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EUV Lithography: Issues and Future Prospects

Shinji Okazaki
Central Research Laboratory, Hitachi Ltd.

Outline

1, Introduction

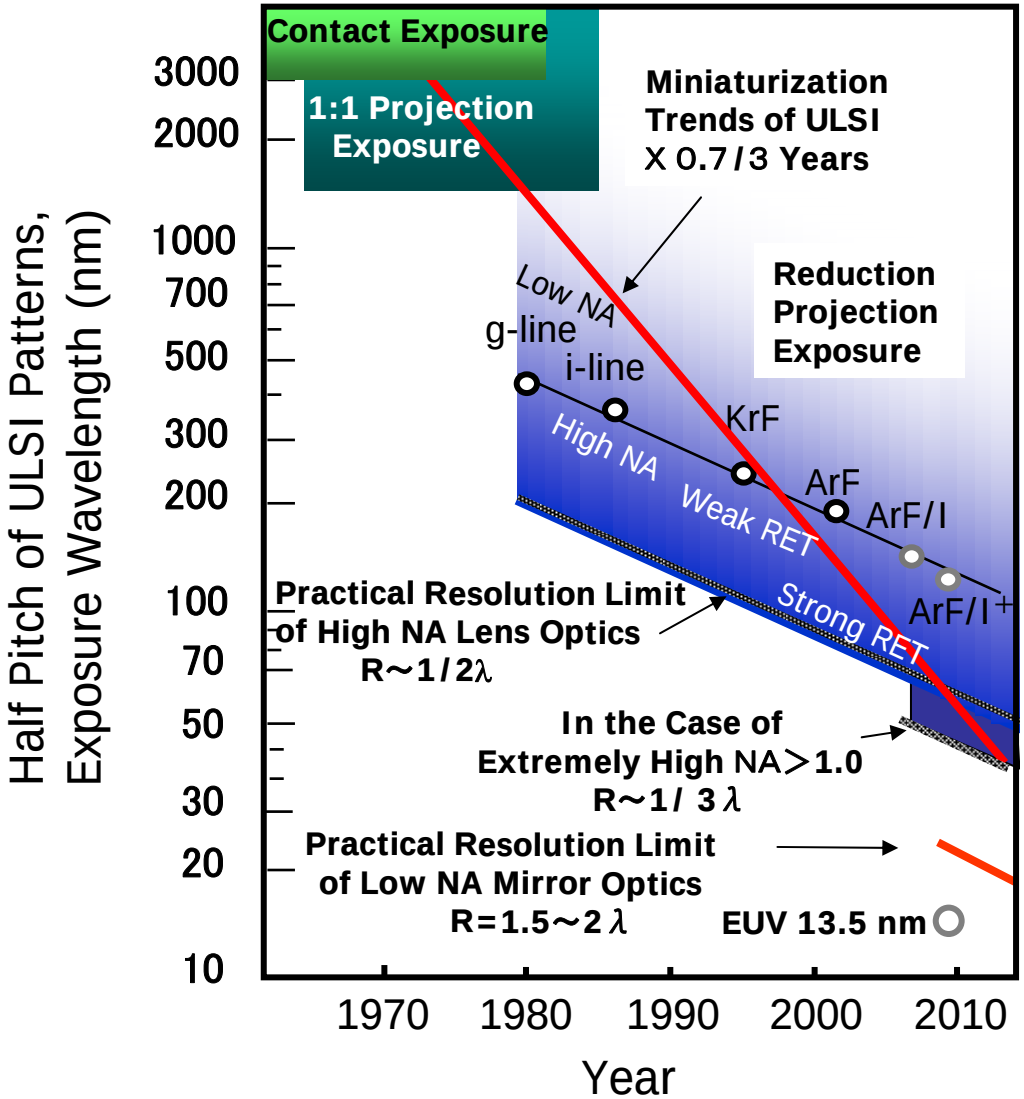
2, Issues of Current Optical Lithography and Advantages of EUV Lithography

