High Acceleration Test for Contamination of Ru Capping Layers for EUVL Projection Optics Mirrors

Yukinobu Kakutani and Masahito Niibe
Laboratory of Advanced Science and Technology for Industry (LASTI),
University of Hyogo

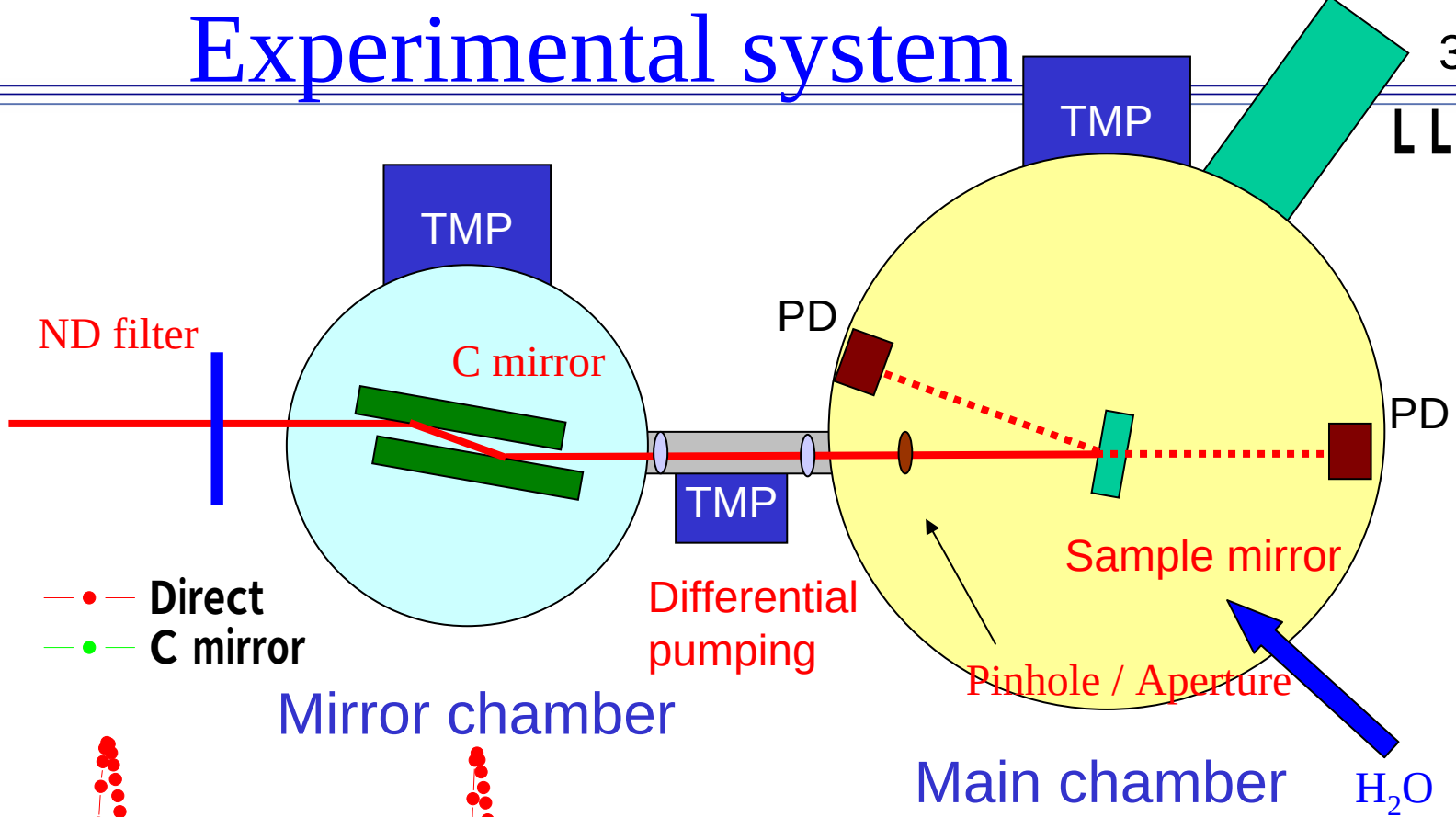
Yoshio Gomei
Canon Inc.

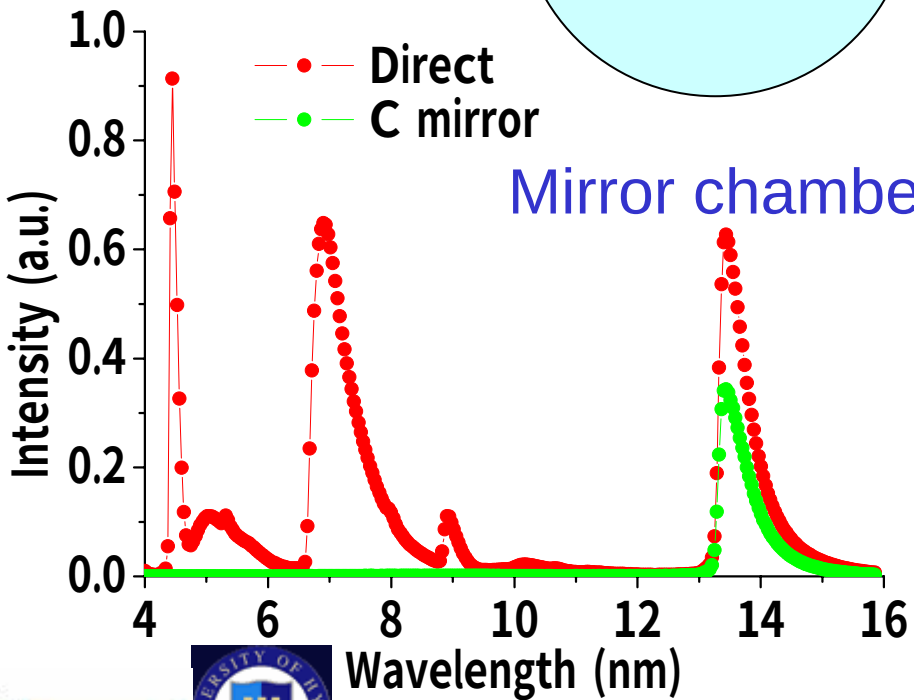
Hiromitsu Takase, Shigeru Terashima, Shuichi Matsunari,
Takashi Aoki, Katsuhiko Murakami, and Yasuaki Fukuda
Extreme Ultraviolet Lithography System Development Association
(EUVA)

