Accuracy of the ASET Dilatometer for Low Thermal Expansion Materials

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Acknowledgement

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Outline

1. Background

2. Methodology Principle & design of the dilatometer

3. Results Performance of the dilatometer

Repeatability, Resetability, Accuracy

4. Status of user use

5. Summary

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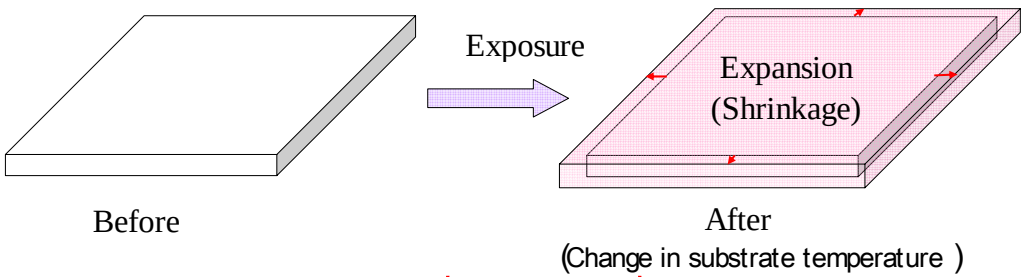
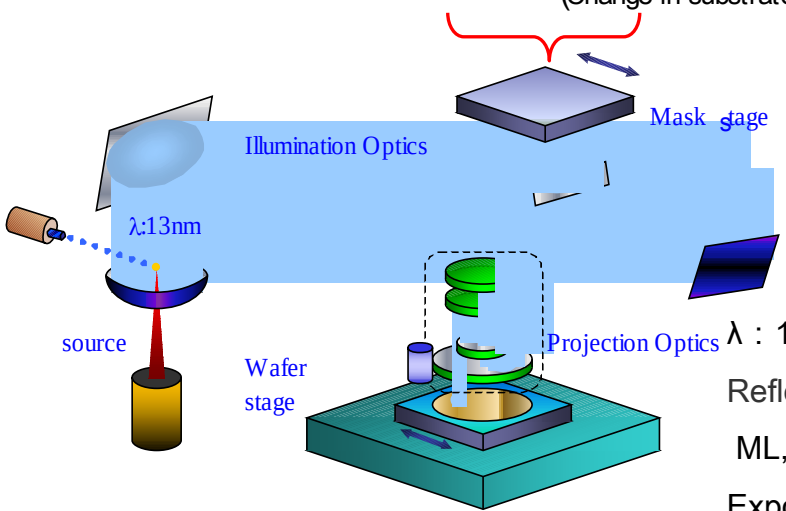
Background (1): CTE Requirement

CTE: Coefficient of Thermal Expansion

Exposure deforms mask.





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): CTE Metrology Development Project

LTEM suppliers

AGC
TOSOH
OHARA
NIHON CERATEC
ShinEtsu
TOSHIBA CERAMICS CO., LTD.
TOSHIBA

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

Background (3): 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

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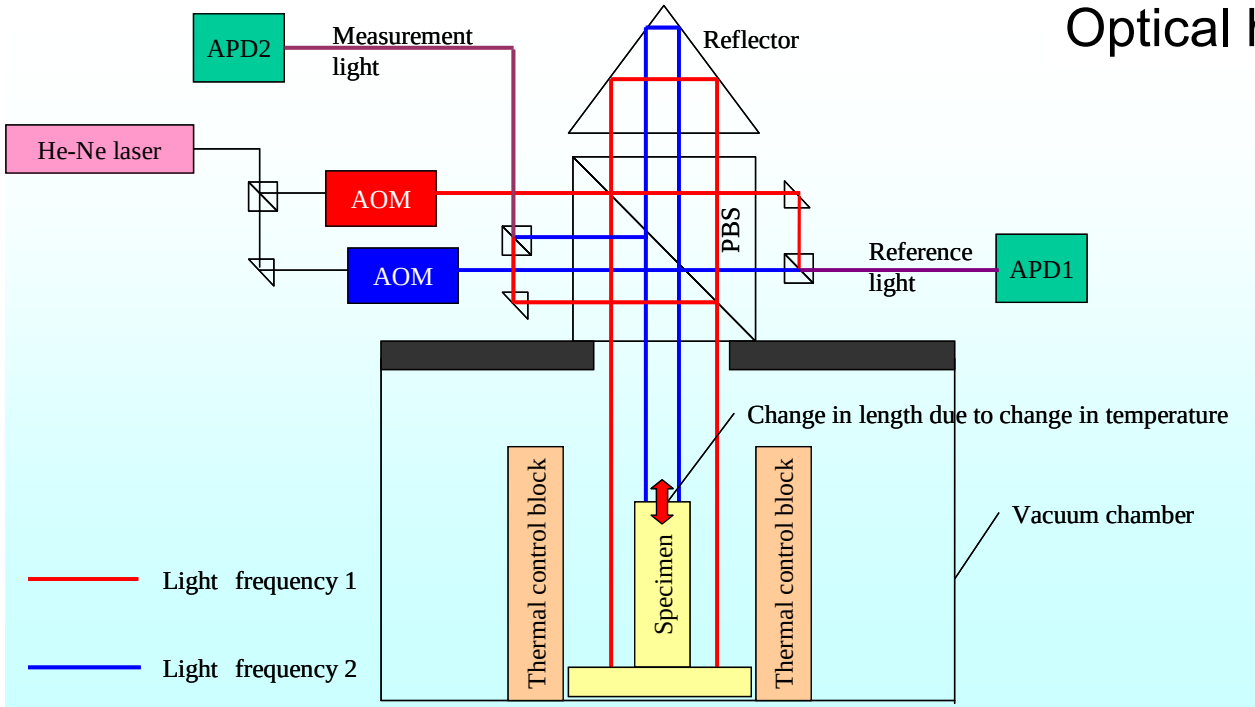
Methodology (1): Principle of Measurement