3, History of EUVL Developments

4, Issues and Future Prospects of EUV Lithography

5, Summary

Miniaturization Trend of ULSI Devices and Exposure Wavelength Reduction Trend



R: Resolution

$$R = k_1 \frac{\lambda}{NA}$$

λ: Exposure Wavelength

NA: Numerical Aperture

k_1: Constant depends on Resist Materials and Exposure Conditions

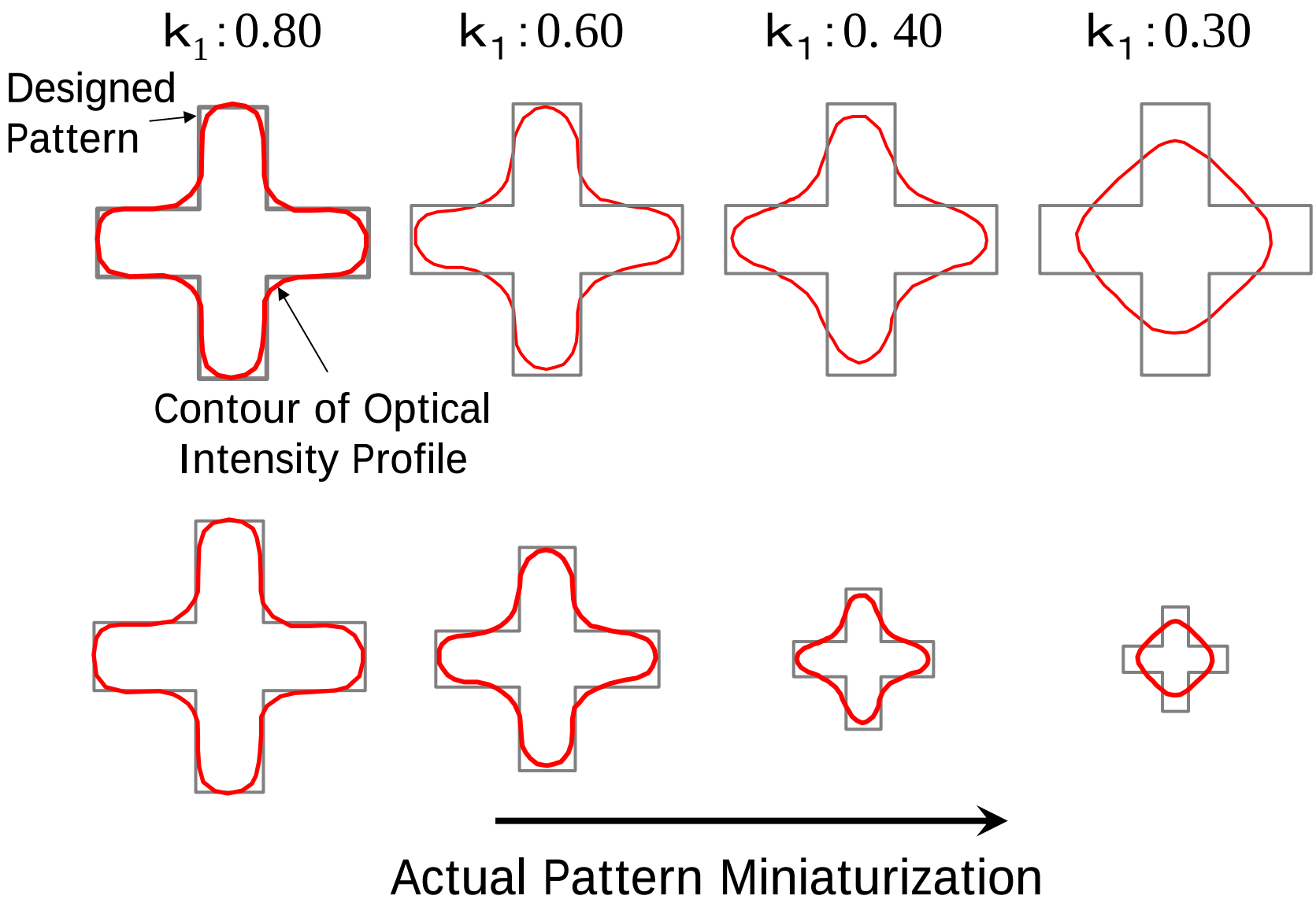
k_1 Factors

Year		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
hp(nm)		130	115	100	90	80	70	65	58	50	45	40	36	32	28	25	22
ArF Dry	0.75	0.51	0.45	0.39	0.35	0.31	0.27	0.25	0.23	0.19							
	0.85	0.57	0.51	0.44	0.40	0.35	0.31	0.29	0.26	0.22	0.20						
ArF Immersion Water	1.1			0.57	0.51	0.46	0.40	0.37	0.33	0.28	0.26	0.23	0.21				
	1.3				0.61	0.54	0.47	0.44	0.39	0.34	0.30	0.27	0.24	0.22			
ArF Immersion High Refractive Index	1.4					0.58	0.51	0.47	0.42	0.36	0.33	0.29	0.26	0.23	0.20		
	1.6						0.58	0.54	0.48	0.41	0.37	0.33	0.30	0.27	0.23	0.21	
EUV	0.25							1.20	1.07	0.93	0.83	0.74	0.67	0.59	0.52	0.46	0.41
	0.30								1.29	1.11	1.00	0.89	0.80	0.71	0.62	0.56	0.49
	0.35									1.30	1.17	1.04	0.93	0.83	0.73	0.65	0.57

