  Resetability (Dynamic) :

  Reproducibility obtainable from measurements involves changing the sample

- Accuracy of measurements: Under evaluation

Results (1): Measurable CTE range and materials

- Alumina
- SiC

} several ppm/ °C

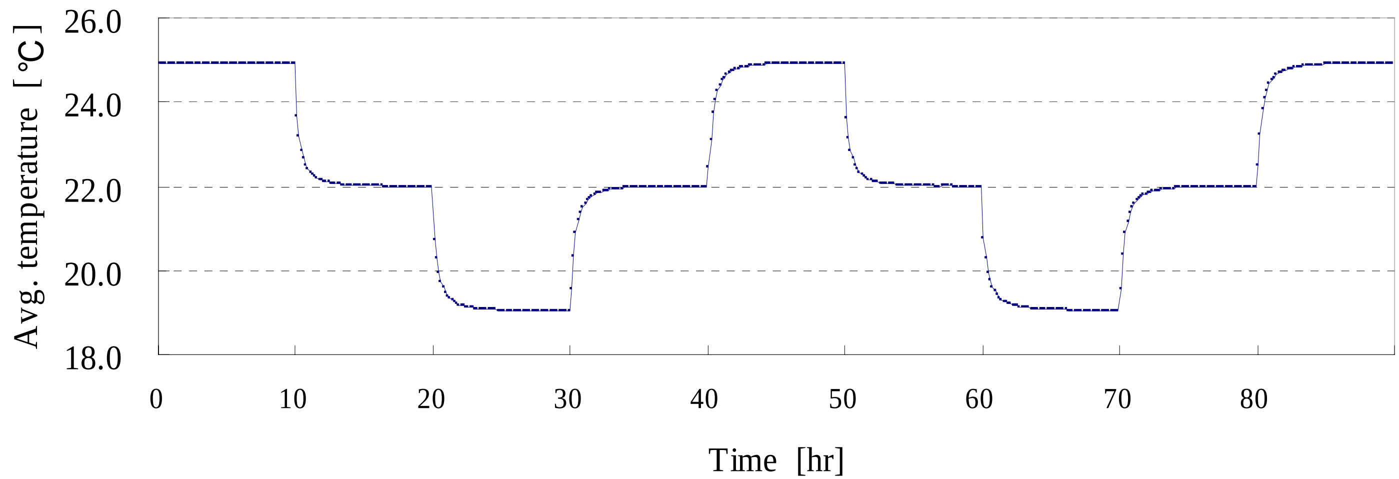
- Silica glass → hundreds ppb/ °C
- Ti-doped silica glass (LTEM)
- Glass ceramics (LTEM)

<u>CTE-01 can handle a wide variety of materials</u>

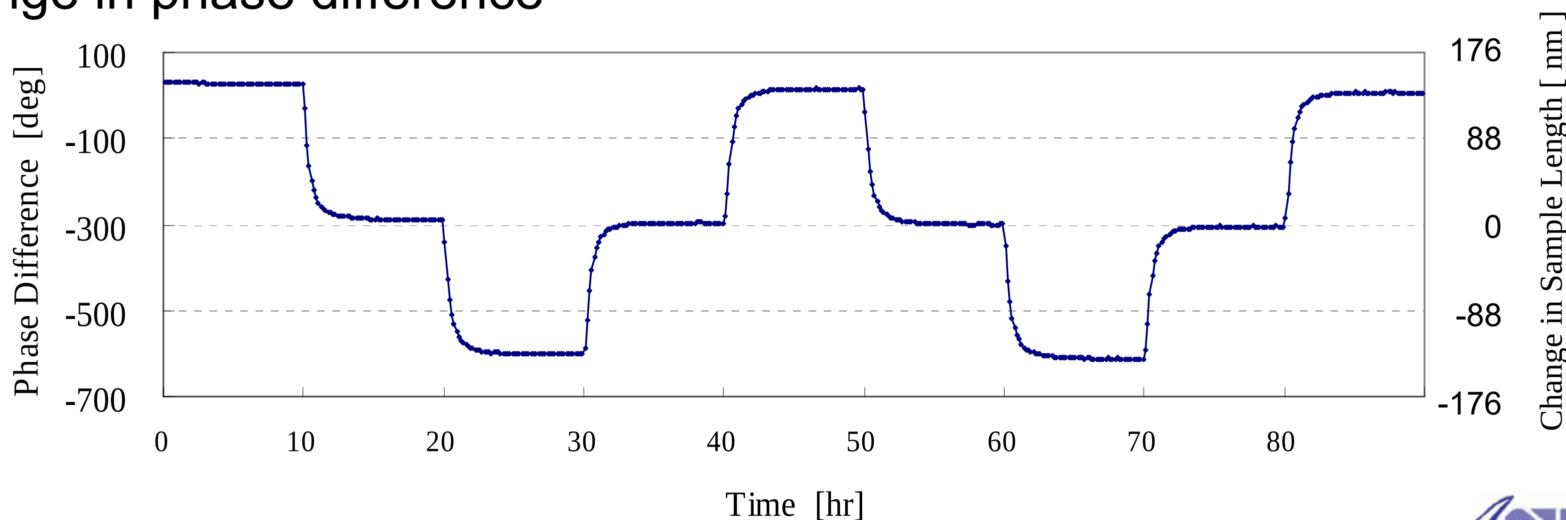
<u>Measurable CTE range: from ppm/°C to ppb/°C</u>

