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## Measurement of Mask Temperature Rise and Distortion in SR Lithography

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The results of experimental studies on temperature rise and thermal distortion of X-ray masks in synchrotron radiation lithography are presented. A novel thermo sensor to measure the mask membrane temperature rise induced by X-ray irradiation is presented. Observations on a SiN mask with a  $5x5mm^2$  Au absorber in a vacuum chamber show a temperature rise of 51 °C at the periphery and 94°C at the center at 146mW/cm<sup>2</sup> absorbed X-ray power, and radial elongation of 0.8  $\mu$ m /8 mm at 196mW/cm<sup>2</sup> absorbed X-ray power.

### 1. Introduction

Lithography using Synchrotron radiation(SR), a very powerful and naturally collimated X-ray, is one of the most promising fine-pattern replication technologies. This technology, however, has the problem of X-ray mask thermal distortion, which was discussed theoretically in previous papers.<sup>1), 2)</sup>

Recently, the temperature rise of an X-ray mask frame was measured by a thermocouple<sup>3)</sup>, and the mask thermal distortion was measured by double exposure.<sup>4)</sup> However, the relationship between the temperature rise of the mask membrane and the mask thermal distortion has not been studied experimentally.

This paper proposes a thermo sensor to measure the temperature rise of X-ray mask membranes and presents the measurements of the X-ray mask temperature rise by SR irradiation, as well as the mask thermal distortion induced by the temperature rise during exposure in a vacuum environment.

## 2. SR Exposure Conditions

The beam line BL-1B at the Photon Factory (2.5GeV electron energy) was used with SR is deflected by 2 ° using a flat SiC mirror to eliminate the hard X-ray.

To eliminate VUV components, a Ti  $(0.5\,\mu$ m) coated 7.5  $\mu$ m thick Polyimide window was used. The calculated SR spectrum is shown in Fig. 1. The spectrum of SR to expose the mask peaks at 7Å and is suitable for lithography. An X-ray mask in a vacuum chamber (10 <sup>-6</sup> torr) was set 31m away from the SR source. In this condition,



in the measurement.

the total x-ray power density on the mask surface is calculated to be 50mW  $/ \text{cm}^2$  in the Ti(0.5  $\mu$ m) coated 7.5  $\mu$ m thick Polyimide window at 100 mA ring current.

#### 3. Thermo Sensor

A novel thermo sensor was devised to measure the temperature rise of the mask membrane. This thermo sensor was fabricated on a mask membrane to measure the mask temperature rise using the temperature dependence of metal film's electrical resistance on the X-ray mask membrane.

A thermo sensor pattern fabricated on a SiN



Fig. 2 A thermo sensor pattern fabricated on a SiN membrane.

membrane (2  $\mu$ m thick) is shown in Fig. 2. Evaporated Au film was used as the electrical resistance film.The thermo sensor was a 150  $\mu$ m wide, 0.4  $\mu$ m thick Au line surrounding a 5x5 mm<sup>2</sup> exposure area. The space between the thermo sensor and exposure area was 100  $\mu$ m.

Two types of model X-ray masks, each with a thermo sensor, were made; Type A with the exposure area covered by  $0.4\,\mu$ m thick Au as X-ray absorber, and type B with no Au film in the exposure area. To calibrate the characteristics of thermo sensors, model X-ray masks were set in a constant temperature furnace and the temperature dependence of their electrical resistance was measured by the four-terminal method.

The calibration characteristics of some of the thermo sensors are shown in Fig. 3. Electrical resistance increases linearly with temperature in both types. The thermo sensor sensitivities are estimated to be  $40.2 \text{ m}\Omega \nearrow \text{°C}$  (Type A) and 37.9 m  $\Omega \cancel{\text{°C}}$  (Type B).

### 4. Measuring Mask Temperature Rise

The model X-ray mask having a thermo sensor on it was set behind a  $5x5mm^2$  aperture, and was exposed by SR irradiation in a vacuum chamber. The mask membrane temperature was measured in the steady-state condition by the four-terminal method.

The mask membrane temperature rise dependence on the ring current is shown in Fig. 4. Mask membrane temperature rises linearly with the ring current. At 100 mA ring current, the temperature rise at the periphery of the  $5x5 \text{ mm}^2$  exposure area is estimated to be 15°C in Type A and 8°C in Type B. In Type A ,incident SR is efficiently converted to heat at Au layer.



Fig. 3 The calibration characteristics of thermo sensors.



Fig. 4 The temperature rise in the SiN mask irradiated by SR. (1)Ring current dependence.



Fig. 5 The temperature rise in the SiN mask irradiated by SR. (2)X-ray filter transmittance dependence.

Therefore, Type A shows greater temperature rise.

The relationship between the temperature rise and X-ray filter transmittance (SiN  $2\mu$ m thick film and Al  $5\mu$ m thick film) is shown in Fig. 5. Mask membrane temperature rises linearly with the X-ray filter transmittance.