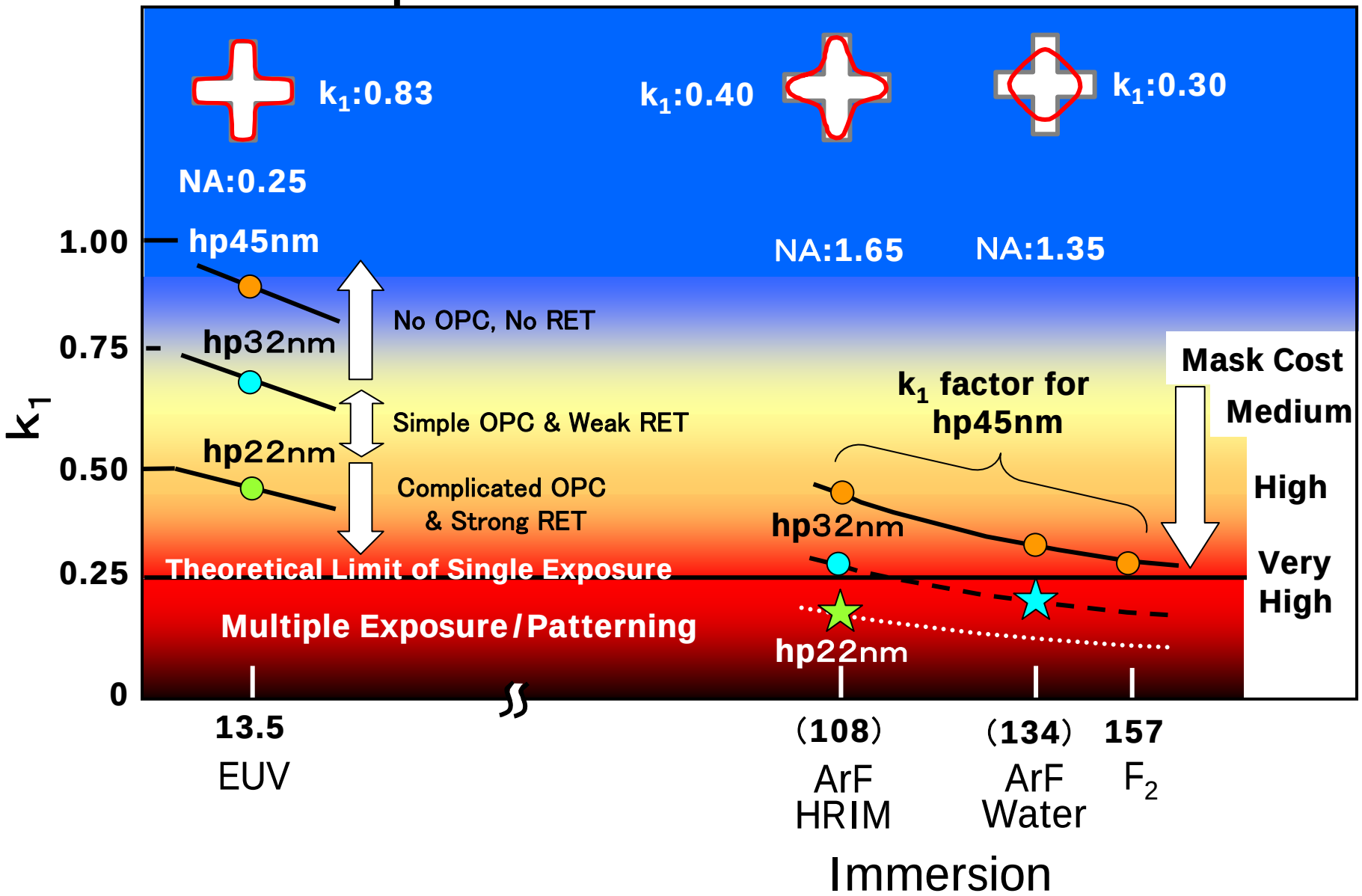
Double Patterning

Conventonal $k_1 > 0.5$ Weak RET $k_1 > 0.38$ Strong RET $k_1 > 0.25$

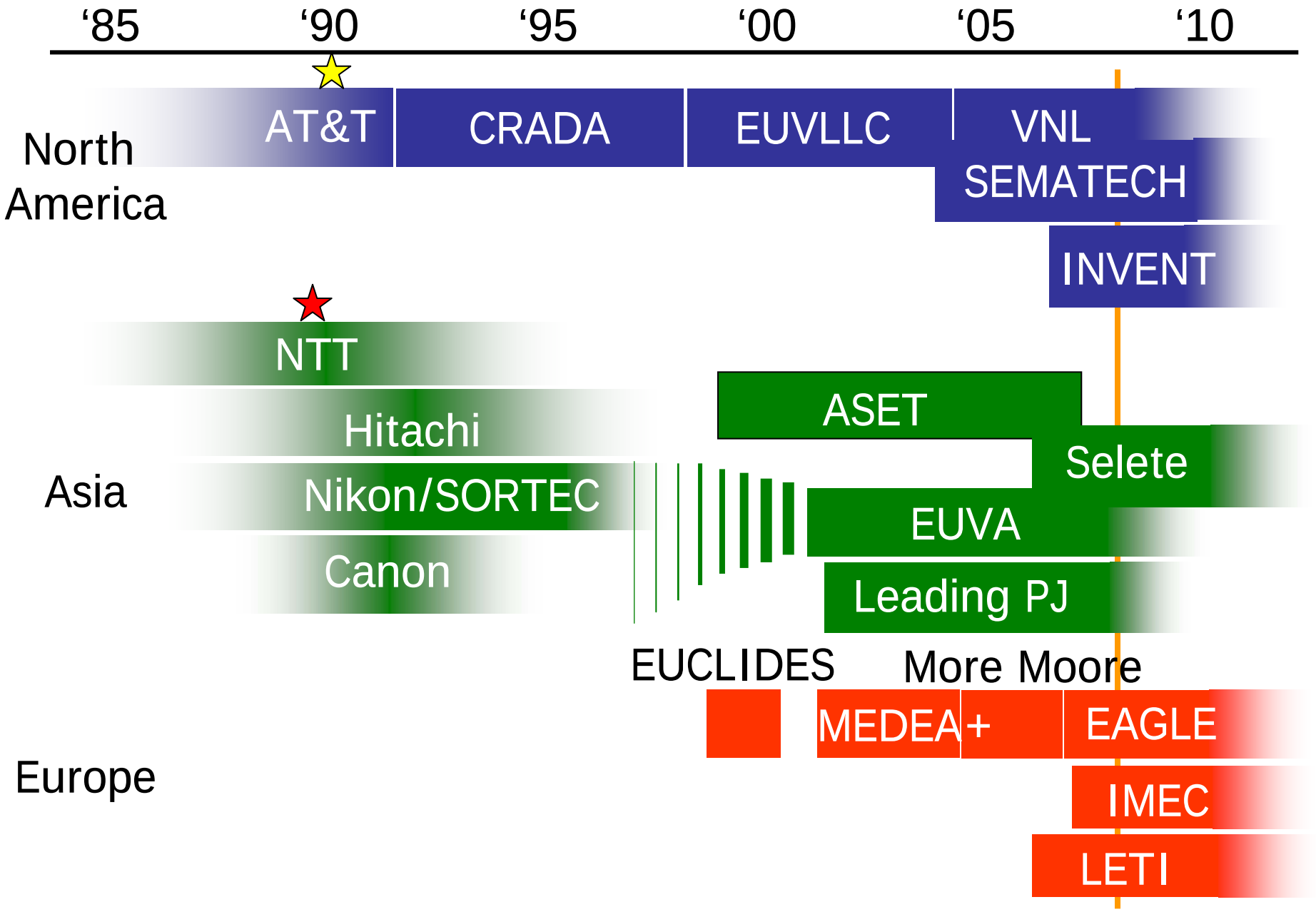
k_1 Factor and Pattern Deformation



Comparison of k_1 Factor: Optical vs. EUV



History of EUVL Developments



Pioneering Works of EUV Lithography

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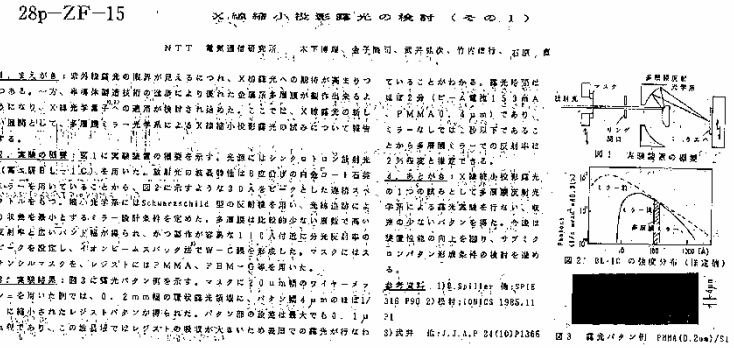
H. Kinoshita et al, Japan Applied Phys. Society Fall Meeting
Abstract No. 28p-ZF-15 p322 (1986) (Japan Domestic)

Soft x-ray reduction lithography using multilayer mirrors

H. Kinoshita, K. Kurihara,[a] Y. Ishii, and Y. Torii
NTT LSI Laboratories, 3-1 Morinosato Wakamiya, Atsugi-shi, Kanagawa 243-01, Japan

(Received 30 May 1989; accepted 11 July 1989)

A soft x-ray lithograpy using multilayer mirrors for demagnifying optics and a reflecting mask has been designed and studied experimentally. In this system, a wavelength of 45–130 Å has been selected based on the optical characteristics, the exposed depth of the resist film, and the reflectivity of the multilayer mirror. To obtain a replication pattern resolution of 0.2 μm, the numerical aperture required is estimated to be greater than 0.0125 or 0.0325 for a wavelength of 50 or 130 Å, respectively. These values show that the multilayer optics using two mirrors can be realized to replicate a 0.2 μm pattern. The experiments were performed on the SR beamline BL-1 of the KEK-PF storage ring. The Schwarzschild demagnifying optics with a ring field were designed and fabricated. Demagnified exposure patterns of less than 0.5 μm have been obtained using a reflecting mask. The feasibility of the soft x-ray reduction method using multilayer mirrors has been confirmed. Furthermore, new telecentric optics are proposed to realize a practical reduction lithography system.


28p—ZF—15 ※縮小投影露光の検討（その1）

NTT 電気通信研究所 木下博雄、金子敏司、鈴井弘泉、竹内信行、石訳、貴

1. 目的：微細化の限界が見えるにつれ、X線露光への期待が高まりつつある。一方、半導体製造技術の進歩により従来の金属原子多層膜が製作出来るようになり、X線光学素子への適用が検討され始めた。ここでは、X線露光の新しい展開として、多層膜ミラー光学系による縮小投影露光の試みについて報告する。

2. 実験の概要：図1に実験装置の概要を示す。光源にはシンクロトロン放射光（高エネルギー研BL-1C）を用いた。放射光の波長特性は8度位の白色コート石英ミラーを用いていることから、図2に示すような30Åをピークとした連続スペクトルとなる。縮小光学系にはSchwarzschild型の反射鏡を用い、光軸近傍により収差を最小とするミラー設計条件を定めた。多層膜は比較的少ない層数で高い反射率と広いバンド幅が得られ、かつ製作が容易な11層交互反射膜のピークを設定し、イオンビームスパッタ法でW－C膜を形成した。マスクにはタングステンマスクを、レジストにはPMMA、PBM－Oを用いた。