Results (2): Measured CTE of Silica Glass

Change in sample temperature



Change in phase difference



Results (2): Measured CTE of Silica Glass

Results of measurement f o r CTE of silica glass

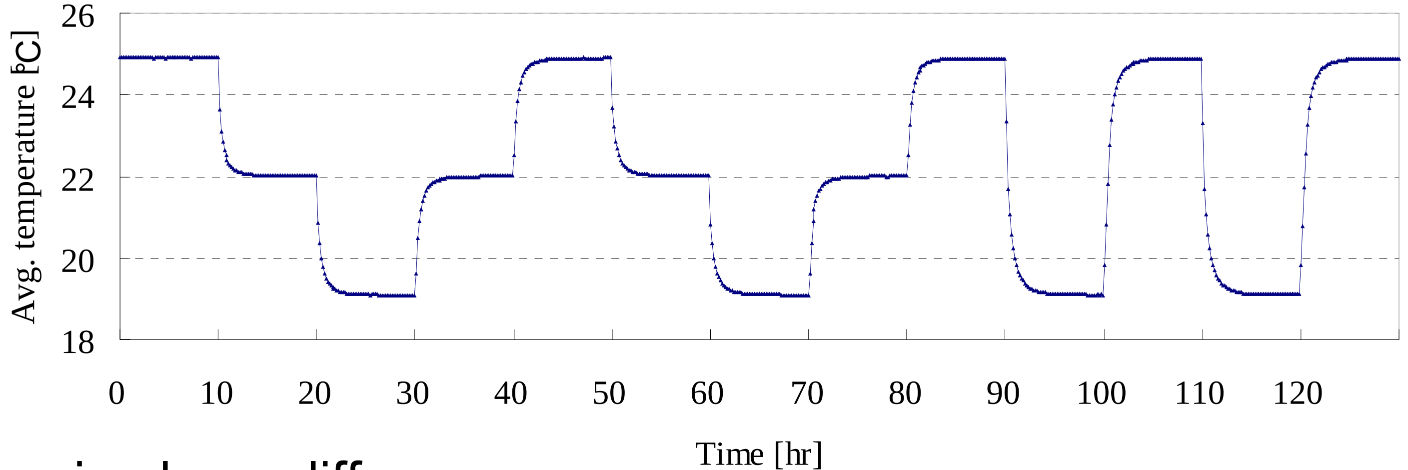
[ppm/° C]

T1	T2	Meas.1	Meas.2	Δ (Meas.2-Meas.1)
19	22	0.460	0.464	0.004
22	25	0.470	0.471	0.001

