Scaling Study of Carbon Deposition Rate on EUVL Optics

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poster 7271-134 , T. Nakayama et al.

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Motivation

In order to estimate the damage of optics in the EUV exposure tool, we have to make an accelerated irradiation test. The scaling law for the degradation for a certain period of operation needs to be figured out.

Purpose

Scaling parameters for accelerated test are
- EUV intensity
- characteristics of EUV source
- hydrocarbon partial pressure
- hydrocarbon species.

Purpose of this study is to figure out the dependence of carbon deposition rate on EUV intensity, hydrocarbon partial pressure and characteristics of EUV source.

Beamline parameters

- EUV exposure facility
  - SBL-2 is a **bending magnet** beamline of Super-ALIS at NTT Atsugi R&D center
  - BL9 is an **undulator** beamline of NewSUBARU at University of Hyogo

Beamline	SBL-2	BL9
EUV peak intensity (mW/mm^2)	12~24	~200
Pulse width (psec.)	78	26
Frequency (MHz)	125	500

Experimental conditions

■Injected gas : Decane($C_{10}H_{22}$)

■Multilayer mirror : [Si(4.2nm)/ Mo(2.8nm) $]^{50}$

We made experiments on six conditions.

No.	Beamline	Hydrocarbon Partial pressure (Pa)	Water partial pressure (Pa)	Total pressure (Pa)	Irradiation time (hrs)
1	SBL-2	6.0×10^{-5}	2.1×10^{-6}	6.5×10^{-5}	4
2	SBL-2	1.2×10^{-6}	4.6×10^{-7}	1.9×10^{-6}	5
3	SBL-2	7.3×10^{-7}	3.6×10^{-7}	1.1×10^{-6}	5
4	SBL-2	2.3×10^{-7}	3.0×10^{-7}	5.8×10^{-7}	8
5	BL9	1.2×10^{-6}	3.3×10^{-6}	5.0×10^{-6}	1.3
6	BL9	2.5×10^{-7}	3.5×10^{-7}	7.0×10^{-7}	2.7