3. 実験結果：図3に露光パターン例を示す。マスクに20μm幅のワイヤーパターンを用いた例では、0.2mm幅の環状露光領域に、パターン幅4μmの縮小1/5に縮小されたレジストパターンが得られた。パターン部の線幅は最大でも0.1μmであり、この結果からはレジストの感度が大きいため長時間での露光が行なわれていることがわかる。露光時間は縮小2倍（ビーム電流133mA、PMMA0.4μm）であり、ミラーなしでは、約1時間であることから多層膜ミラーでの反射率は2%内外と推定できる。

4. まとめ：X線縮小投影露光の1つの試みとして多層膜反射光学系による露光実験を行ない、収差の少ないパターンを得た。今後は装置性能の向上を図り、サブミクロンパターン形成条件の検討を進める。

参考文献：1) B.Spiller 他：SPIE 316 P90 2) 松村：IONICS 1985.11 P1 3) 武井 他：J.J.A.P 24(10)P1366

H. Kinoshita et al, J. Vac. Sci.Technol. B7(6) p1648 (1989)

Reduction imaging at 14 nm using multilayer-coated optics: Printing of features smaller than 0.1 μm

J. E. Bjorkholm, J. Bokor, L. Eichner, R. R. Freeman, J. Gregus, T. E. Jewell,[a] W. M. Mansfield, A. A. Mac Dowell,[a] E. L. Raab,[a] W. T. Silfvast,[b] L. H. Szeto, D. M. Tennant, W. K. Waskiewicz,[a] D. L. White,[a] D. L. Windt,[a,c] and O. R. Wood II
AT&T Bell Laboratories, Holmdel, New Jersey 07733-1988

J. H. Bruning
GCA Corporation/Tropel Division, Fairport, New York 14450

(Received 29 May 1990; accepted 19 July 1990)

We demonstrate high resolution reduction imaging in the soft x-ray spectral region using multilayer-coated reflective optics. In particular, a Schwarzschild objective was used at 20:1 reduction with 14 nm radiation to image line and space features from a transmission mask onto a resist-coated silicon wafer with a resolution better than 0.1 μm. The mirrors of the objective were coated with Mo/Si multilayers to provide nearly 40% reflectance at near-normal incidence for the 14 nm radiation. Our results demonstrate that multilayer coatings are capable of enhancing the reflectance of optical components at soft x-ray wavelengths without significantly degrading their imaging performance.

J. E. Bjorkholm et al, J. Vac. Sci. Technol. B8(6) p1509 (1990)

Overall EUVL Development Plan in Japan

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'98 '99 '00 '01 '02 '03 '04 '05 '06 '07 '08

ASET
Basic Technologies
100% Government Funded

Post ASET
α Tool & β Tools Development
Partially Industry Funded?

Production Tools Development

70nm Node & Below

Selete or Equivalent Consortium
Application Technology Development
Industry Funded?

Member Companies of ASET EUVL:

Fujitsu, Hitachi, Intel, Matsushita, Mitsubishi, NEC, Nikon, Oki, Samsung, Sanyo, Sharp, SONY, SPC, Toshiba

EUVL ASET

EUVL Development Plans in Japan

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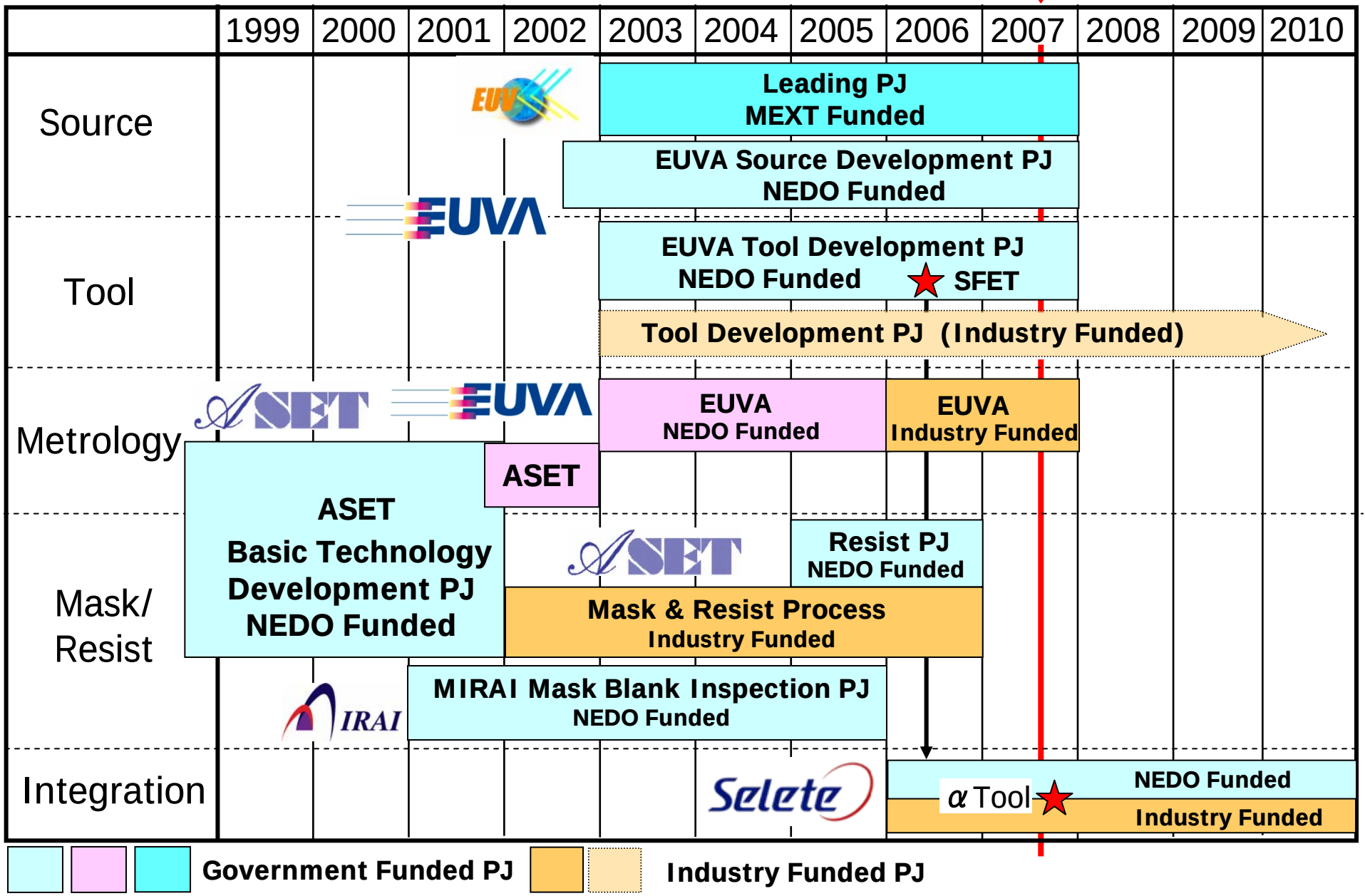

Comparison of Various Lithography Developments

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	Stepper / Scanner	KrF / ArF	RET / Immersion	EUV
1970	Mask Repeater			
1980	DSW g-line Industrial Use i-line	KrF Projection Experiment KrF Experimental Report KrF Stepper Application	Immersion Patent Alternate Phase Shift Mask Patents & Experiment Att Phase Shift Mask Patent	
1990	Scanner development Scanner Industrial Use	ArF Experimental Report KrF Industrial Use	Alternate PSM Rediscover Att. PSM. Experiment Att. PSM. Industrial Use	Experimental Reports
2000		ArF Industrial Use	Alternate PSM Industrial Use Immersion Rediscover Immersion Industrial Use	EUVLLC,EUCLIDES,ASET SEMATECH, EUVA, L-PJ MEDEA+, IMEC, LETI Selete
2010				?