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

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

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

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

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

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

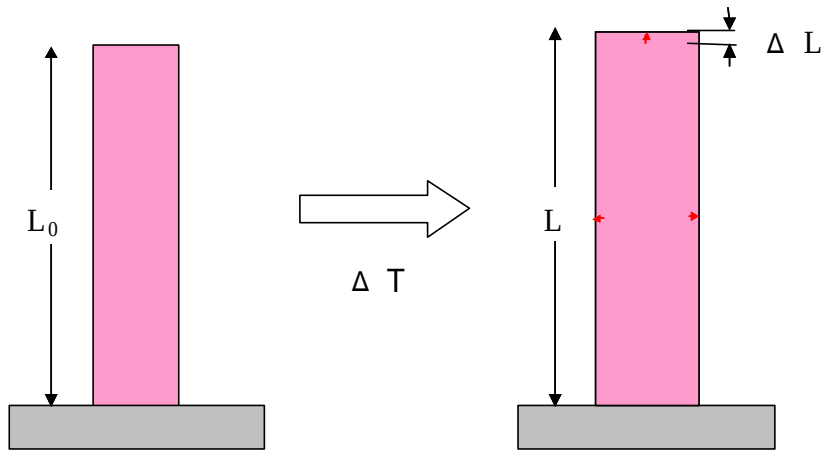
Change in phase difference between T_1 and T_2 :

$$\Delta(\phi_{APD2} - \phi_{APD1}) = \frac{2\pi \Delta L}{\lambda}$$

ΔL : Change in length

(Quadruple - sensitivity)

Methodology (2): CTE Calculation



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

Consideration of error factors

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

α : low

Determination of sample length

This term has little influence.

Determination of change in sample length due to thermal expansion

This term has a large influence.

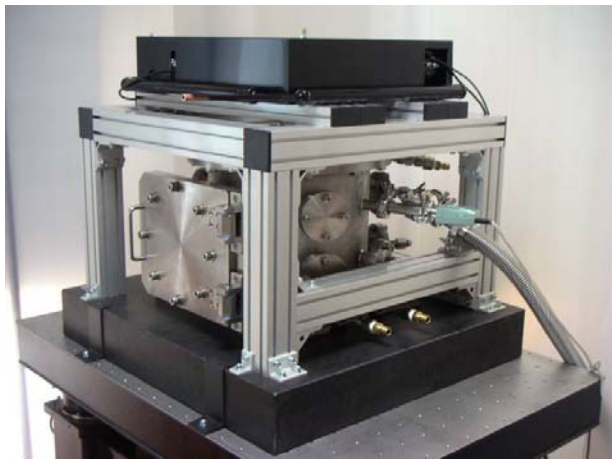
Stability of thermo control and determination of temperature

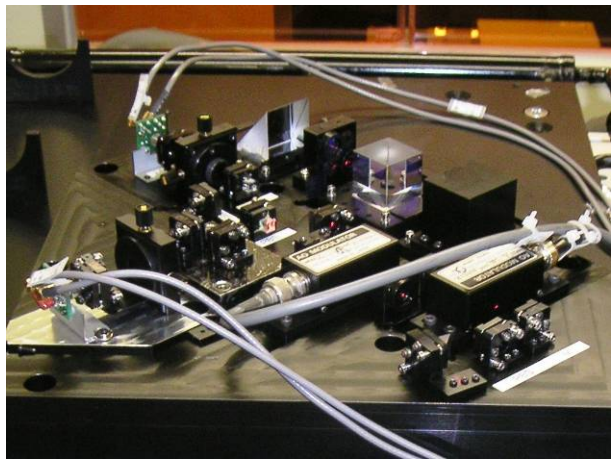
This term has little influence.