Introduction

- Contamination study for EUVL projection optics (PO) mirrors has been performed in NewSUBARU SR facility.
- Intense EUV power of 150 mW/mm^2 is available by using an undulator radiation.
- This power corresponds to about 1000 times, compared with the maximum power expected in PO mirrors of EUVL production tools (0.18mW/mm^2).
- Conditions to meet this kind of high acceleration test were investigated for Ru capping layers.

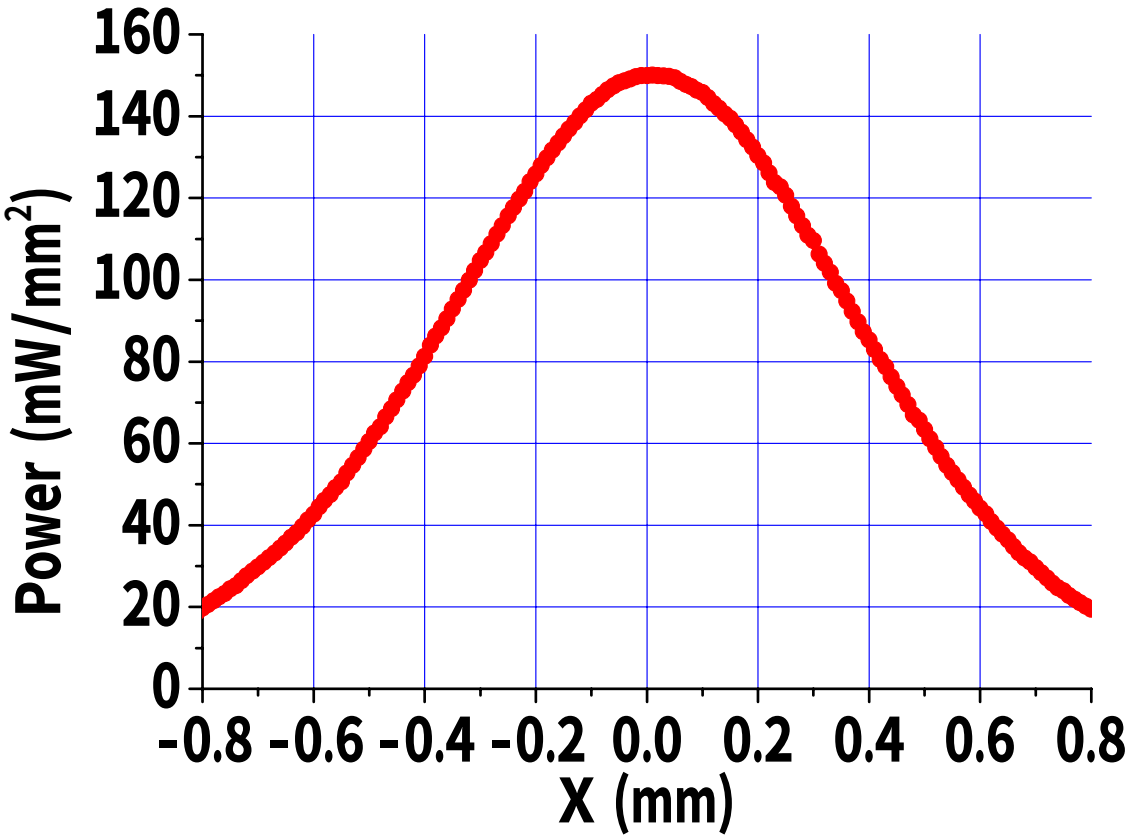
Experimental system





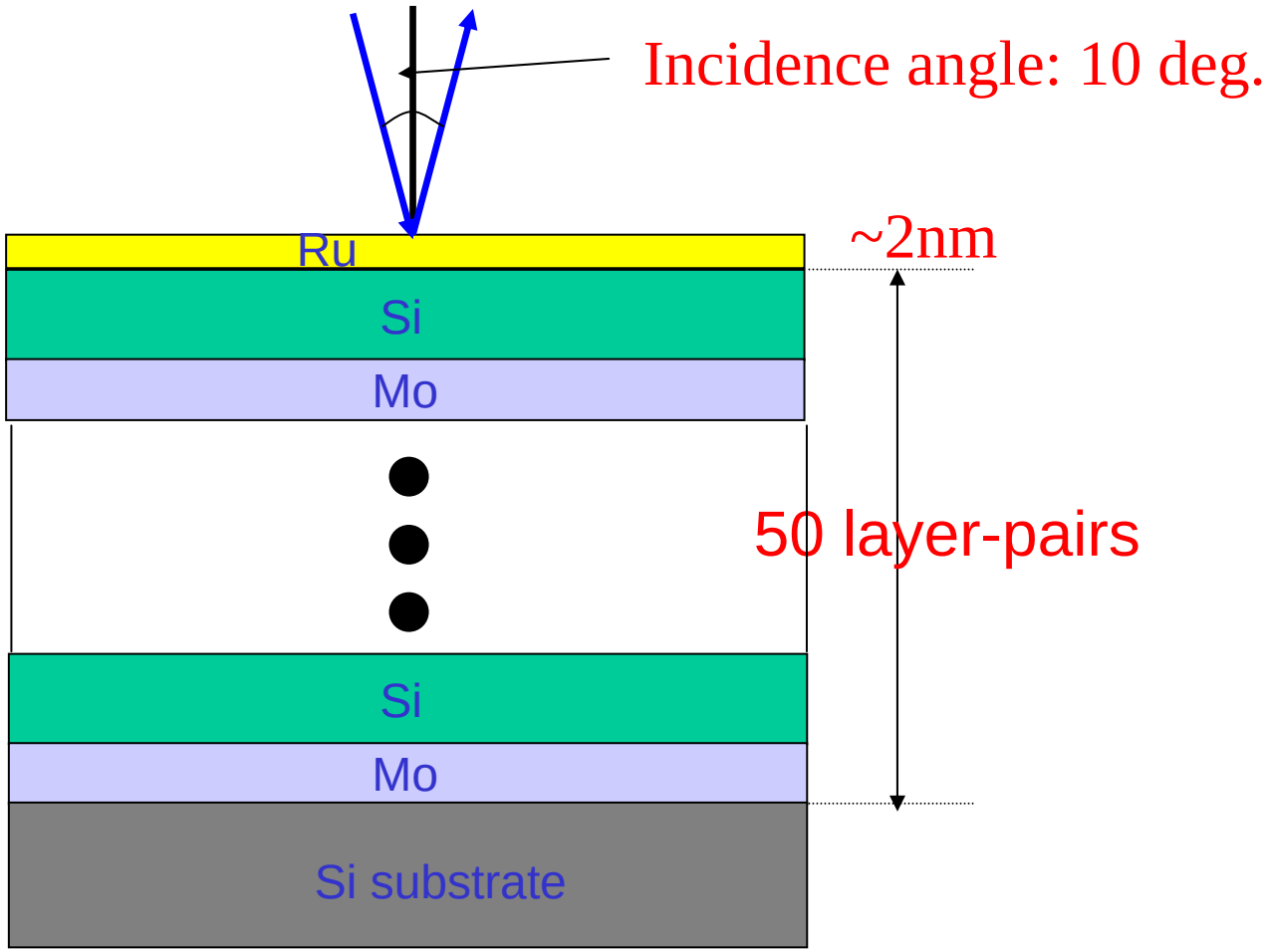
Ultimate vacuum: 2E-7 Pa

Beam profile (Horizontal)

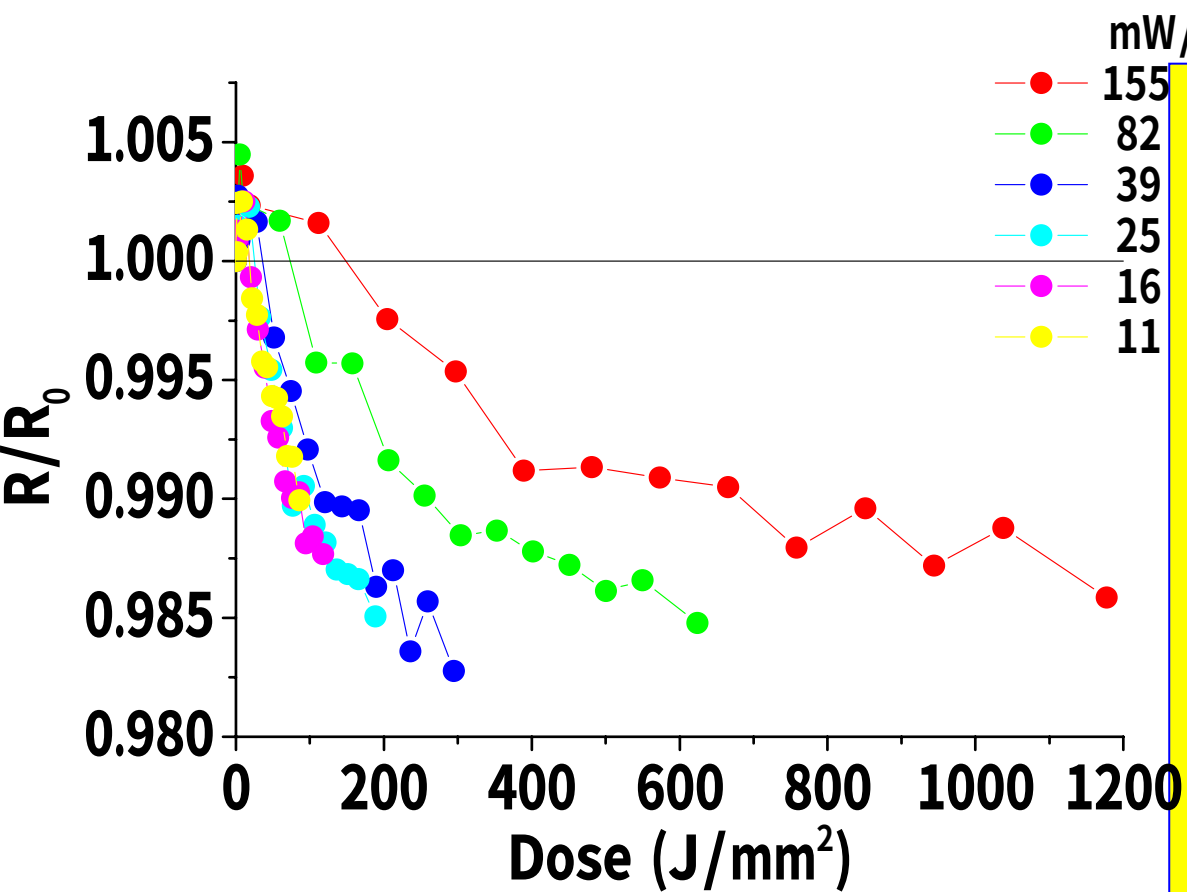


- Gaussian distribution.
- A pinhole (50 um in diameter) used for reflectance measurement to restrict measured areas.
- An aperture (2 mm in diameter) used when EUV was irradiated.
- Reflectance changes at different EUV power were simultaneously measured by using the pinhole.