International Collaboration is the Key for Early Industrial Application of EUVL

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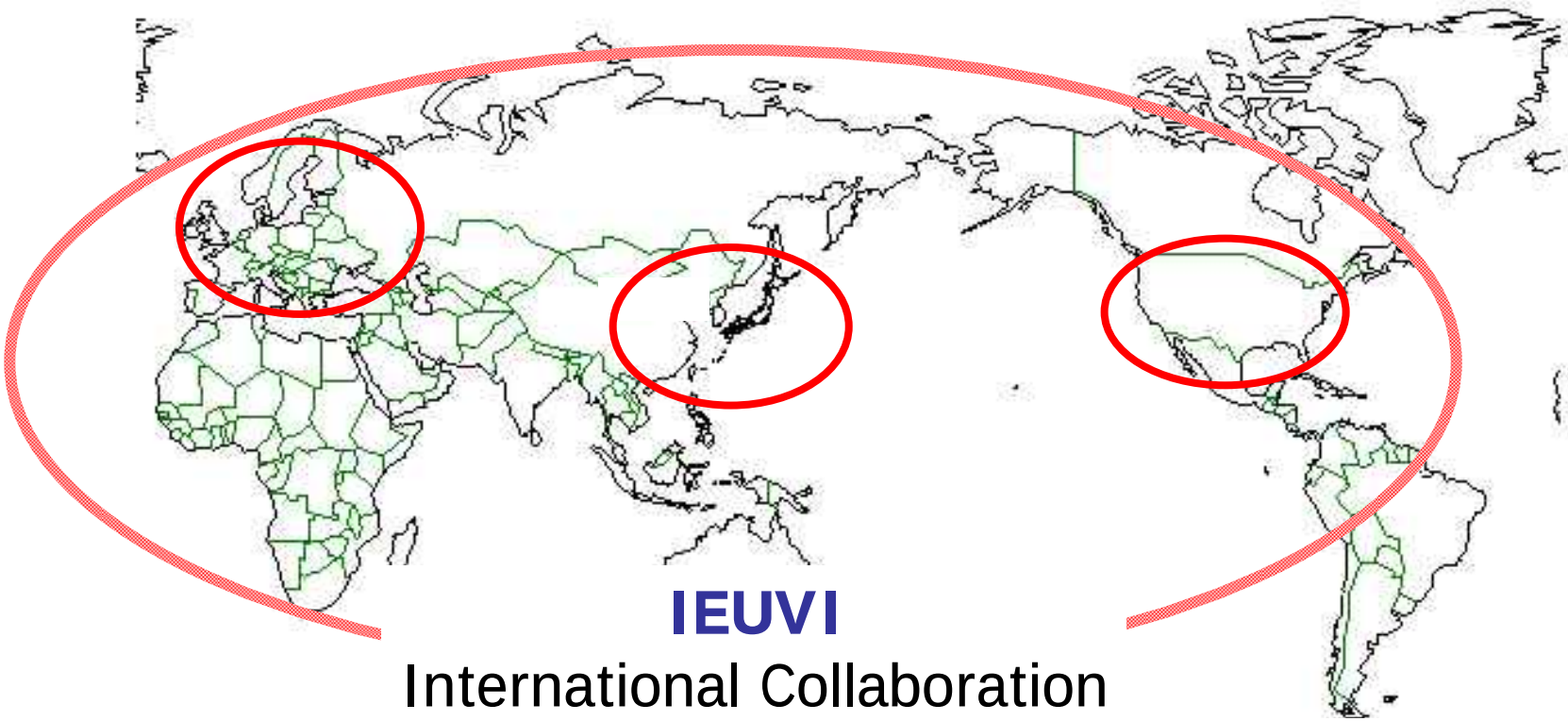

IEUVI

International Collaboration

MEDEA+
EAGLE
More Moore
EXTATIC, EUV Sources
EXTUMASK,EXCITE
EUCLIDES

Korea

EUVA, Leading PJ
Selete
ASET,MIRAI

SEMATECH-N, INVENT
VNL, Albany Nanotech
EUVLLC

Issues of EUV Lithography

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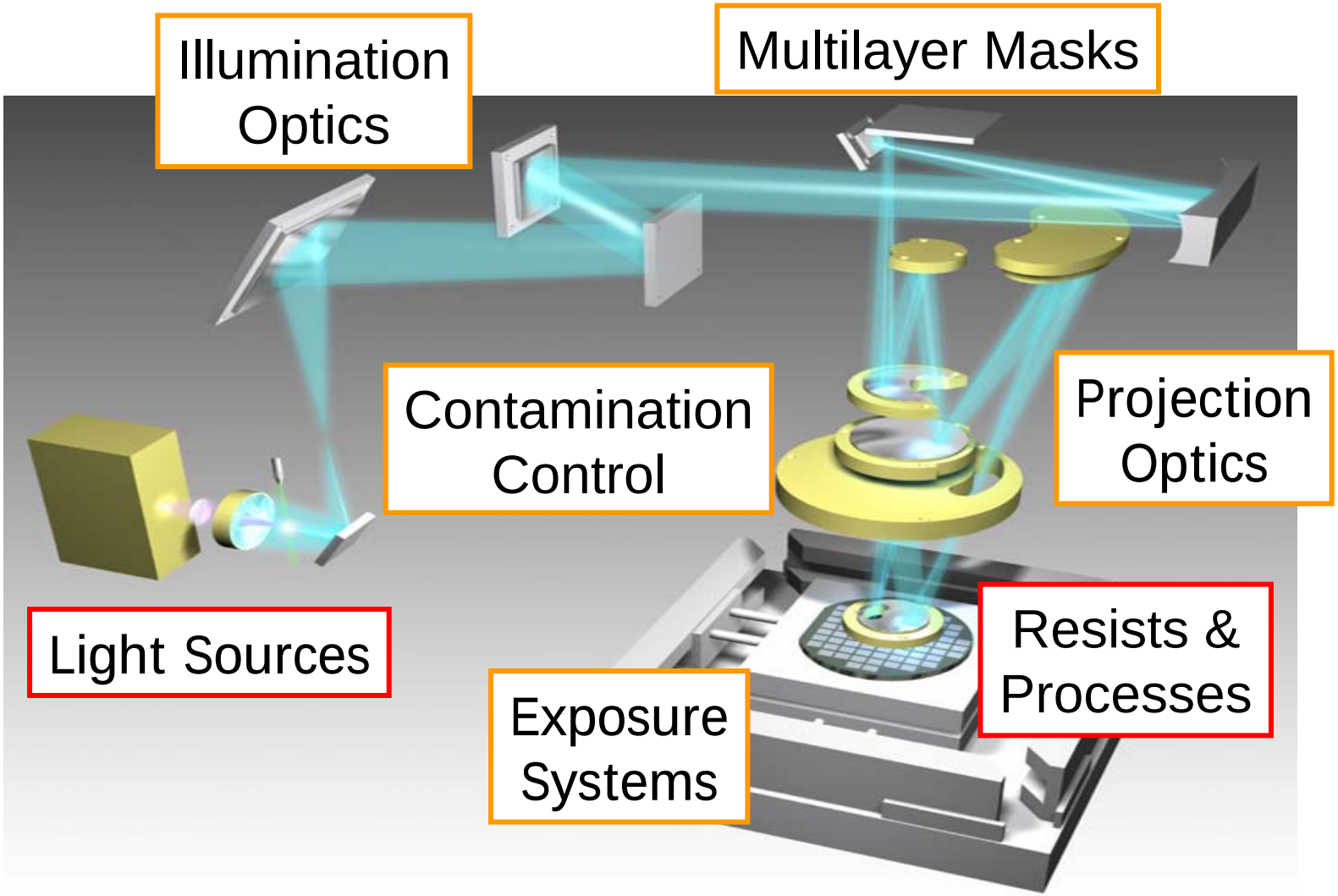