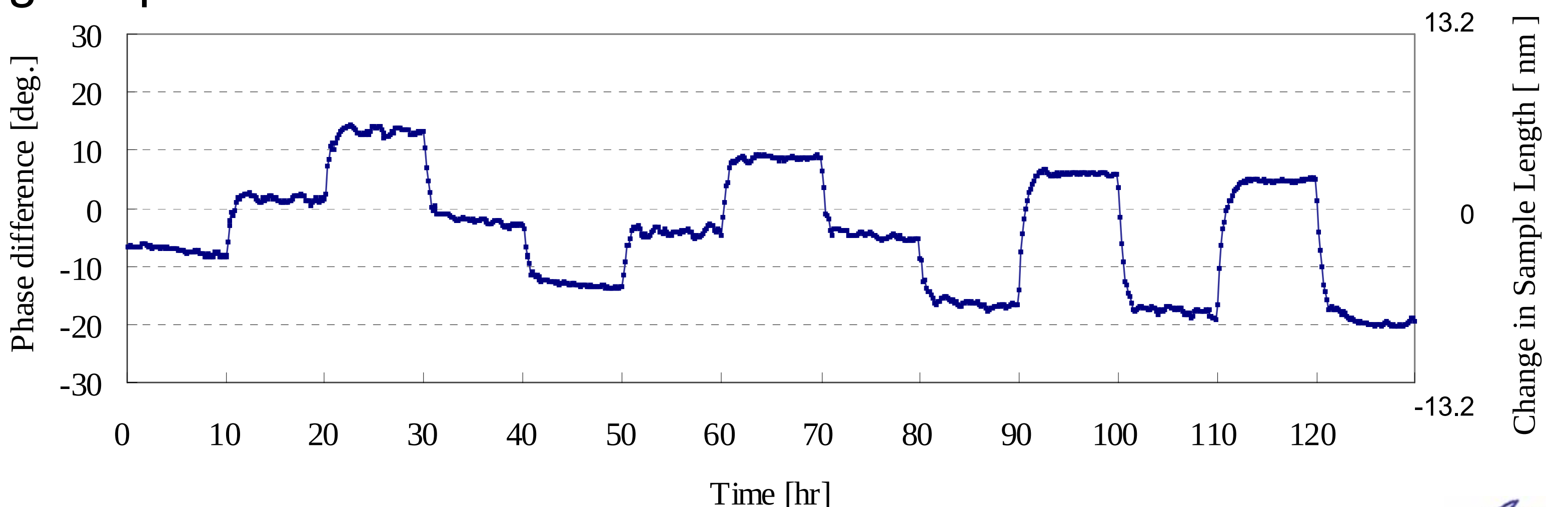
These values tell us that the measurement reproducibility is about several ppm per degree.

Results (3): # Measured CTE of Ti-doped silica glass

Change in sample temperature



Change in phase difference



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Results (3): # Measured CTE of Ti-doped silica glass

Results of measurement for CTE of LTEM

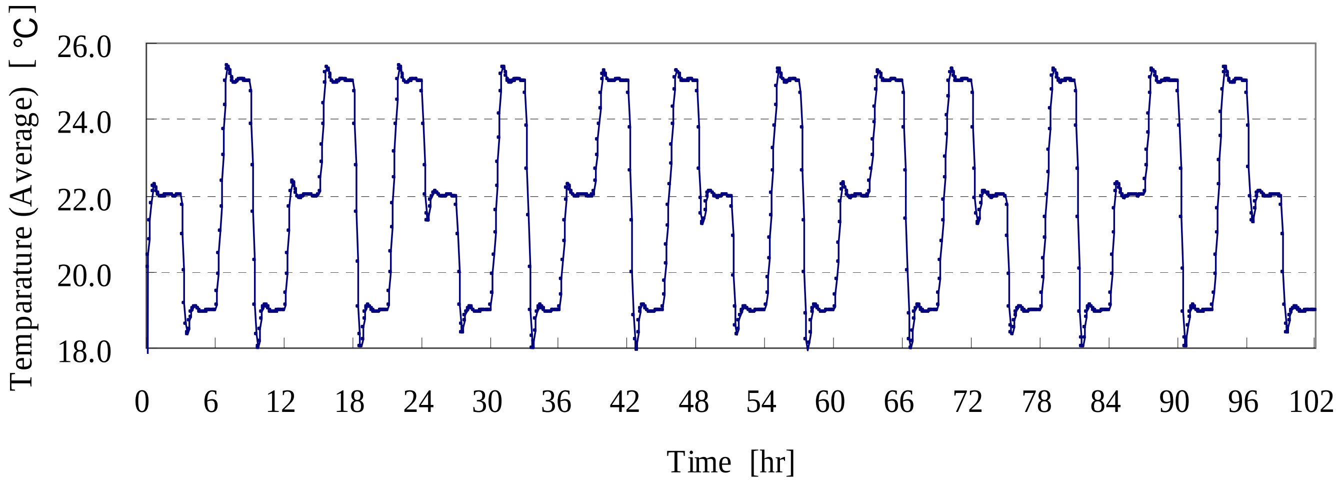
[ppb/˚ C]