Sample mirror



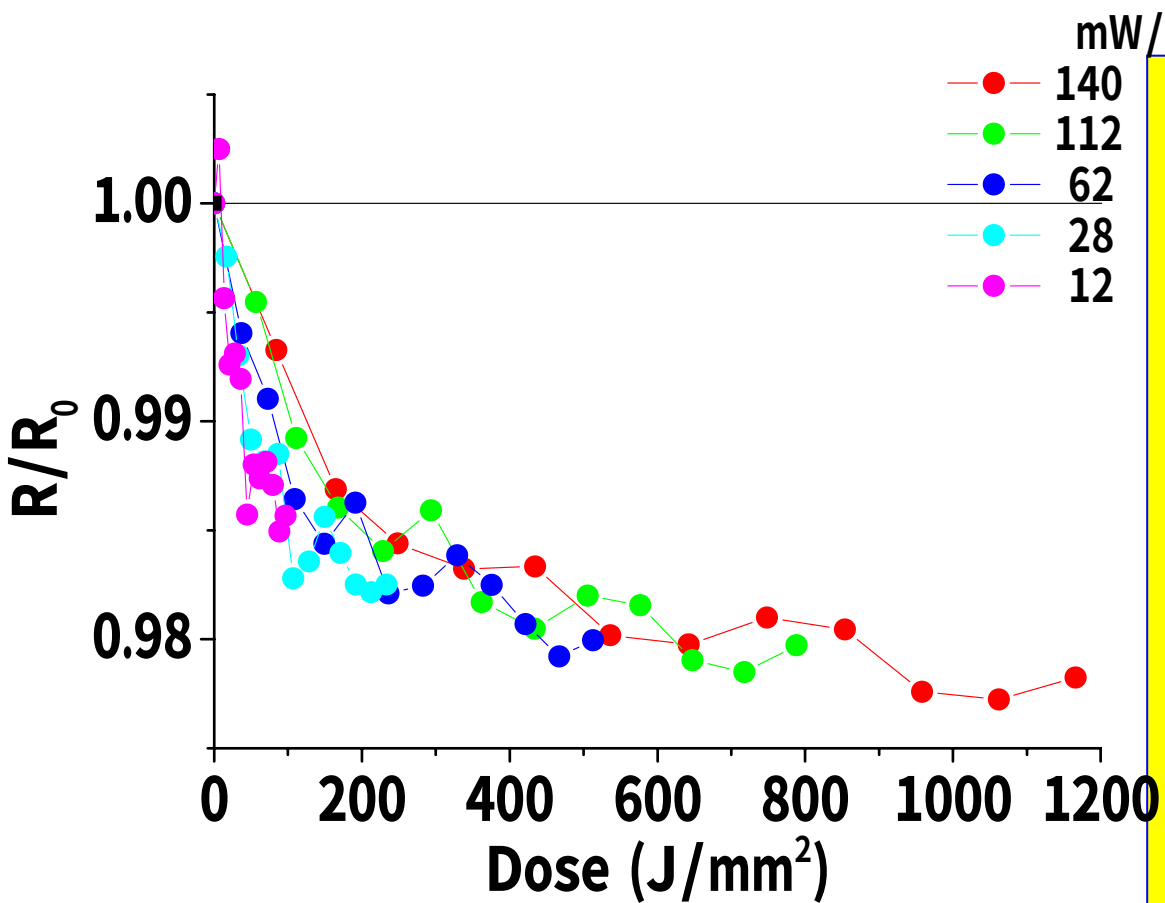
Reflectance changes (H_2O: 1.3E-5 Pa)



- This pressure may be typical in EUVL production tool.*
- Below 25 mW/mm^2, all of the measured reflectance change showed similar trends.
- Over 25 mW/mm^2, the reflectance changes were dependent on photon intensity.