Carbon thickness and EUV intensity in SBL-2

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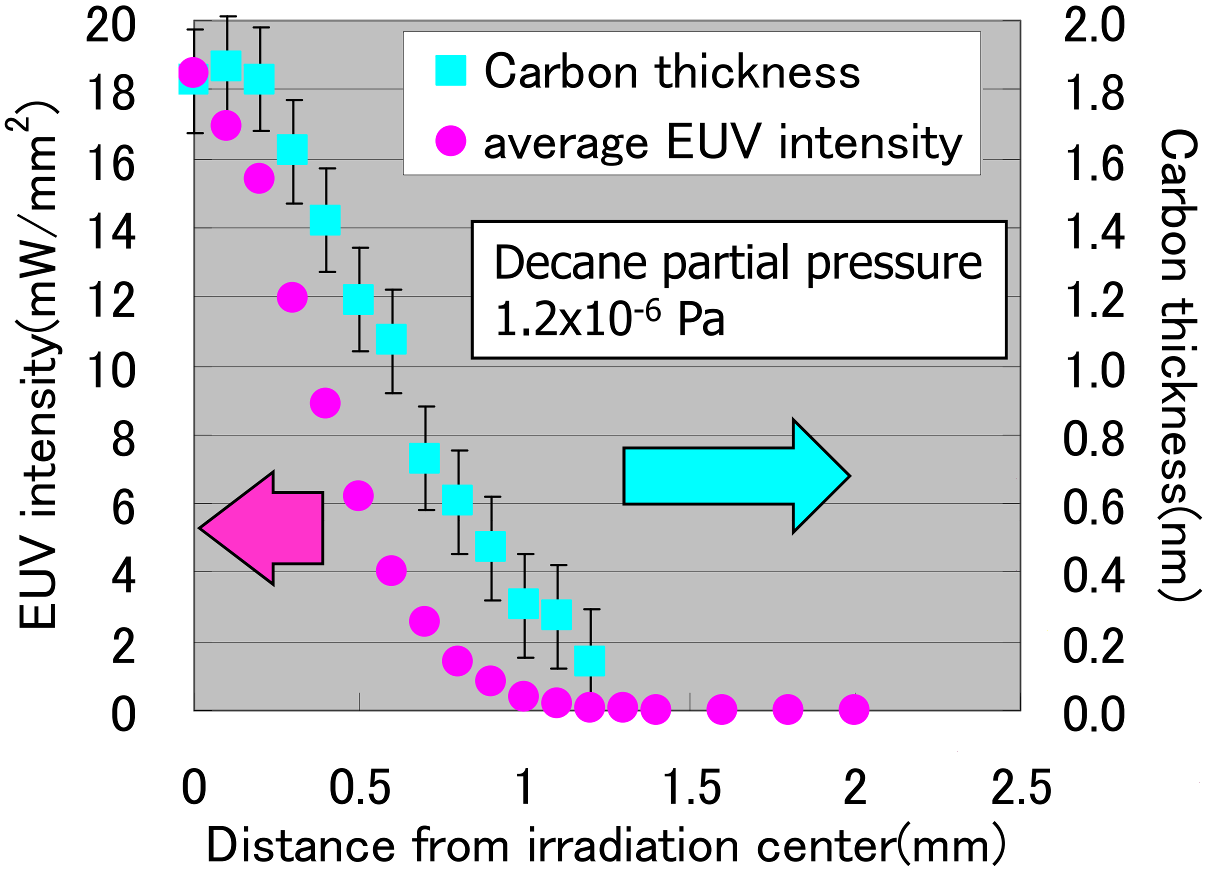
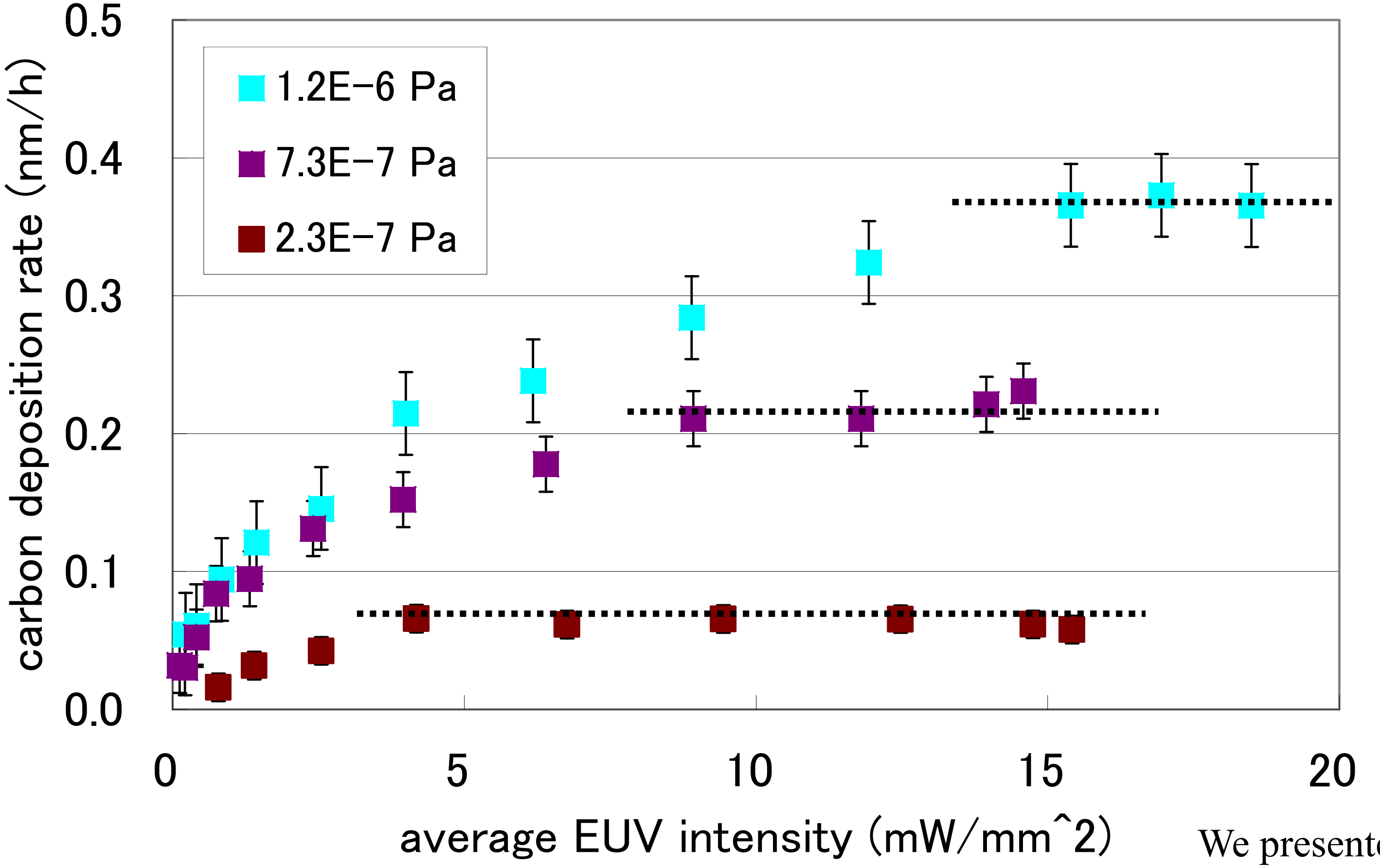