T1	T2	Meas.1	Meas.2	Δ (Meas.2-Meas.1)
19	22	-19.95	-19.42	0.53
22	25	-13.06	-13.88	-0.83
19	25	-17.32	-17.68	-0.36

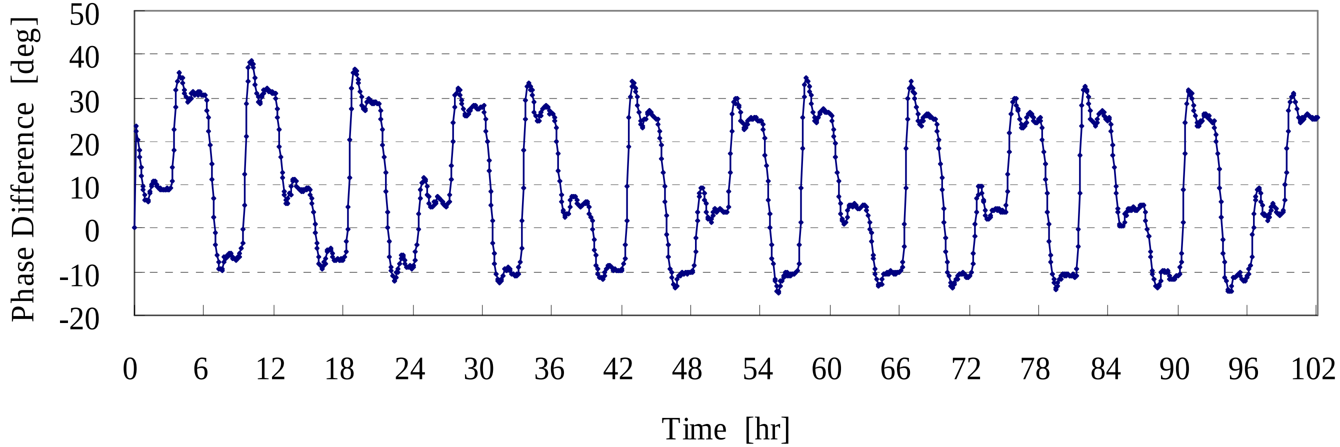
These values indicate that the measurement reproducibility is less than 1 ppb per degree.

Results (4): Reproducibility of Measurements

Change in sample temperature



Change in phase difference



Results (4): # Reproducibility of Measurements

Calculated CTE values (Test No.1)

S/N	Preset temperature		Actual temperature		T	CTE
	T1	T2	T1	T2		
1	19	25	18.996	25.016	22.006	−27.657
2	25	19	25.016	19.006	22.011	−27.921
3	25	19	25.013	18.999	22.006	−26.339
4	19	25	18.999	25.020	22.009	−27.600
5	19	25	19.002	25.017	22.009	−28.142
6	25	19	25.017	19.005	22.011	−27.604
7	25	19	25.019	19.007	22.013	−25.765
8	19	25	19.007	25.030	22.019	−26.111
9	19	25	19.001	25.023	22.012	−25.793
10	25	19	25.023	19.005	22.014	−27.068
11	25	19	25.017	19.002	22.009	−26.004
12	19	25	19.002	25.019	22.010	−26.583
13	19	25	18.988	25.026	22.007	−25.873
14	25	19	25.026	19.002	22.014	−26.551
15	25	19	25.010	19.001	22.005	−26.534
16	19	25	19.001	25.008	22.004	−26.891

Average: -26.8 ppb/°C , σ: 0.80 ppb/°C

Results (4): # Reproducibility of Measurements

Reproducibility of measurements

[ppb/° C]

Test No.	No. 1	No. 2	No. 3
n	16	12	16
σ	0.80	0.68	0.70
2σ	1.60	1.37	1.39
3σ	2.40	2.05	2.09
Average	-26.8	-25.6	-27.3

Repeatability

σ: 0.80 ppb/°C

Resetability

ΔCTE: ±0.85 ppb/°C

Repeatability (Static) :
reproducibility obtainable from measurements of the same sample without moving it .