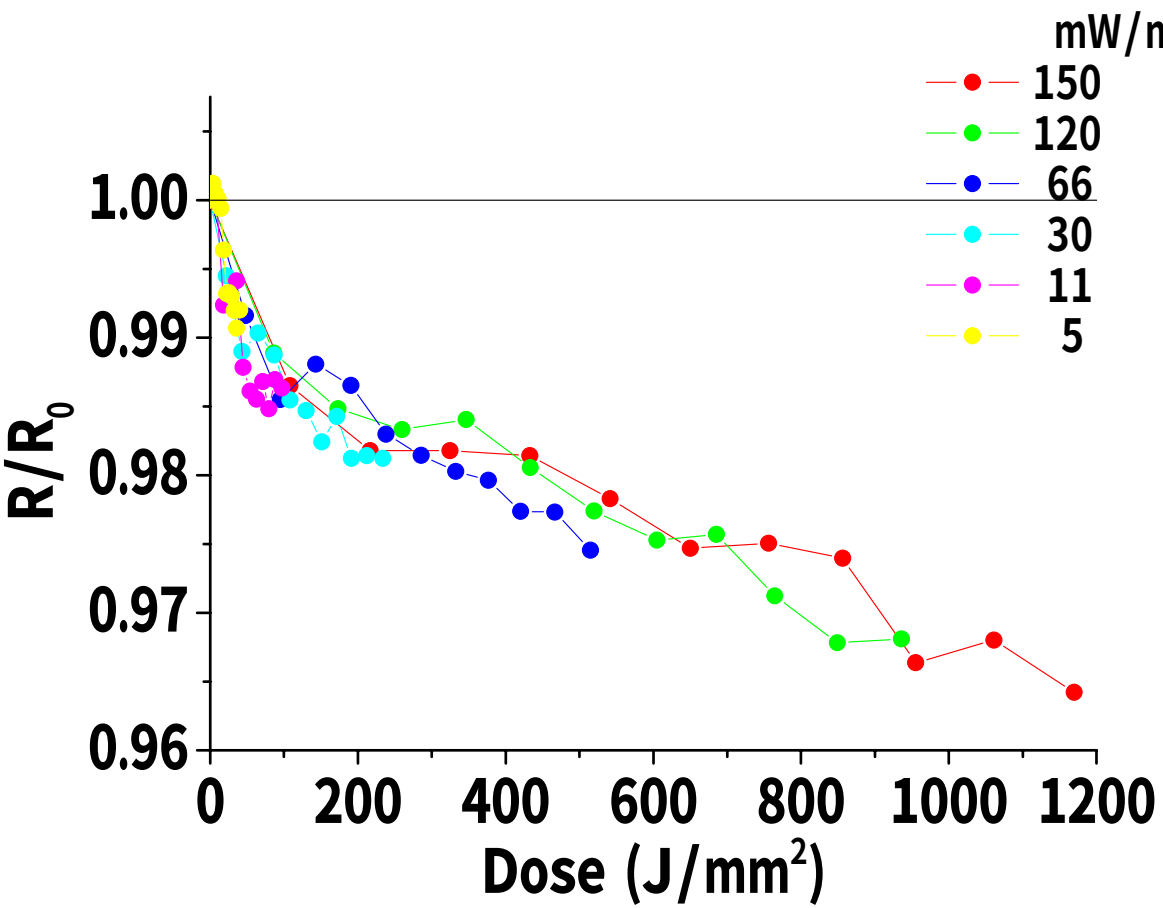
* H. Meiling, *et al.*, Proc. SPIE., **6151** (2005), 615108.

Reflectance changes (H_2O: 1.3E-4 Pa)



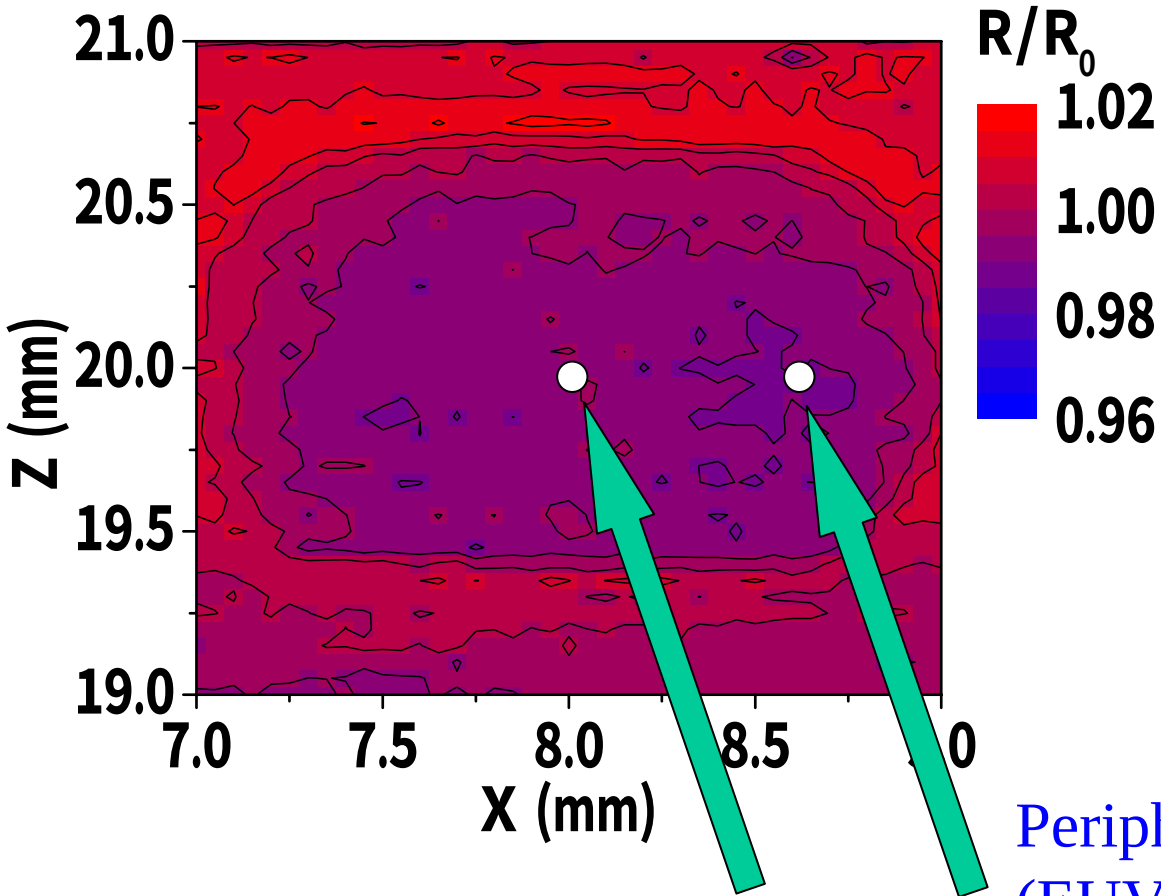
- Below 28 mW/mm^2, all of the measured reflectance change showed similar trends.
- Saturated behavior was observed when the reflectance dropped to about 0.985.
- The reflectance change before saturation was taken into consideration because we would like to discuss about contamination at surface.

Reflectance changes (H_2O: 1.3E-3 Pa)



- All of the measured reflectance change showed similar trends.
- The reflectance change was independent of photon intensity.
- Inflection points were observed when the reflectance dropped to about 0.985.