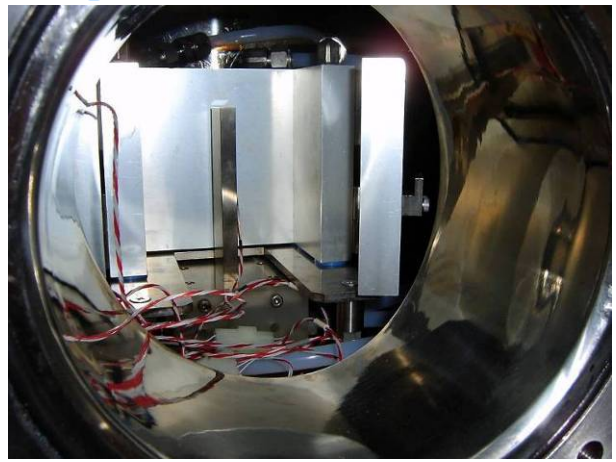
Methodology (3): ASET's Dilatometer

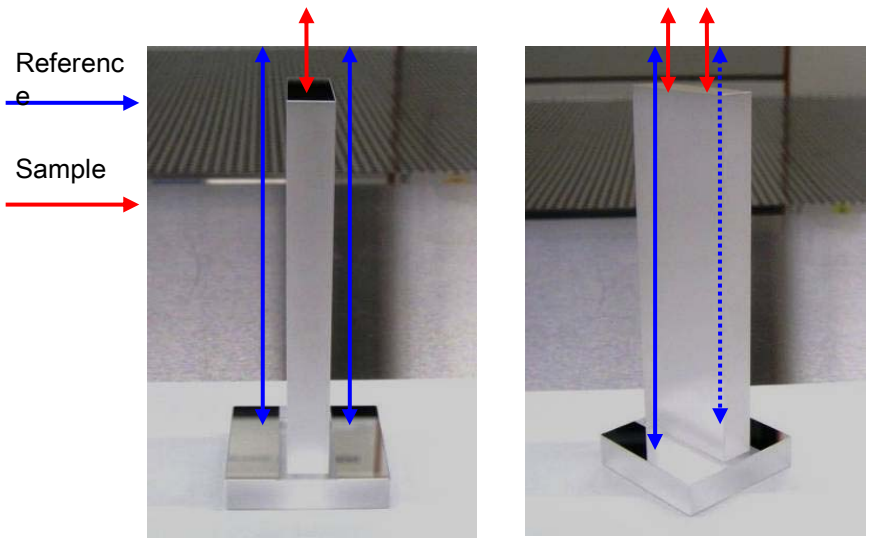
CTE-01

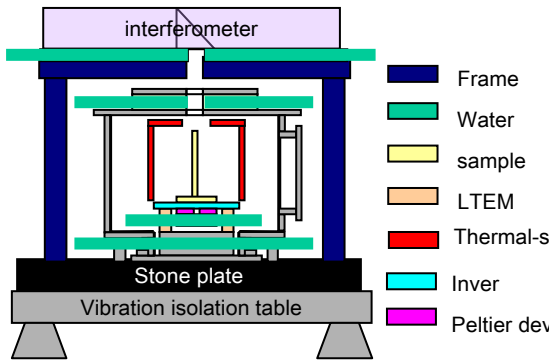
Equipment supplie uniopt