Mask temperature rise depends on SR power density irradiating the mask as shown in Fig.4 and Fig.5.

In a vacuum, the heat distribution mechanism of mask membrane depends on the thermal conduction in the SiN membrane (thermal conductivity 0.14W/m °C) as well as the thermal radiation. Bearing this in mind, the temperature rise distribution of the mask membrane exposed by SR irradiation was derived theoretically.<sup>2)</sup>

Experimental results and theoretical values<sup>2)</sup> at the periphery of the exposed area at 100mA ring current are shown in Table 1. Experimental results agree with theoretical values. These results show that the novel thermo sensor is a powerful tool to measure the temperature rise of mask itself.

Using measurement values, the temperature rise at the center of the exposure area is estimated to be 28 °C in Type A and 11 °C in Type B at 100mA ring current.

Thermo sensor	Filter (µm)	Exposed power (mW/cm²) calcu.	Absorbed power (mW/cm <sup>2</sup> ) calcu.	Temp. rise ( °C)	
				Experi.	Theory
Type A (Au+SiN)		50	43	15	15
	SiN (2)	27	23	8	8
	A1 (5)	10	9	4	3
Type B (SiN)		50	23	6	8

Table 1 SiN mask temperature rise at the periphery of the exposed area. (ring current 100mA)

# 5. Mask Thermal Distortion

To estimate the mask thermal distortion, the one dimensional model shown in Fig. 6 was studied. In this model, both edges of the mask membrane are fixed dynamically and a part of the mask membrane is exposed by uniform SR irradiation. The thermal distortion (displacement)  $\Delta 1$  at the boundary of the exposure area is

$$\Delta 1 = \alpha \times \Delta t \times (a \times b) / (a + b)$$









where  $\alpha$  is the thermal expansion coefficient of the mask membrane,  $\Delta t$  the temperature rise, 2a the exposure area, and b the non exposure area.

The X-ray mask for measuring the mask thermal distortion is shown in Fig. 7. The X-ray mask has a 8  $\times$ 8 mm<sup>2</sup> exposure area and 16 $\times$ 16mm<sup>2</sup> SiN mask membrane area( $\alpha$  = 2.5x10 <sup>-6</sup>/ °C). Mask distortion was measured using 0.7  $\mu$ m width cross patterns in an exposure area covered with 0.6  $\mu$ m thick Ta absorber.

Assuming an average 90 °C temperature rise of this mask, the mask thermal distortion is estimated to be 0.4  ${\sim}0.5~\mu{\rm m}.$ 

## 6. Measuring Mask Thermal Distortion

Two methods were adopted to measure the mask distortion induced by the temperature rise.

One involved a double exposure using the same X-ray mask. In exposing resists, at first, X-ray resist was exposed by low level power and then the same mask-wafer set was exposed by high level power. SR is deflected by 2° using a Pt coated flat SiC mirrow and transmitted on a  $10\,\mu$ m thick Be window. At 100mA ring current high level exposure, the temperature rise of the X-ray mask was measured to be 51°C at the periphery. Using this value, the temperature rise of 94°C was estimated at the center of the expose area. The absorbed X-ray power is estimated to be 146mW/cm<sup>2</sup>. Low level power was achieved adding a 50 $\mu$ m thick polyimide filter. The SR power ratio of high level to low level was 7:1. Double exposure resist patterns were observed by SEM. The mask distortion measured at 134 mA ring current (196mw/ cm<sup>2</sup> absorbed X-ray power density) is shown in Fig. 8. The mask distortion had a magnitude of 0.4  $\mu$ m at the periphery of the 8x8mm<sup>2</sup> exposure area.

The other method involved measuring resist pattern positions by laser micro-pattern analyzer. By comparing the resist patterns exposed by high and low level power, a  $0.4 \ \mu$ m radial elongation of the mask was confirmed.

Observed thermal distortion values agree with expected values.

## 7. Conclusions

Our studies on the temperature rise and thermal distortion of X-ray masks in synchrotron radiation lithography resulted in the following :

 A mask membrane temperature measurement method was developed. Measured values agreed with theoretical values. Temperature rise of SiN mask with a  $5x5mm^2$  Au absorber by  $146m\text{W/cm}^2$  absorbed power density SR irradiation was averages  $80{\sim}90^{\circ}\text{C}$  during exposure in a vacuum environment.

(2) Mask distortion caused by SR irradiation was measured using a double exposure method and laser micro pattern analyzer. At 196mW/cm<sup>2</sup> absorbed X-ray power, 0.8 μm/8mm mask elongation was observed during exposure in a vacuum environment. This suggests the needs for temperature control of the mask to achieve highly accurate pattern registration.

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Fig. 8 The measured mask distortion induced by temperature rise. Ring current :134mA.