Distribution of reflectance changes (H_2O: 1.3E-5 Pa)

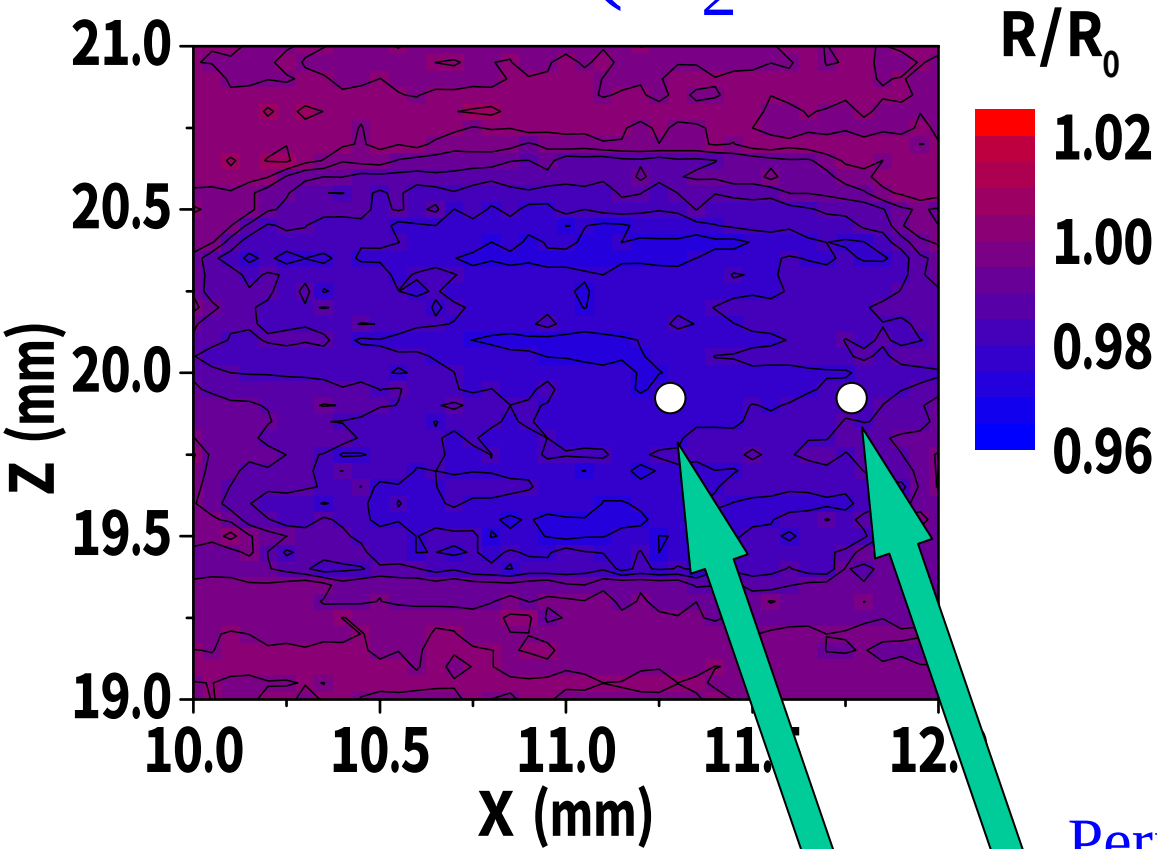


- Surface analyses were performed at positions of white circles.
- The map consisted of final values in dose dependence of reflectance change.

Peripheral in XPS analysis
(EUV power: 25 mW/mm^2)

Center in XPS analysis
(EUV power: 155 mW/mm^2)

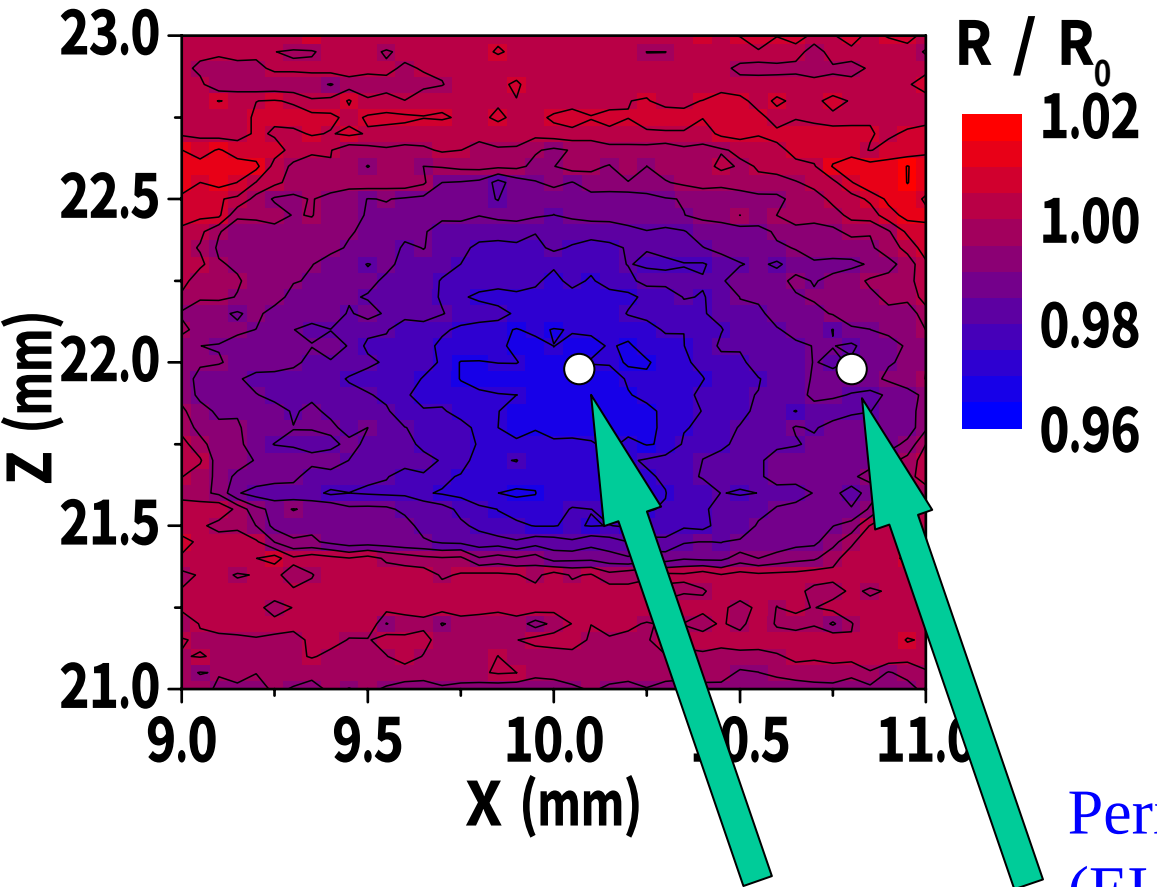
Distribution of reflectance changes (H_2O: 1.3E-4 Pa)