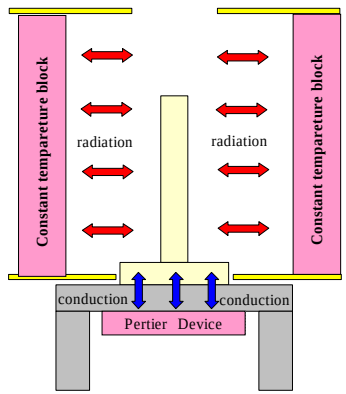






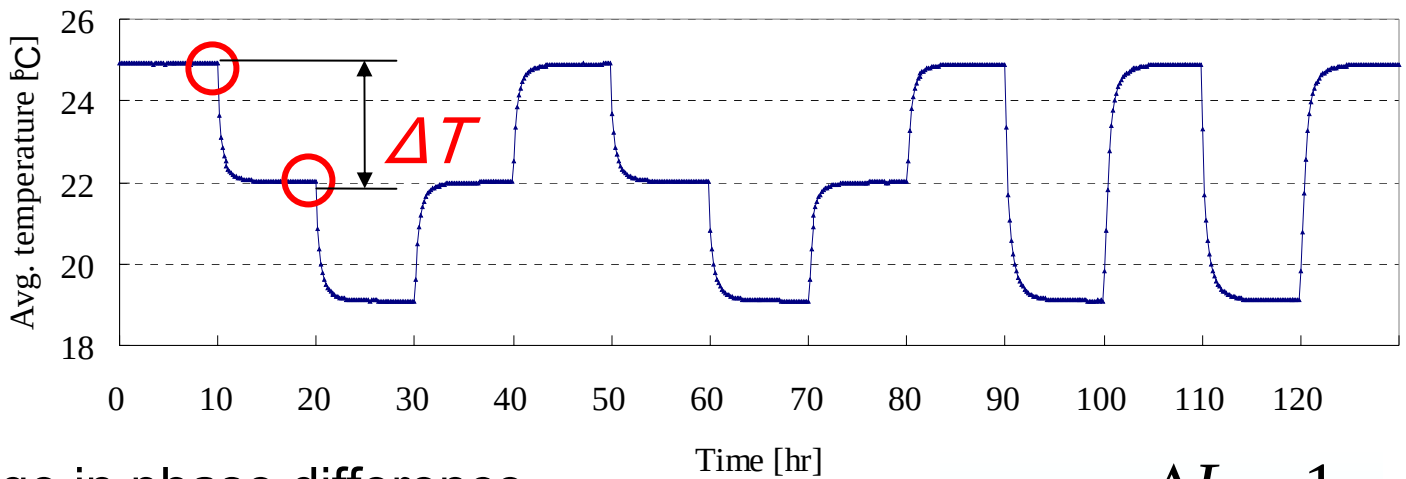


Structure of dilatometer



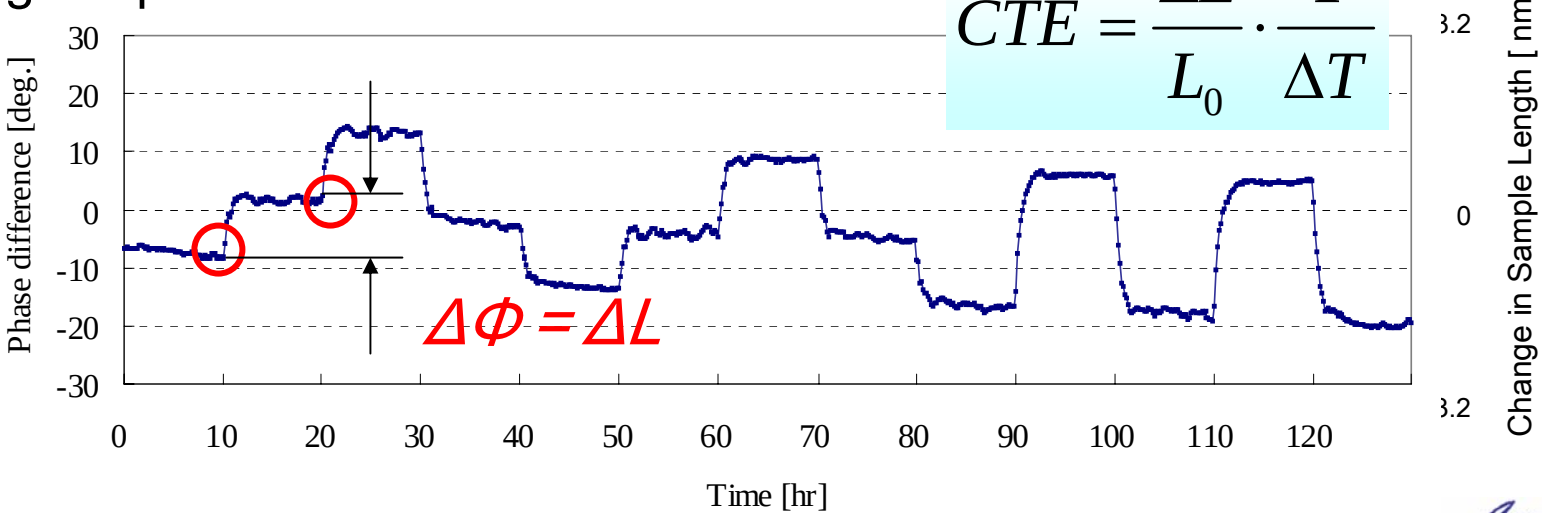
Methodology (4): Example of Data Ti-doped silica glass

