Available online at www.sciencedirect.com
SCIENCE DIRECT®

ELSEVIER

Microelectronic Engineering 83 (2006) 1617–1620

MICROELECTRONIC ENGINEERING

www.elsevier.com/locate/mee

Performance of dilatometer for determining absolute CTE of EUVL LTEMs

Yoshimasa Takeichi [a,*], Iwao Nishiyama [a], Naofumi Yamada [b,c,*]

[a] *ASET EUV Process Technology Research Laboratory, 3-1 Morinosato Wakamiya, Atsugi-shi, Kanagawa 243-0198, Japan*
[b] *National Institute of Advanced Industrial Science and Technology, AIST Central-3, 1-1-1 Umezono, Tsukuba-shi, Ibaraki 305-8563, Japan*
[c] *National Metrology Institute of Japan, AIST Central-3, 1-1-1 Umezono, Tsukuba-shi, Ibaraki 305-8563, Japan*

Abstract

An optical heterodyne interferometric dilatometer, which was specially designed to meet the requirements of extreme ultraviolet lithography (EUVL), has been developed. It employs an interferometer to measure the absolute coefficient of thermal expansion (CTE), which means that it directly measures the change in sample length. An examination of its capabilities revealed that it can handle a wide variety of materials with a coefficient of thermal expansion (CTE) ranging from ppm/°C to ppb/°C. In addition, it was found that the reproducibility of CTE measurements (σ) on low-thermal-expansion materials (LTEM) for EUVL was less than 1 ppb/°C. Thus, it was concluded that this dilatometer would be useful for the precise measurement of the CTEs of EUVL-grade LTEMs.

Keywords: Optics; Mask substrate; CTE; LTE; Optical heterodyne interferometer

---

1. Introduction

In order to eliminate errors in printed patterns caused by the thermal expansion of the optics and mask substrate, EUVL requires a material with an ultralow CTE. More specifically, the SEMI standards (P37-1102) specify the CTE of a class-A mask substrate to be less than ±5 ppb/°C for a temperature range of 19–25 °C. So, we need a measurement resolution of 1 ppb/°C. This is equivalent to a 0.1 nm change in the length of a 10 cm-long sample.

The increasing interest in EUVL has led many material suppliers to launch LTEM development projects. However, the fact that there are no commercial dilatometers with a measurement resolution of 1 ppb/°C is an obstacle to research in this field. So, a strong demand has arisen among LTEM suppliers for a metrology that meets EUVL requirements. Based on this, we formed a CTE metrology development team in cooperation with the National Institute of Advanced Industrial Science and Technology (AIST), and companies interested in EUVL LTEMs: Asahi Glass Co. Ltd., Ohara Inc., Kyosera Corp., Shin-Etsu Chemical Co. Ltd., Toshiba Ceramics Co. Ltd., Tosoh Corp., and Nihon Ceratec Co. Ltd. The goal was the development of a practical dilatometer with a resolution of 1 ppb/°C and a measurement reproducibility (σ) of 1 ppb/°C as a foundation for further LTEM research.

2. Methodology

The CTE, α, in units of inverse degrees centigrade is given by

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

where L_0 is the initial sample length, ΔT is the change in sample temperature, and ΔL is the change in sample length.

Since our focus is on CTE metrology for LTEMs, we need to measure very small changes in length. This led to the selection of the double-path optical heterodyne interferometric technology developed by AIST [1]. The system

---

[*] Corresponding authors. Tel.: +81 46 270 6688; fax: +81 46 270 6699 (Y. Takeichi).
E-mail address: takeichi@aset-euv.jp (Y. Takeichi).