The carbon thickness was obtained by using XPS at each point where EUV intensity was measured. The analyzed area of XPS was 100 μm .

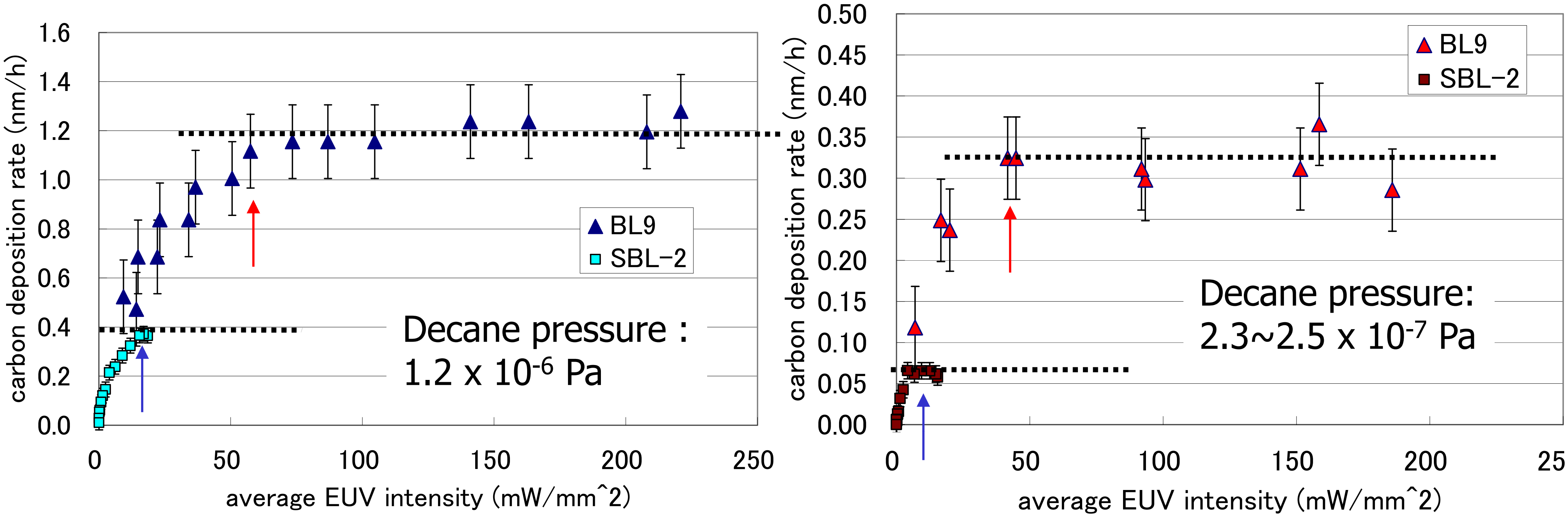
Definition of limit carbon deposition rate in SBL-2



We presented at SPIE 2008.