Change in sample temperature



Change in phase difference

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



1. Background

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Performance of the dilatometer

Repeatability, Resetability, Accuracy

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5. Summary

Results (1): Evaluation Items

- Reproducibility

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

  Resetability (Dynamic) :

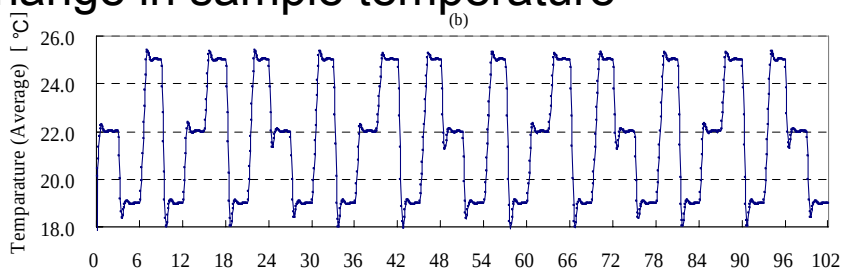
  Reproducibility obtainable from measurements involves changing the sample

- Accuracy

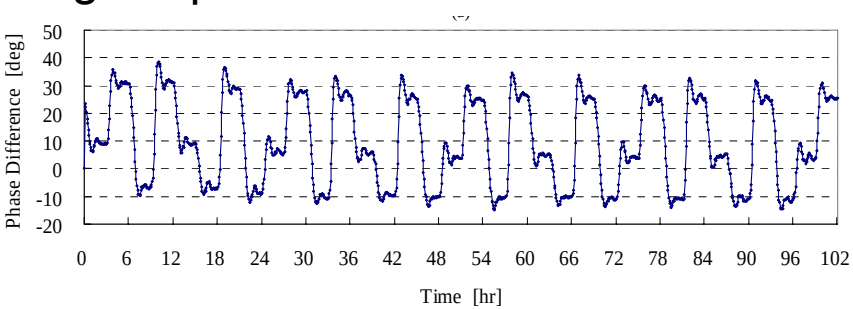