0167-9317/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.mee.2006.01.244

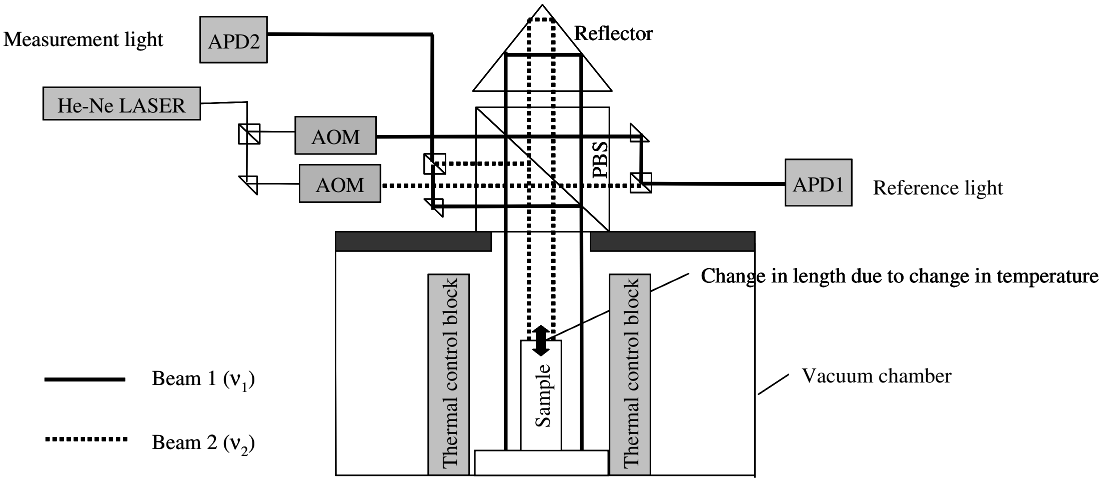

Fig. 1. Schematic diagram of double-path optical heterodyne interferometric dilatometer.

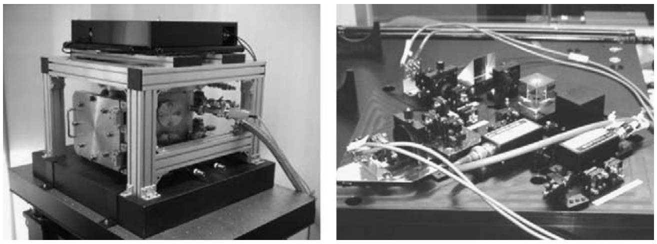

Fig. 2. Photographs of double-path optical heterodyne interferometric dilatometer: (left) vacuum chamber and interferometer and (right) interferometer.

is based on two key technologies. One is an optical heterodyne interferometer, which is the type of interferometer that provides the highest resolution [2–5] because it detects a change in sample length as a phase difference in light. The other is a double-path interferometer, which increases the sensitivity to changes in length by a factor of four and cancels out the tilt of a sample. Fig. 1 shows a schematic diagram of the dilatometer.

The beam from a He–Ne laser is split into two beams, and the frequency of each is modulated with an acousto–optic modulator (AOM). Each of these beams is again

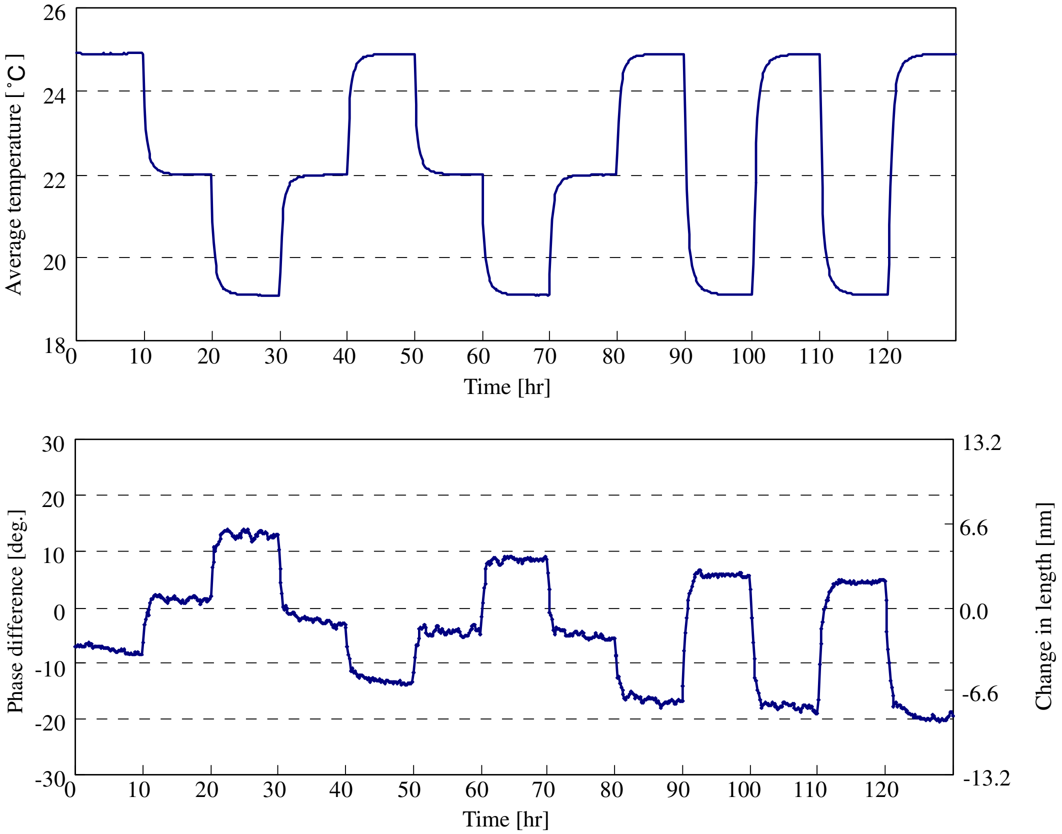

Fig. 3. CTE measurement data for LTEM: (top) change in sample temperature and (bottom) change in phase difference.