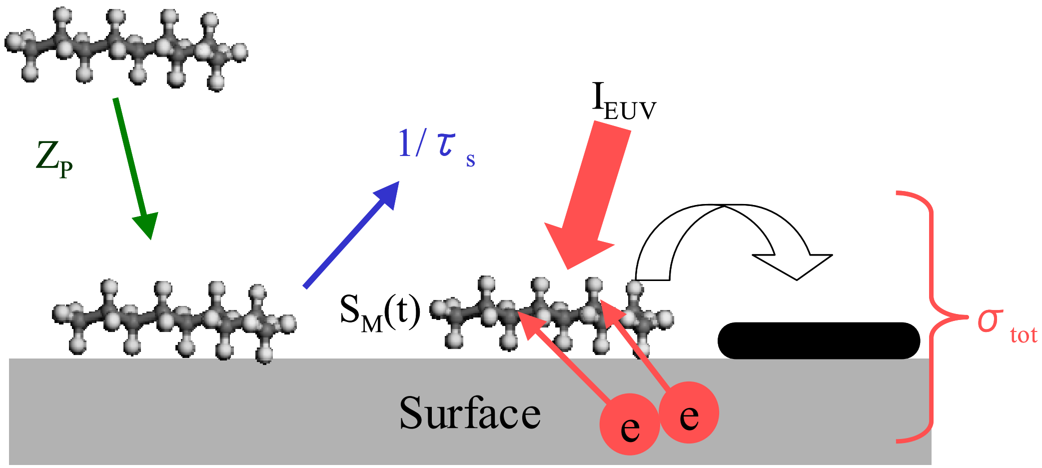
We define the maximum carbon deposition rate at each decane pressure as "limit carbon deposition rate."
It is indicated by the dotted lines in the figure.

Dependence of carbon deposition rate on average EUV intensity in SBL-2 and BL9



"Limit carbon deposition rate" in BL9 is 3 to 5 times larger than that in SBL-2. The average EUV intensity to reach the limit carbon deposition rate in BL9 (red arrow) is also over 4 times larger than that in SBL-2 (blue arrow). Carbon deposition rate depends not only on the average EUV intensity.

NIST Simple thick-C-growth model



Single-species contaminant

- $S_M(t)$: coverage of adsorbed intact molecules [molecules *cm^{-2}]
- S_{max} : Site-limited max coverage (= ~1ML)
- Z_P : Impingement rate [molecules*cm^{-2}*s^{-1}]
- τ_S : Surface-residence time [s]

First-order photo reaction

- σ_{tot} :total cross section[cm^2]
  - Secondary e-dissoc. dominates
  - Photo-desorption negligible
- Linear in S_M and I_{EUV}

$$\frac{dS_M(t)}{dt} = Z_P\left(1-\frac{S_M(t)}{S_{\max}}\right) - \frac{S_M(t)}{\tau_s}$$

$$\frac{dS_M(t)}{dt} = Z_P\left(1-\frac{S_M(t)}{S_{\max}}\right) - \frac{S_M(t)}{\tau_s} - I_{peak}\sigma_{tot}S_M(t),$$

k : Carbon-growth rate [C atoms*cm^{-2}*s^{-1}]

$$k = \nu N_C \int_0^{t_p} I_{peak}\sigma_{tot}S_M(t)dt.$$

S. B. Hill et. al., IEUVI-TWG, EUVL symposium, 2007

"NIST simple thick-C-growth model" is used as a reaction model.