Development of EUVL Source

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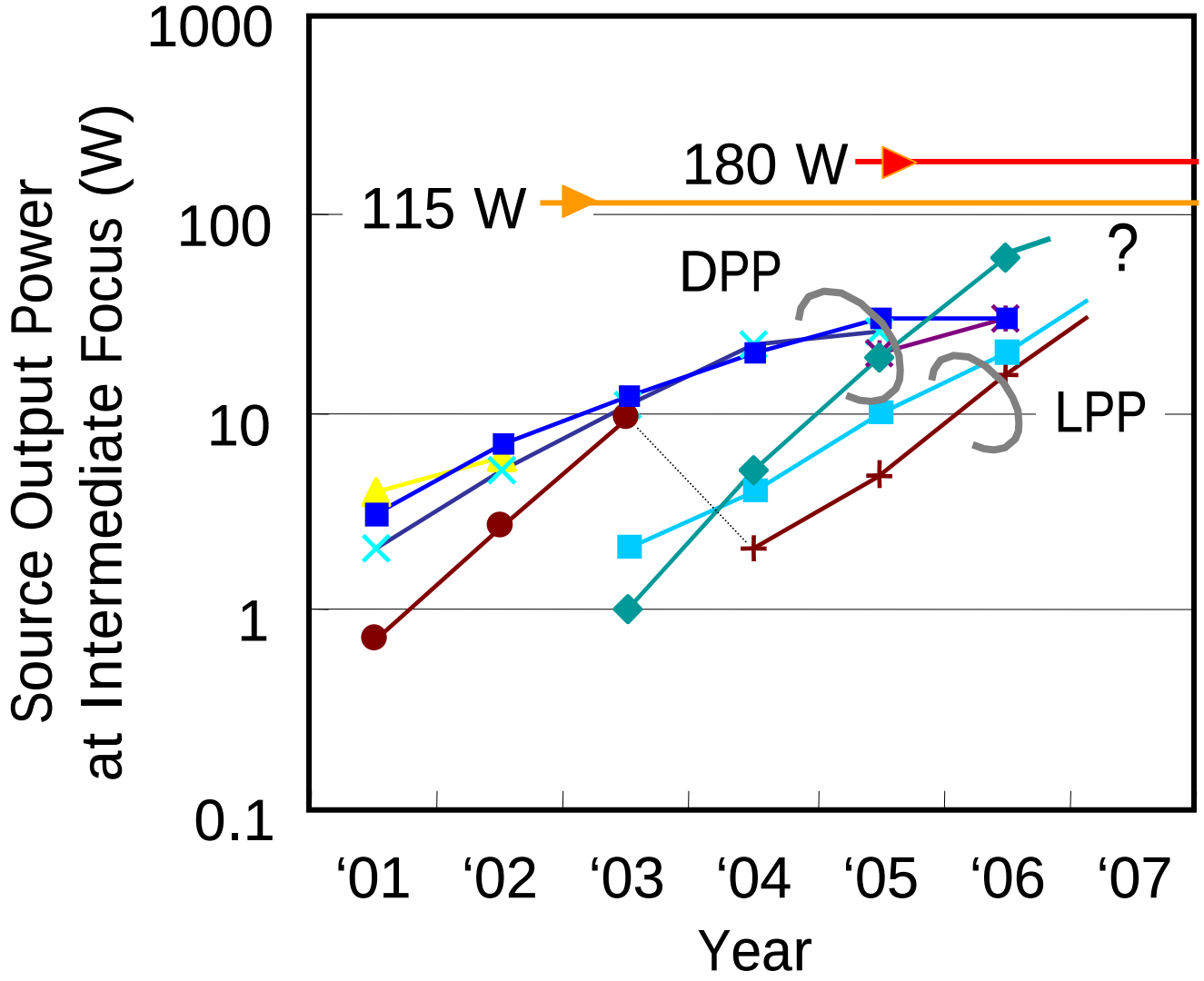