Table 1
Results for two measurements of CTE of LTEM

*T*1 (°C)	*T*2 (°C)	Meas. 1 (ppb/°C)	Meas. 2 (ppb/°C)	Meas. 2–Meas.1 (ppb/°C)
19	22	−19.95	−19.42	0.53
22	25	−13.06	−13.88	−0.83
19	25	−17.32	−17.68	−0.36

split, yielding two pairs of beams. One pair is fed into an avalanche photodiode (APD1), producing a beat-signal with a constant phase. Regarding the other pair, one beam strikes the surface of the sample; and the other strikes the surface of the reference surface. These beams are fed into APD2 and produce a beat signal containing information on the phase change that accompanies a temperature change. If we measure the phase difference between the two signals, $\varphi_{\mathrm{APD2}} - \varphi_{\mathrm{APD1}}$, at two temperatures; *T*1 and *T*2, then we can obtain the change in sample length, ΔL, from the following equation:

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

The left side means the change in the phase difference between $(\varphi_{\mathrm{APD2}} - \varphi_{\mathrm{APD1}})_{T1}$ and $(\varphi_{\mathrm{APD2}} - \varphi_{\mathrm{APD1}})_{T2}$. The design of the dilatometer has been optimized to yield a high accuracy and good measurement reproducibility by taking uncertainty factors and their contributions into account [6]. A prototype (Fig. 2) was constructed in accordance with this design.

3. Results

To test the capabilities of the dilatometer, we measured the CTEs of various materials: alumina; SiC, which has a CTE of several ppm/°C; commercial silica glass, which has a CTE of hundreds of ppb/°C; titanium-doped silica glass; and glass ceramics, which are candidates for EUVL LTEMs. All the measurements were successful, which means that our dilatometer can handle a wide variety of materials and CTEs ranging from ppm/°C to ppb/°C.

The temperature of titanium-doped silica glass was cycled in steps through 25 °C, 22 °C, and 19 °C; and the change in phase difference, $\varphi_{\mathrm{APD2}} - \varphi_{\mathrm{APD1}}$, was recorded at each step. Fig. 3 shows (top) the change in sample temperature and (bottom) the change in phase difference. The holding time at each temperature was 10 h. Clearly, the steps in the change in phase difference reflect the step-wise changes in the temperature of the sample. The CTE was calculated from the change in phase difference for each change in temperature, and the results are shown in Table 1. The average CTE for the temperatures 19 °C and 22 °C was measured twice and was found to be −19.95 ppb/°C