Fitted result of carbon deposition rate in SBL-2

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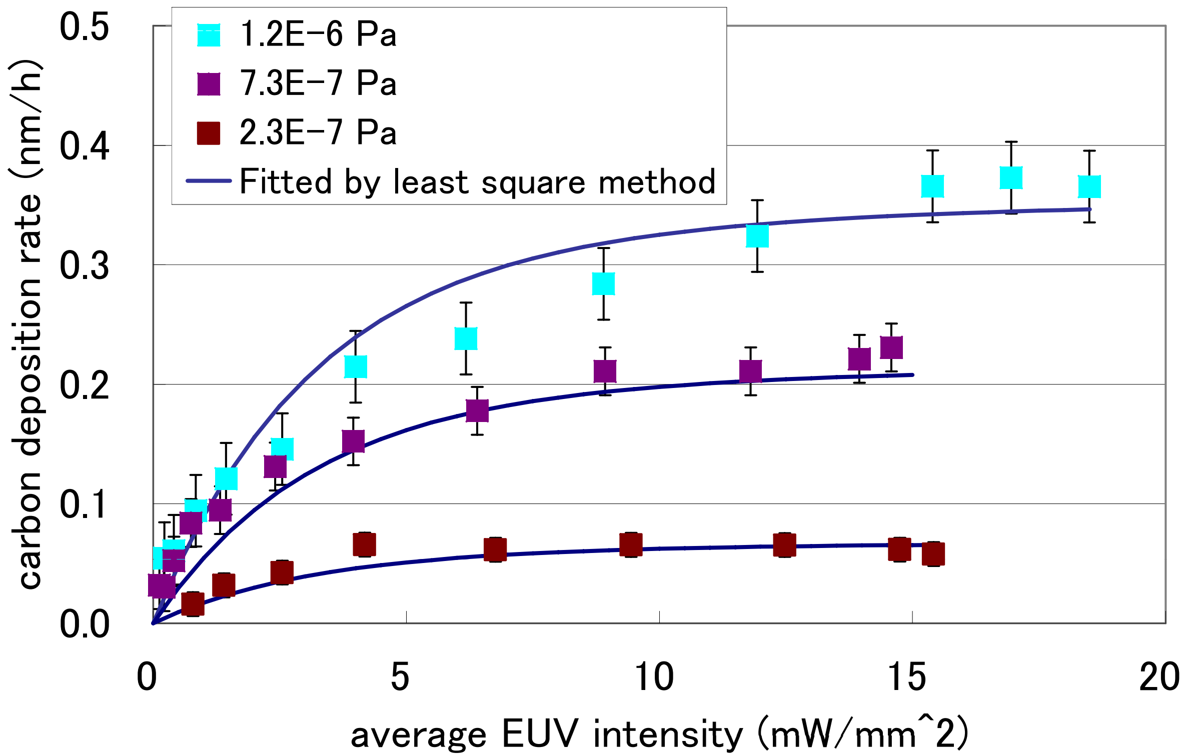
Calculation parameters