Resetability (Dynamic) :
reproducibility obtainable from measurements involves changing the sample.

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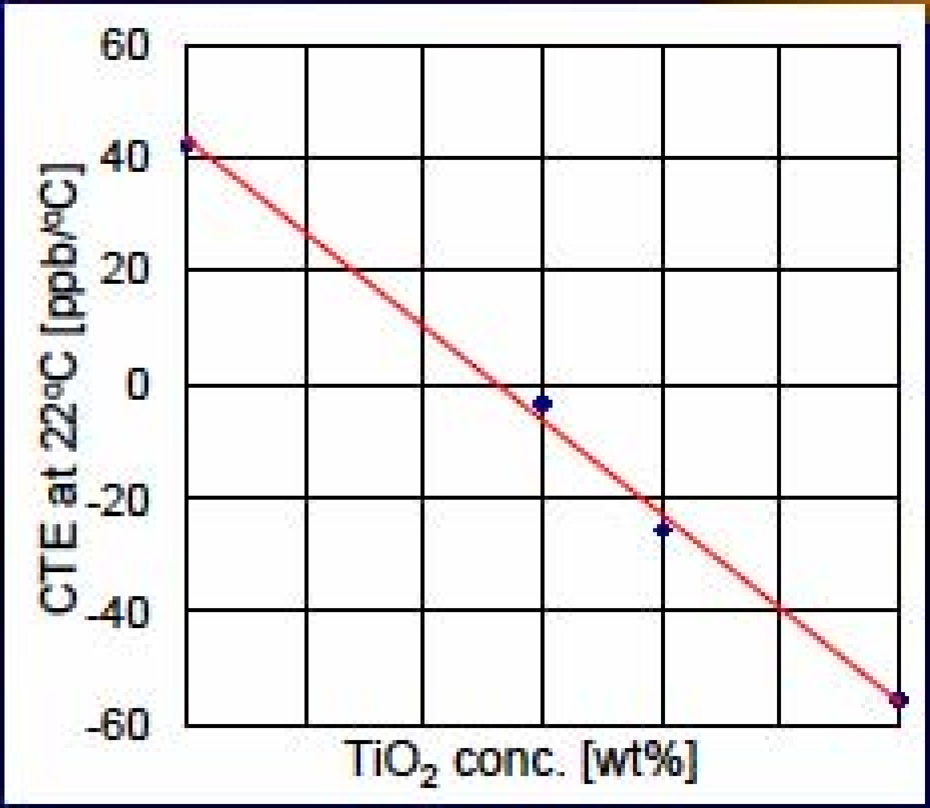
Results (5): Case of CTE Measurements

Tuesday, November 8

Development of Zero Expansion Glass for EUVL Substrate

Optimization CTE to zero

Newly developed dilatometer at *ASET*



- CTE of our low thermal expansion materials (=LTEM) have measured by newly developed dilatometer at ASET.
- We have demonstrated that CTE at 22ºC is in proportion to TiO_2 concentration in our LTEM.
- We have optimized CTE to 0+/-5 ppb/ºC by adjusting TiO_2 concentration.

5. Summary

Summary

- An optical heterodyne interferometric dilatometer (CTE-01) tailored to meet EUVL requirements has been developed.

- The CTE-01 can handle a wide variety of materials, including LTEMs.

- Reproducibility of data

  Repeatability, σ: < 1 ppb/°C

  Resetability, ΔCTE: < $\pm$1 ppb/°C

  These values meet the target specifications.

- We confirm that the CTE-01 will be useful for the precise measurement of the CTEs of EUVL-grade LTEMs.