Peripheral in XPS analysis
(EUV power: 12 mW/mm^2)

Near center in XPS analysis
(EUV power: 87 mW/mm^2)

Distribution of reflectance changes (H_2O: 1.3E-3 Pa)



Peripheral in XPS analysis
(EUV power: 11 mW/mm^2)

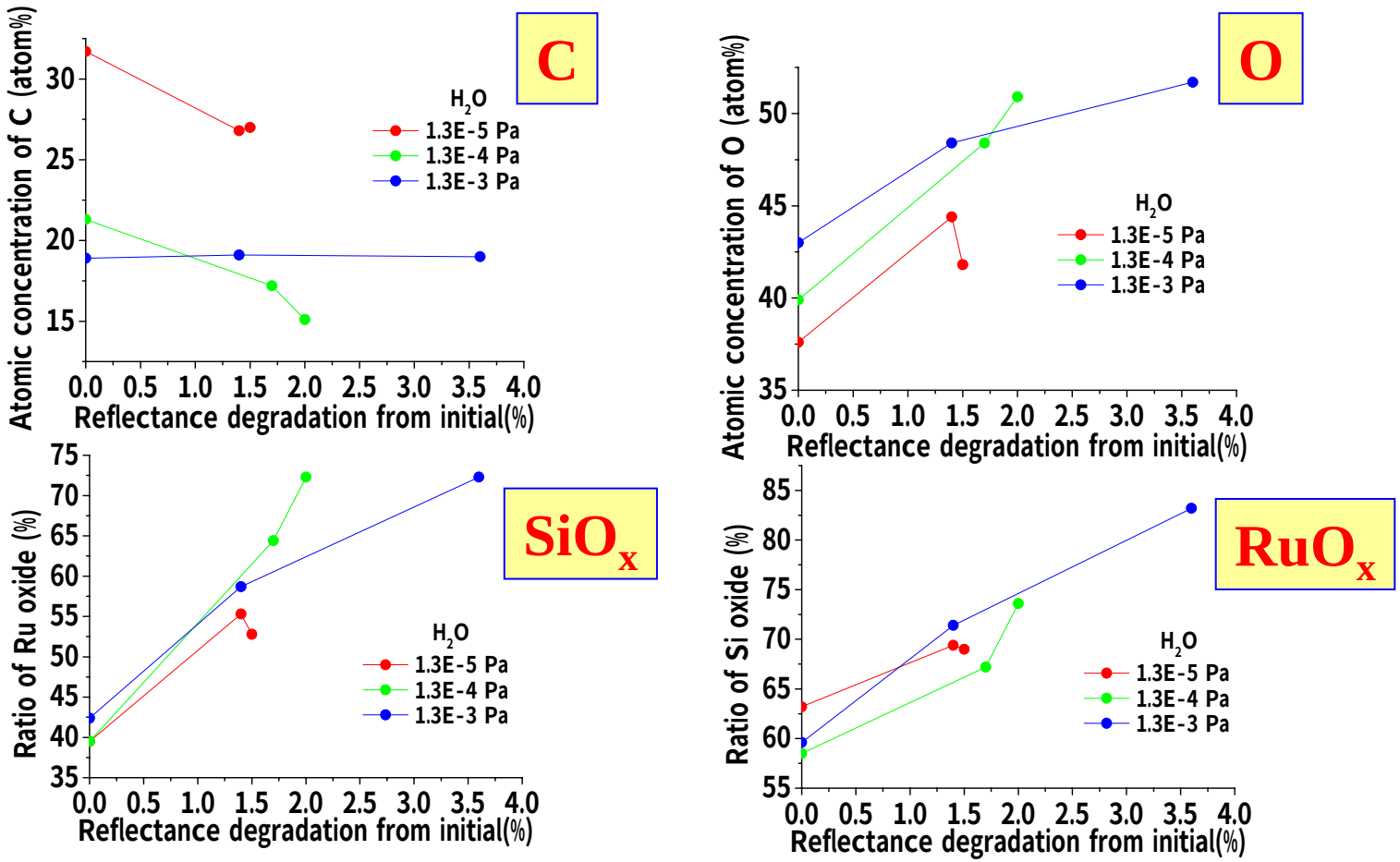
Center in XPS analysis
(EUV power: 150 mW/mm^2)

Surface analysis (XPS) (1)

Condition	Location	Reflectance change from initial (%)	C (atom %)	O (atom %)	SiO_x/ ($Si+SiO_x$) (%)	RuO_x/ ($Ru+RuO_x$) (%)
1.3E-5 Pa	Center	-1.4	26.8	44.4	69.4	55.3
	Peripheral	-1.5	27.0	41.8	69.0	52.8
	Reference	-----	31.7	37.6	63.2	39.5
1.3E-4 Pa	Near center	-2.0	15.1	50.9	73.6	72.3
	Peripheral	-1.7	17.2	48.4	67.2	64.4
	Reference	-----	21.3	39.9	58.5	39.5
1.3E-3 Pa	Center	-3.6	19.0	51.7	83.2	72.3
	Peripheral	-1.4	19.1	48.4	71.4	58.7
	Reference	-----	18.9	43.0	59.6	42.4

- All of reflectance degradation was caused by oxidation

Surface analysis (XPS) (2)



- Carbon was cleaned by EUV irradiation except a case of 1.3E-3 Pa.
- Reflectance changes roughly correlated with degrees of oxidation.