Source Output Power reported at EUVL Symposium

EUV Dose vs. Resolution & LER

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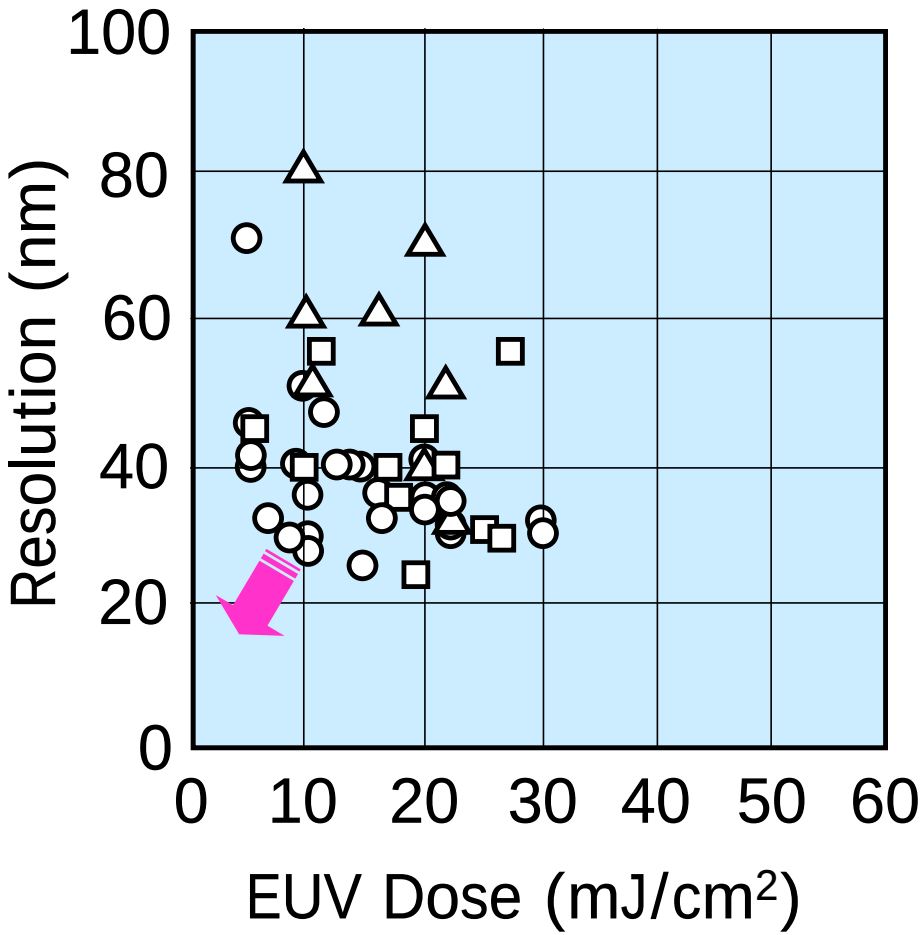
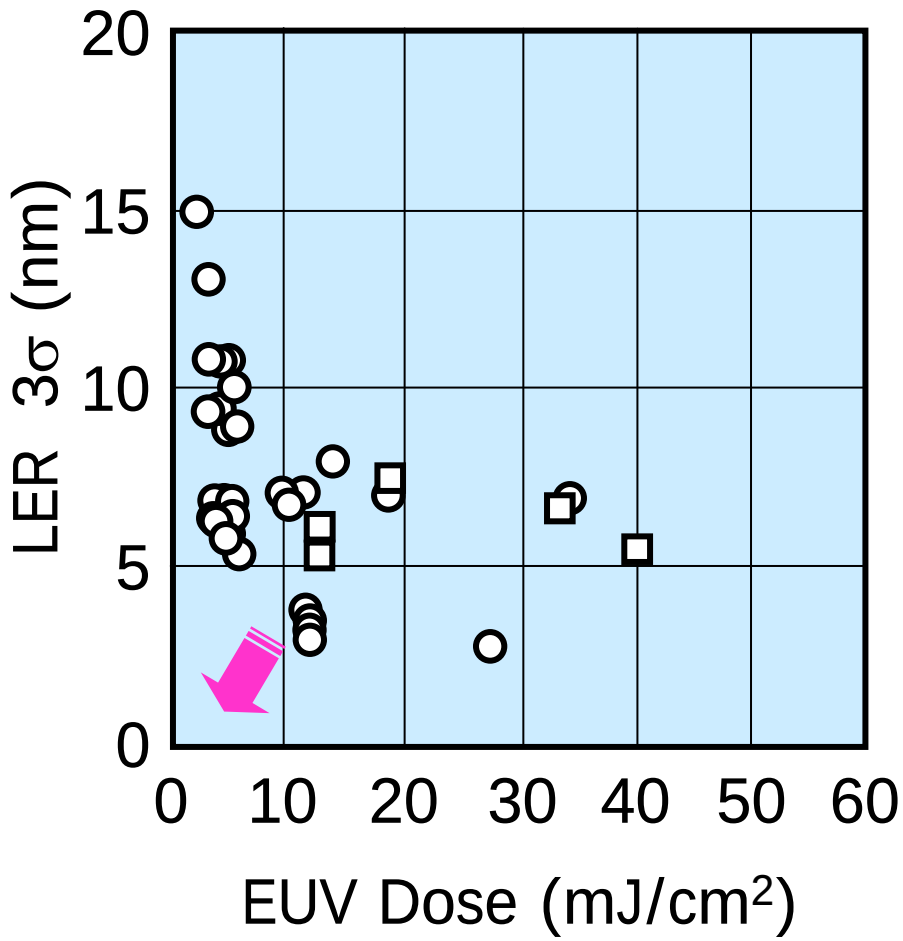
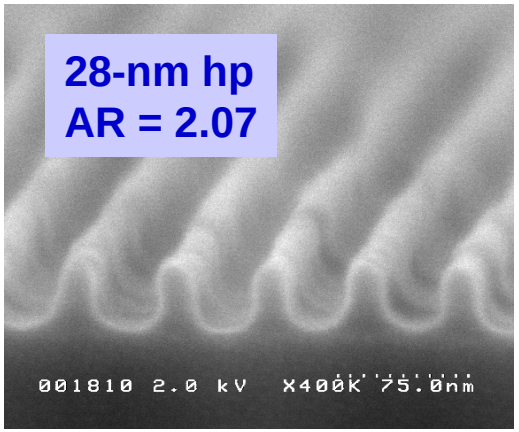
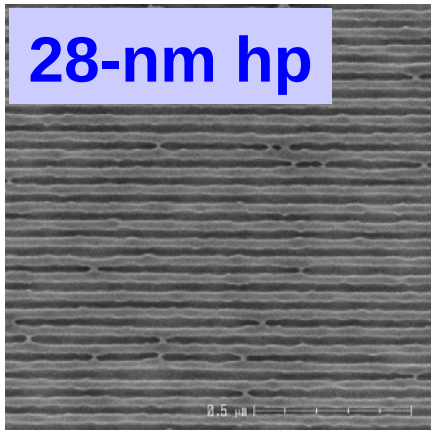