  Comparison with AIST's measurements

Results (2): Reproducibility of Measurements

Change in sample temperature



Change in phase difference



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

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

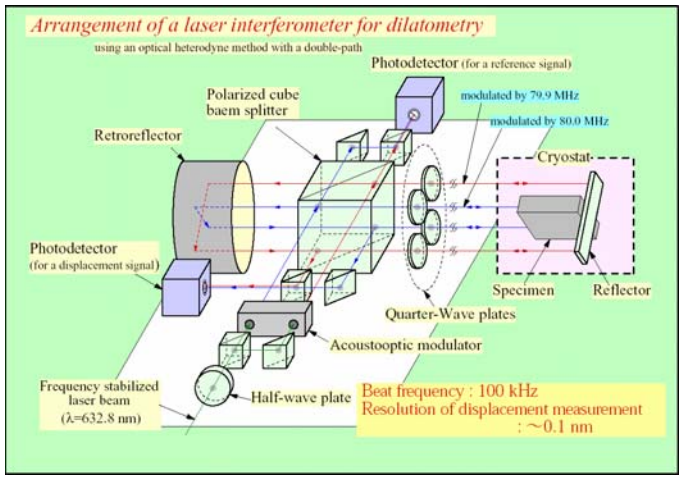
Repeatability

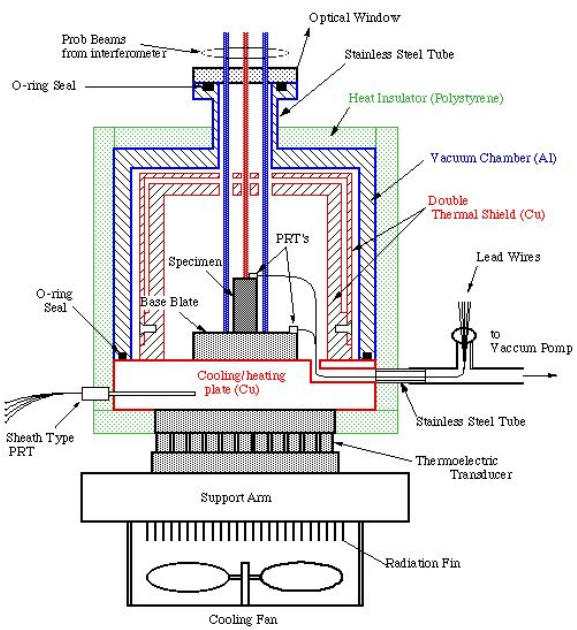
σ: 0.80 ppb/°C

Resetability

ΔCTE: ±0.85 ppb/°C

Results (3): AIST's Dilatometer





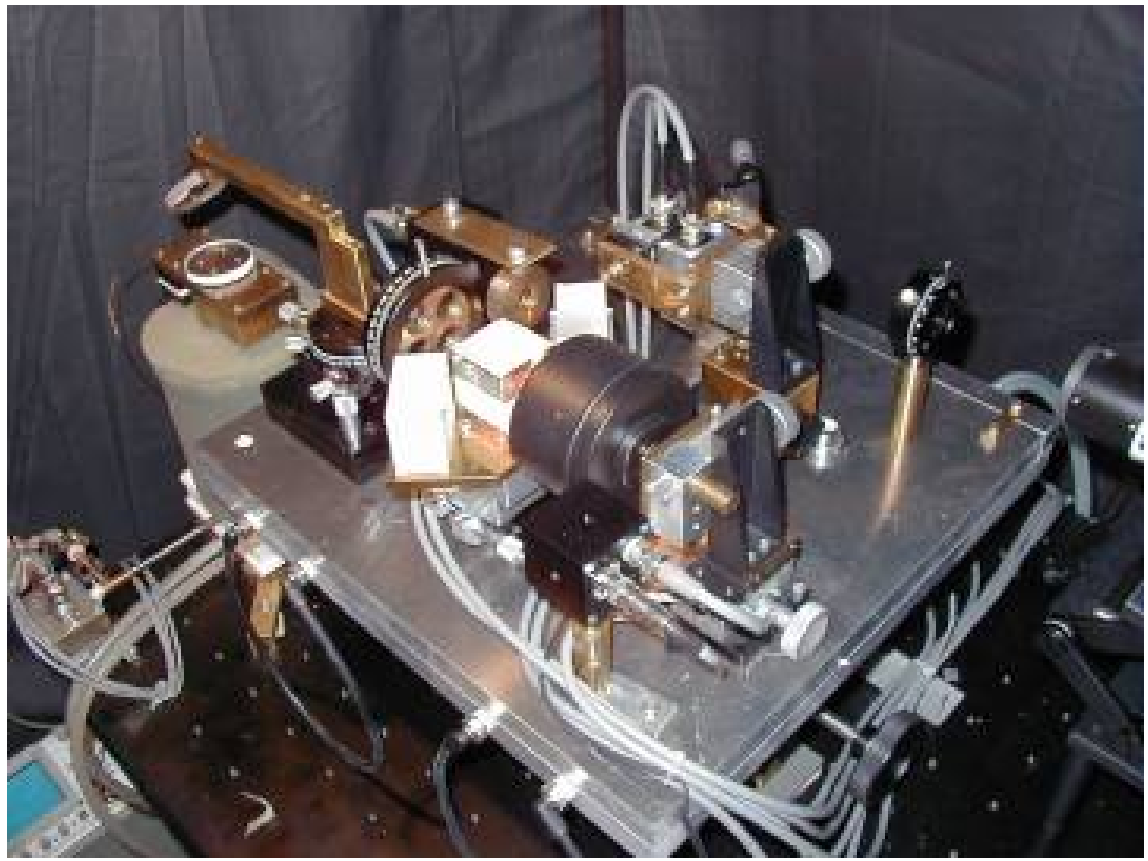
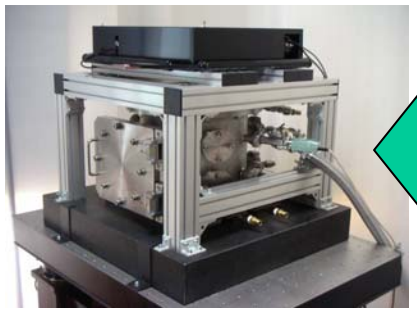
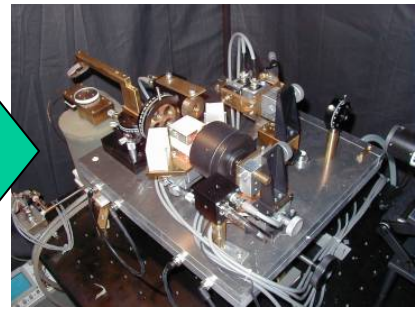


Fig. The high precision CTE measurement equipment at AIST.