Surface physics model

$d\sigma/dt = S\Gamma - \sigma/\tau - \eta P$ --- (1)

- σ: Surface areal density
- S: Sticking probability
- Γ: Arrival rate
- τ: Mean residence time
- η: Photon-induced desorption coefficient
- P: Photon flux intensity

Amount of produced contamination:

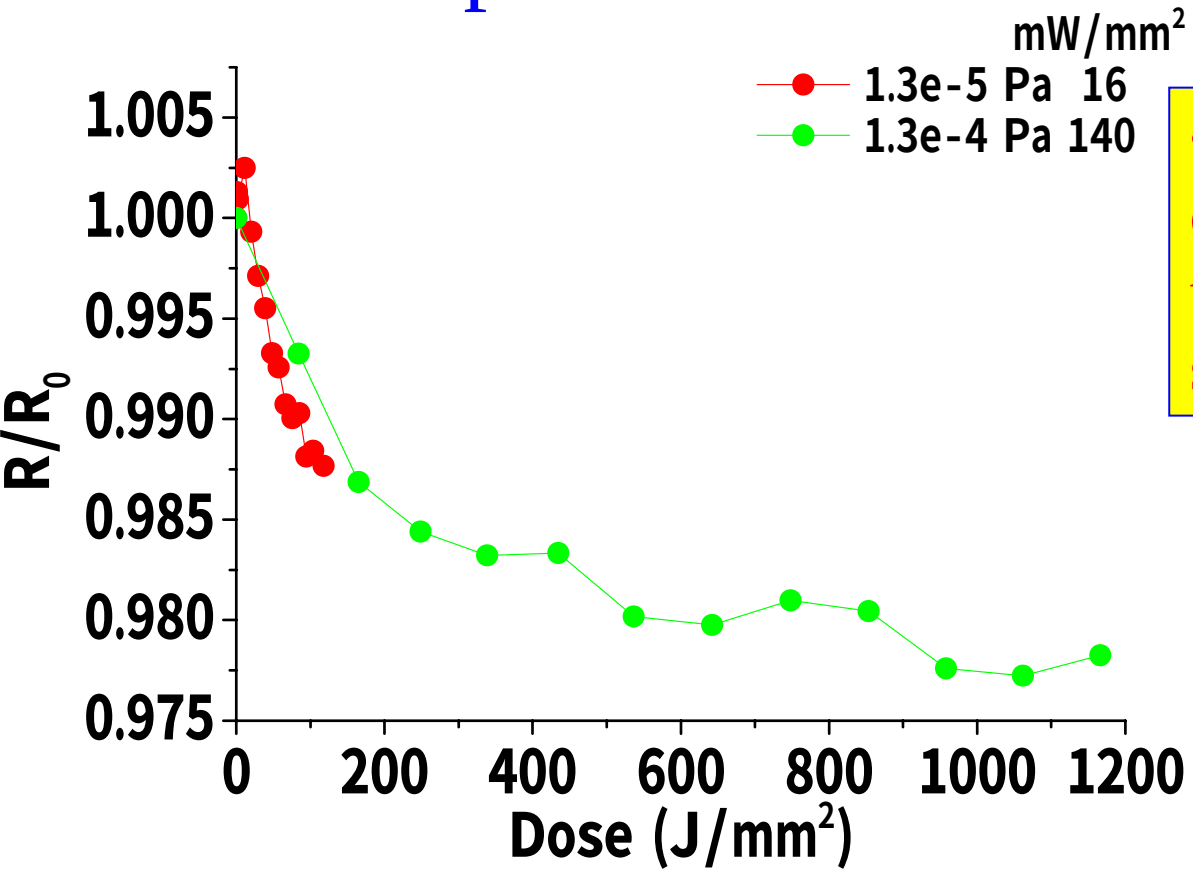
$\int P\sigma dt$ --- (2)

Oxidation only at a surface is taken into consideration.

- When the third term becomes much larger than the second term, reflectance change would be dependent on photon intensity.
- In this condition, photon flux intensity would be large and/or a pressure of water vapor would be small.
- And, the second term would be negligible, water vapor pressure should be increased in proportion to photon intensity not to change the surface areal density.*

* Y. Gomei *et al.*, J. Vac. Sci. Technol., **B 23** (2005), 2848.

Comparison between results taken under atmospheres of 1.3E-5 and 1.3E-4 Pa



- These two reflectance changes showed similar trends as a prediction of surface physics model.

Conclusion

- Reflectance degradation was dependent on photon intensity below a water vapor pressure of 1.3E-4 Pa.
- According to a surface physics model, dependence of photon intensity arise from photon-induced desorption when it is much larger than thermal desorption.
- To accomplish high acceleration test, water vapor pressure should be increased in proportion to photon intensity in the region where reflectance degradation is dependent on photon intensity.

Acknowledgments

This work was performed under the management of Extreme Ultraviolet Lithography System Development Association (EUVA) in the Ministry of Economy Trade and Industry (METI) program supported by New Energy and Industrial Technology Development Organization (NEDO).