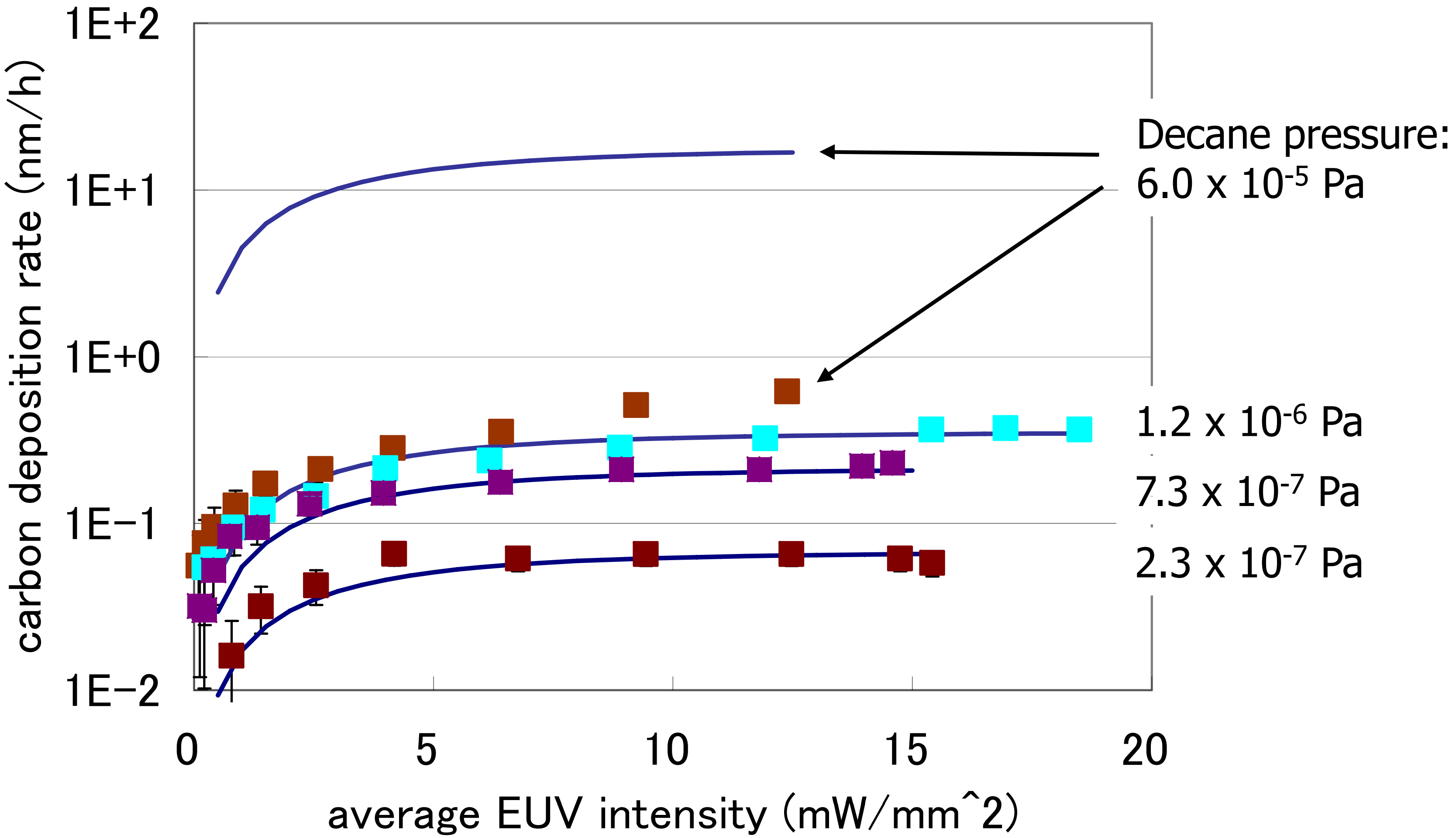
S_{max}(molecules/cm^2)	1×10^{14}
t_D(sec.)	7.8×10^{-11}
ν(Hz)	1.25×10^{8}
T(K)	296
M(Kg/mol)	0.142
N_c(atoms)	10
Deposited carbon density(g/cm3)	2.2



Cross section (σ_{tot}) and residence time (τ_s) is used as fitting parameters and have been fitted by the least square method. Calculation result seems to be fitted well.

τ_s(sec.)	5×10^{-10}
σ_{tot}(cm^2)	6×10^{-9}

Comparing experimental results with calculated in SBL-2



The calculation result does not fit well with our experimental result in a higher partial pressure $6x10^{-5}$ Pa. The model needs to be modified.