Results (4): Accuracy of Measurements





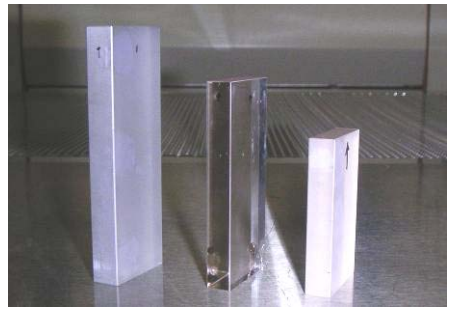


Table. Comparison with AIST Measurement.

[ppb/ ℃]

Sample	ASET	AIST	Expanded Uncertainty (AIST)	Difference (ASET - AIST)	Remarks
Quartz	460.3	461.3	2.3	-1.0	18-22˚C, Δ T :4˚C
LTEM-A	2.0	2.3	1.2	-0.3	19-25˚C, Δ T :6˚C
LTEM-B	8.3	9.6	1.1	-1.3	19-25˚C, Δ T :6˚C

The differences are in the AIST's uncertainty range.
We've verified the accuracy of the ASET's dilatometer.

Results (5): Summary of the evaluation results

Table. Summary of the evaluation results for the dilatometer

Evaluation Items		Target	Results	Evaluation
Resolution (10-cm-long specimen)		< 1 ppb/ ℃	< 0.35 ppb/ ℃	Good
Reproducibility	Static (σ)	< 1 ppb/ ℃	< 0.80 ppb/ ℃	Good
	Resetability (Δ CTE)	-------	< ± 0.85 ppb/ ℃	Good
Accuracy	Comparison with AIST	-------	< 1.3 ppb/ ℃ (within the expanded uncertainty)	Good

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User use (1): Asahi Glass Co., Ltd.

AGC has been developing

Low Thermal Expansion Material for EUVL substrate.

Material : AZ (TiO_2-SiO_2 glass)

Target of CTE property: 0+/- 5 ppb/^oC (at 19-25^oC)

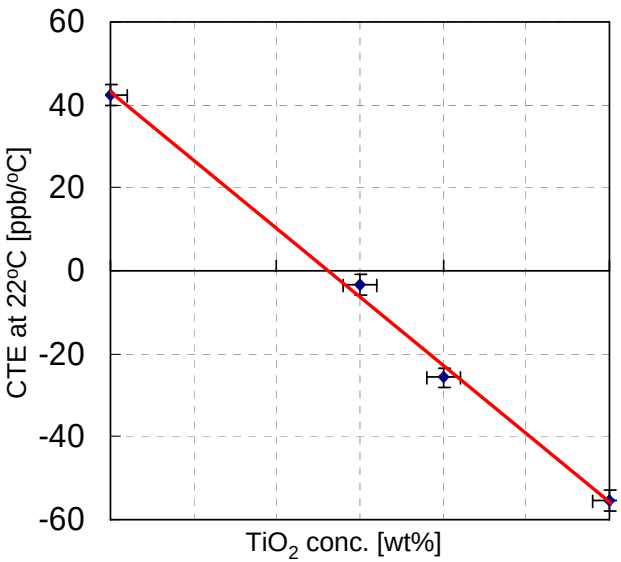


Fig.: Dependence of CTE on TiO2 conc. in AGC's LTEM

AGC had investigated the dependence of CTE on TiO_2 conc. in their LTEM using ASET's dilatometer and they demonstrated the CTE at 22^oC is in proportion to TiO_2 concentration.

The CTE can be optimized to 0+/-5 ppb/^oC by the relationship between the CTE and TiO_2 conc.

Poster Session

Development of Low Thermal Expansion Material and CTE measurement tool for EUVL

User use (2): TOSHIBA CERAMICS CO., LTD.

T/C's LTEM Product Development Target (6025 Sub. material)