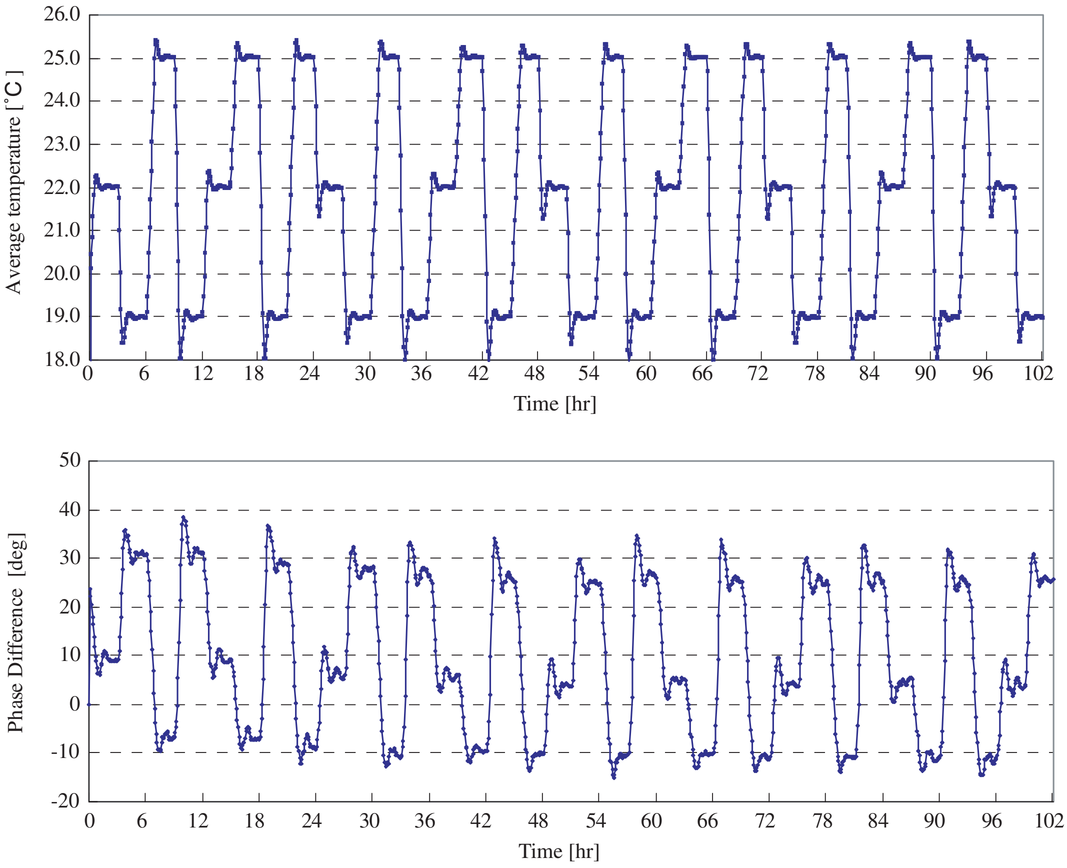

Fig. 4. CTE measurement data for LTEM: (top) change in sample temperature and (bottom) change in phase difference.

Table 2
Reproducibility of CTE measurement for LTEM

Test no.	N	σ (ppb/°C)	Average (ppb/°C)
1	16	0.80	−26.8
2	12	0.68	−25.6
3	16	0.70	−27.3

Table 3
Summary of evaluation results for the dilatometer

Evaluation items	4Target	Results	Evaluation
Resolution (10 cm-long specimen)	<1 ppb/°C	<0.35 ppb/°C	Good
Reproducibility static: (σ)	<1 ppb/°C	<0.80 ppb/°C	Good
Resetability dynamic: (ΔCTE)	–	<0.85 ppb/°C	Good
Accuracy Comparison with AIST	–	Under evaluation	–

and –19.42 ppb/°C, which yields a difference of 0.53 ppb/°C. And for the temperatures 22 °C and 25 °C and the temperatures 19 °C and 25 °C, the differences were –0.83 ppb/°C and –0.36 ppb/°C, respectively. These values indicate that the reproducibility of the measurements is very good.

Subsequently, a more detailed evaluation of the reproducibility of CTE measurements for titanium-doped silica glass was performed. The temperature of the sample was cycled 16 times between 19 °C and 25 °C, and the changes in phase difference were recorded. Fig. 4 shows (top) the change in sample temperature and (bottom) the change in phase difference. We made three sets of measurements, and the results are listed in Table 2. In Test 1, we made 16 measurements on the same sample without moving it, and obtained a static measurement reproducibility (σ) of 0.80 ppb/°C. In Tests 2 and 3, we repeatedly removed the sample, reset it, and made a measurement. This yielded σ's of 0.68 ppb/°C and 0.70 ppb/°C, respectively.

The variation in average CTE for each test represents the dynamic measurement reproducibility, or in other words the resetability, which means the reproducibility of data measured before and after a sample is reset. The value is ±0.85 ppb/°C.

4. Summary

We have developed an optical-heterodyne-interferometric dilatometer tailored to meet EUVL requirements. It is capable of accurately measuring the absolute CTEs of a wide variety of materials, including LTEMs. It can handle CTEs ranging from ppm/°C to ppb/°C.

The main results of the evaluation of the dilatometer performance are listed in Table 3. Although the evaluation results for resolution were not mentioned above, it is limited by the phase measurement resolution of the lock-in amplifier; and we obtained a resolution of 0.35 ppb/°C for a change of 1 ppb/°C in the target. The static reproducibility (σ) is 0.80 ppb/°C or better for a change of 1 ppb/°C in the target. The resetability is ±0.85 ppb/°C or better. These values meet the target specifications. Regarding measurement accuracy, our data are now being compared with those obtained with the AIST dilatometer, the results will be reported in the near future. We feel confident that our dilatometer will be useful for the precise measurement of the CTEs of EUVL-grade LTEMs.

Acknowledgement

This work was supported by the New Energy and Industrial Technology Development Organization (NEDO).

References

[1] M. Okaji, N. Yamada, Metrologia 37 (2000) 165–171.
[2] M. Okaji, H. Imai, J. Phys. E: Sci. Instrum. 16 (1983) 1208–1213.
[3] M. Okaji, H. Imai, J. Phys. E: Sci. Instrum. 17 (1984) 669–673.
[4] M. Okaji, H. Imai, J. Phys. E: Sci. Instrum. 20 (1987) 887–891.
[5] M. Okaji, N. Yamada, K. Nara, H. Kato, Cryogenics 35 (1995) 887–891.
[6] Y. Takeichi, I. Nishiyama, N. Yamada, SPIE Proc. 5751 (2005) 1069–1076.