Comparing experimental results with calculated in SBL-2 and BL9

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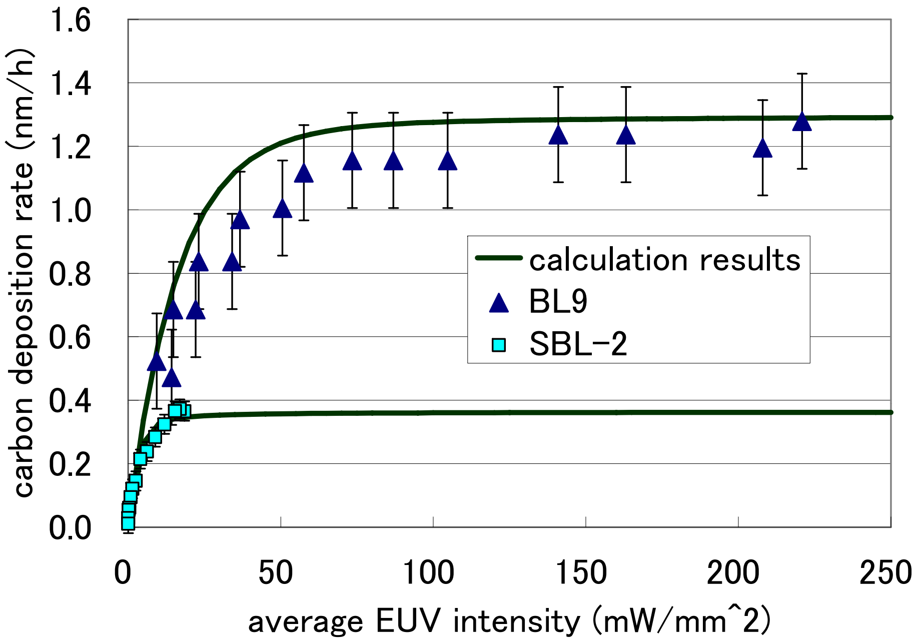
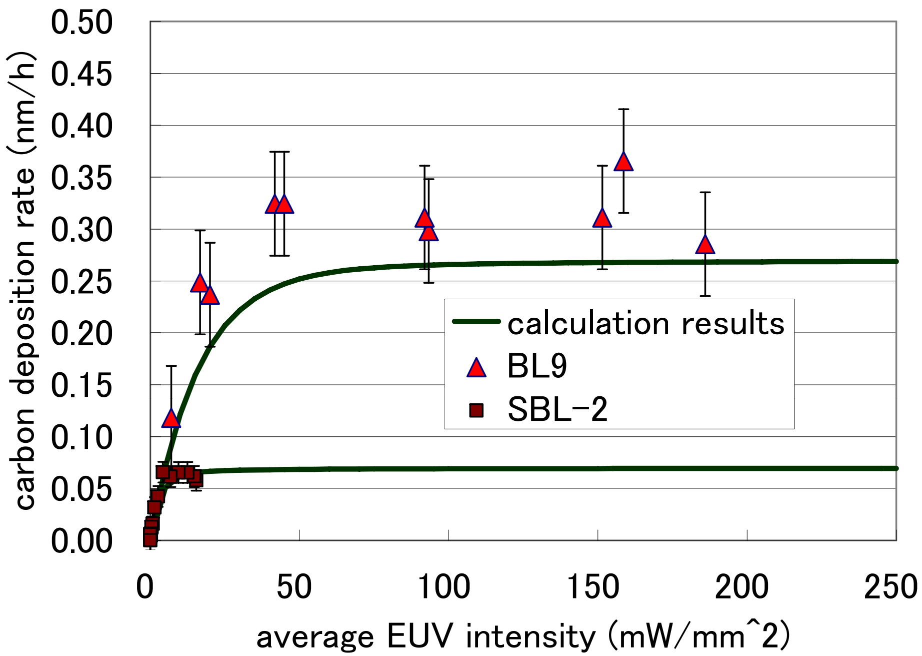
Decane pressure :
1.2×10^{-6} Pa in BL9
1.2×10^{-6} Pa in SBL-2



Decane pressure:
2.5×10^{-7} Pa in BL9
2.3×10^{-7} Pa in SBL-2



We calculated carbon deposition rates of the both beamlines using the same fitting parameter values which were obtained from the fitting for BL9. Calculation results have the same behavior as the experimental one.