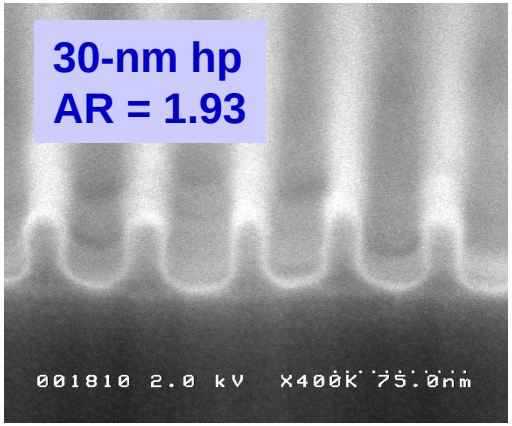


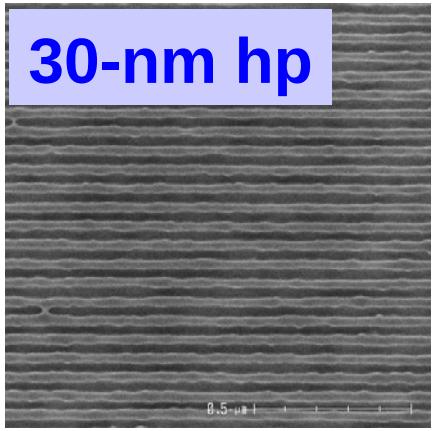
Molecular Resist

High resolution and improved LER are observed in Molecular Resist

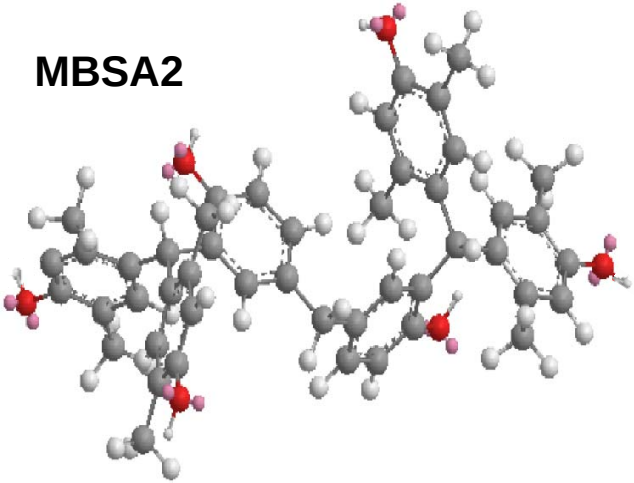






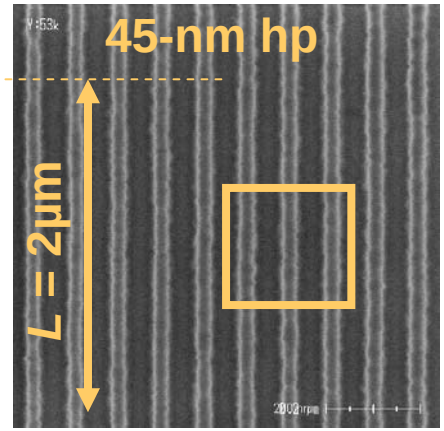


MBSA2



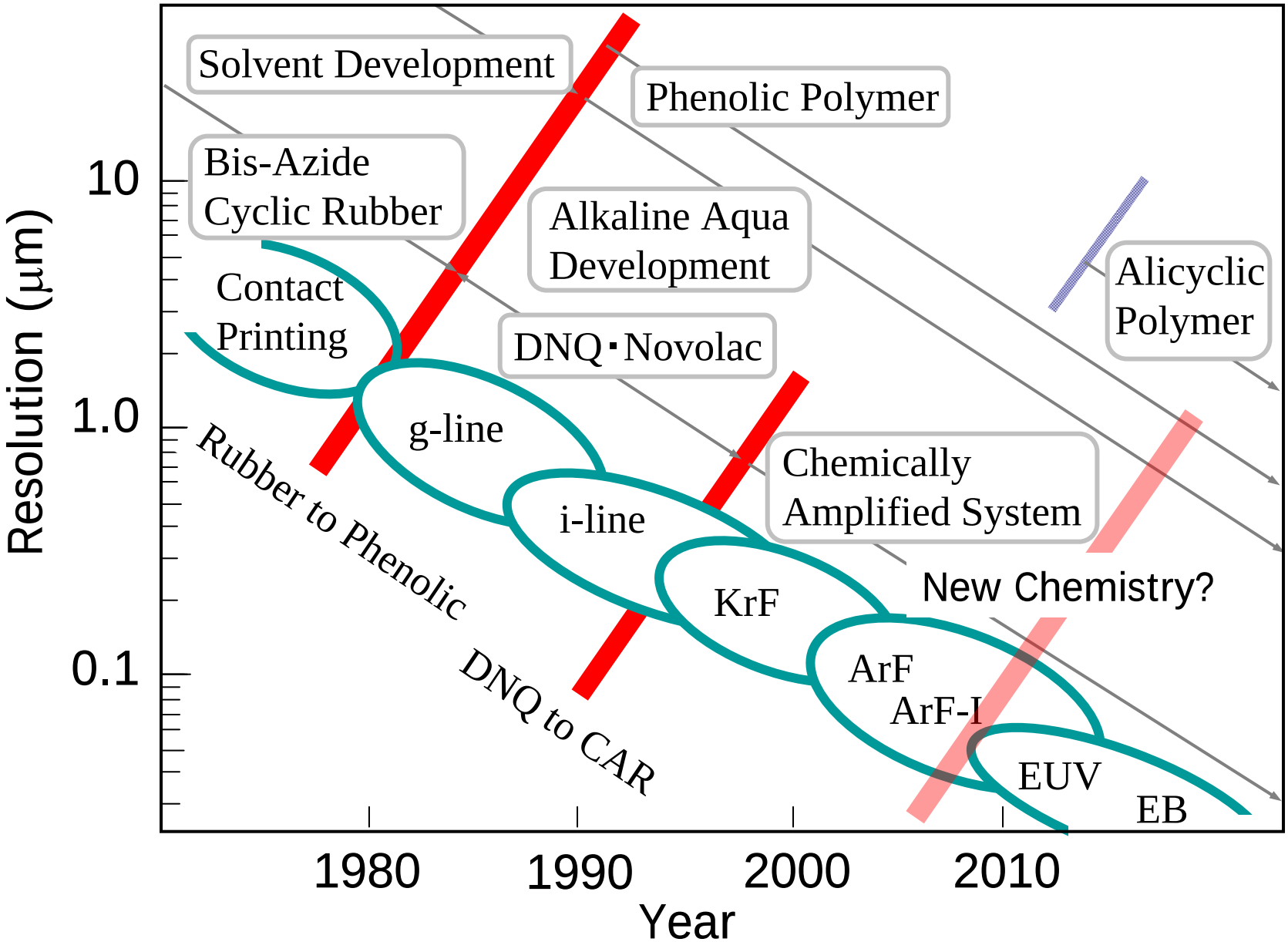
LER evaluation with 2 um measurement length

LER : 3. 4nm (3σ)



EUVL

Evolution of Resist Materials



Summary

1, EUVL moderates design layout constraints in 32 nm design rules and below.

2, No complicated OPC structures will be necessary for EUVL Masks.

3, Light source and resist materials developments are the key for industrial use of EUVL.
Not only a powerful source development, but also a new resist chemistry is really required.

4, International collaboration is indispensable to accelerate EUVL development.

5, Working with many colleagues in Japan and in the World was very enjoyable for me.

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Acknowledgements

I would like to express my sincere thanks to my colleagues of IEUVI, SEMATECH, VNL, MEDEA+, EUVA, Leading PJ, MIRAI, Selete, IMEC, CEA-Leti, Albany Nanotech, Researchers from other Research Institutes, University Professors, Company Engineers and ASET.

I appreciate contributions of colleagues of EUVLLC and EUCLIDES at the first stage of EUVL Developments.

I also thank to NEDO, METI and MEXT for supporting our EUVL Projects in Japan.

Thank you for your kind Attention!