Mean CTE : ±5ppb/deg K

CTE Spatial Variation : + 6ppb/deg K

Now in Development

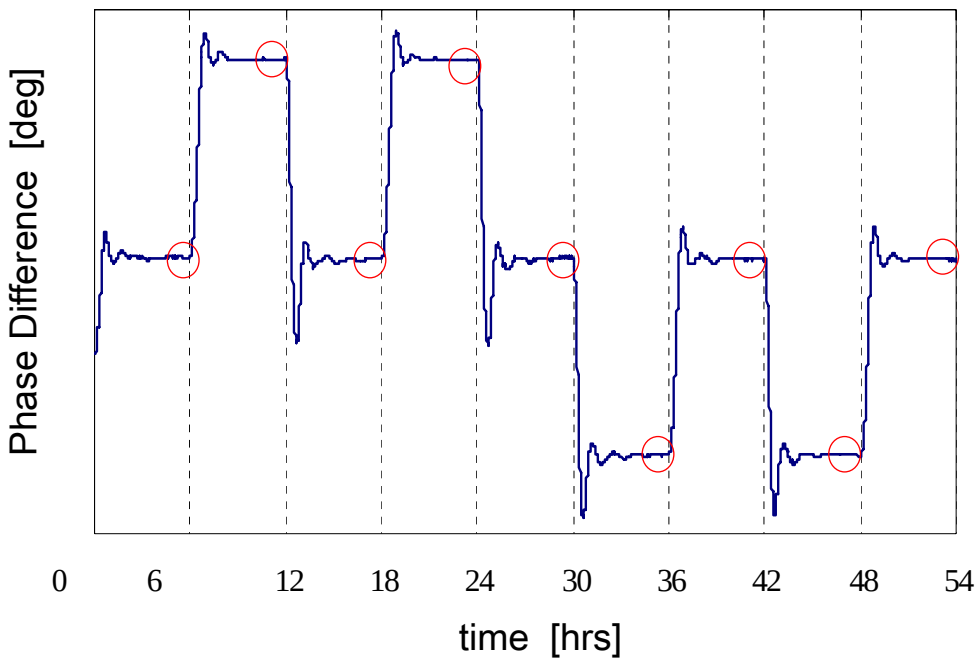


Fig. Change in phase difference

Static Measurement Stability

Change in Phase difference :
$\Delta\theta = 0.2°$(Fig.1 red circle)

Equipment resolution is good enough for LTEM CTE measurement!!

TOSHIBA CERAMICS CO., LTD.

User use (3): NIHON CERATEC CO., LTD.

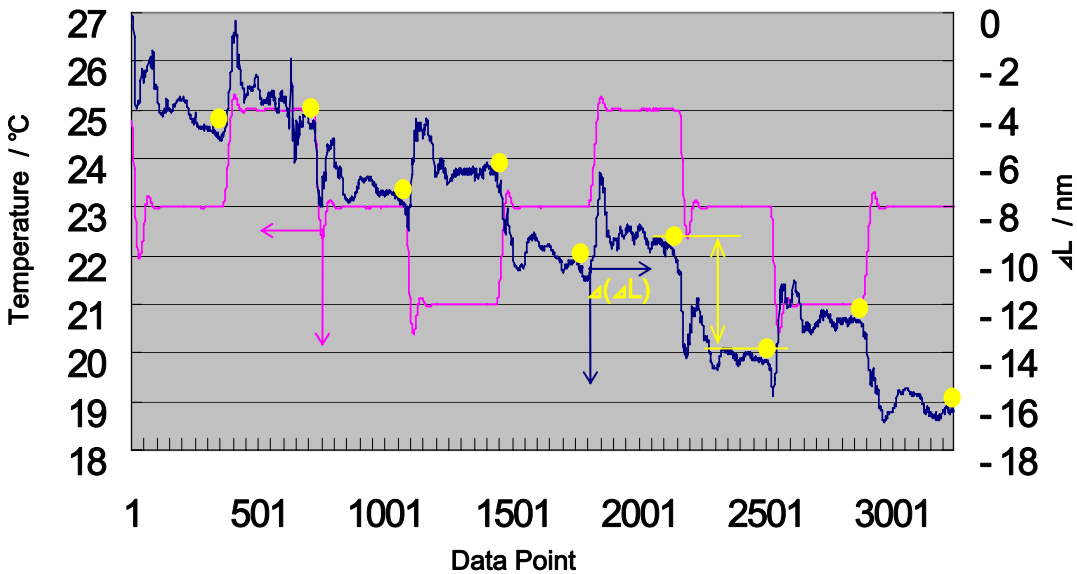
Material

ZPF (Zero thermal expansion Pore Free ceramics)

Feature : ①Low thermal expansion, ②High stiffness(150GPa), ③Pore Free

Application : Parts for equipments of LSI manufacturing (Mirror, Chuck, etc)

Measured Data



(Sample Length : 100.0 mm)

Result

(1)23 to 25 ℃

14ppb/ ℃

(2)21 to 23 ℃

-14ppb/ ℃

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Summary

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

  Repeatability, σ:<1ppb/°C, Resetability, ΔCTE:<$\pm$1ppb/°C

  These values meet the target specifications.
- Accuracy of data

  The differences are in the AIST's uncertainty range.

  We'e verified the accuracy of the ASET's dilatometer.
- LTEM supplier have started CTE evaluation by ASET's dilatometer.
- The CTE-01 will be commercialized from next year. We confirm that i t will accelerate LTEM development.