Dependence of carbon deposition rate on source frequency and pulse width

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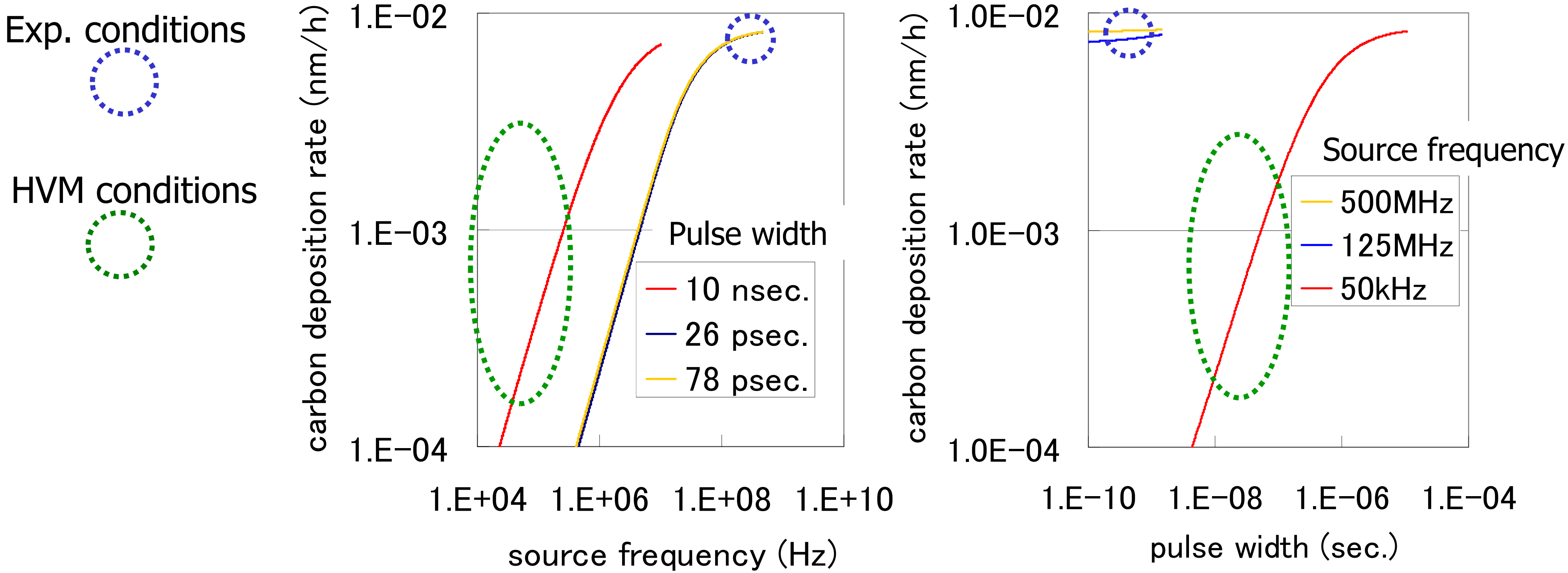

Calculation conditions

decane partial pressure : 1×10^{-7} Pa   average EUV intensity : 1 mW/mm^2

Carbon deposition rate depends on source frequency and pulse width. For mitigating carbon deposition, it is better to make pulse width and source frequency shorter and smaller in the present model.

Summary

Scaling law for two beamlines was examined.

1. The carbon deposition rate depends not only on average EUV intensity.
2. Using NIST simple thick-C-growth model, the calculation results have the same behavior as the experimental data from 2.3×10^{-7} to 1.2×10^{-6} Pa of decane partial pressure.

Future task

- ➢ The reaction model needs to be verified and modified.
  - ✓ Quantitative data of total cross section and residence time.
  - ✓ Dependence of carbon deposition rate on hydrocarbon partial pressure, on gas species and on capping layer.
  - ✓ Standing wave effect.
- ➢ Experiments using an EUV source whose frequency and pulse width are similar to HVM needs to be made.

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