TOSHIBA
Leading Innovation

2014 International Workshop on
EUV and Soft X-ray Sources

Expectation and challenges of higher NA EUV lithography

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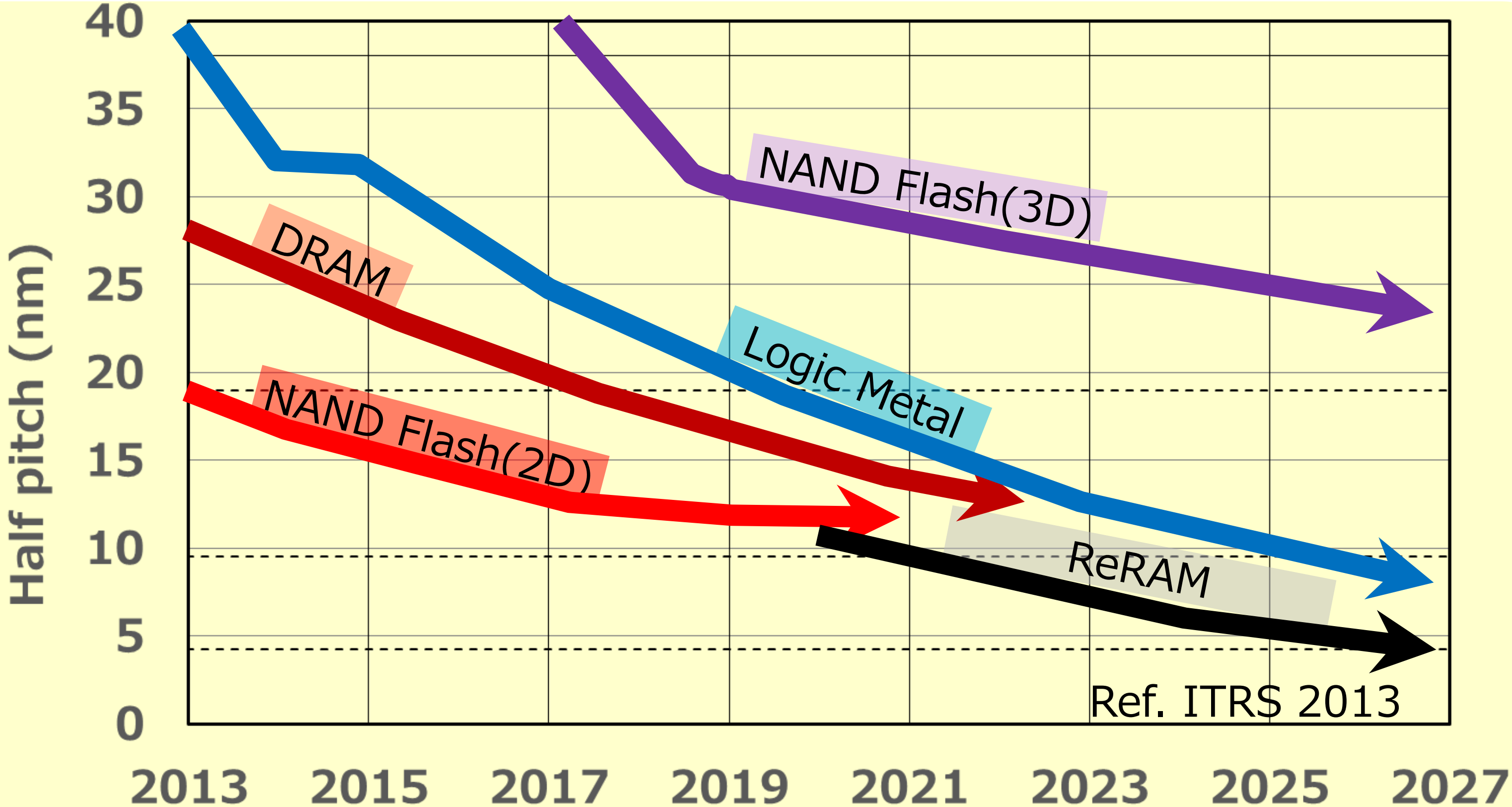
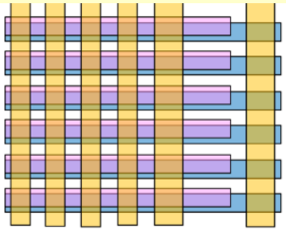
Introduction

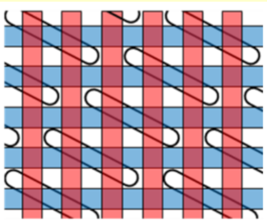
Lithography Challenges for advanced LSI

LSI scaling

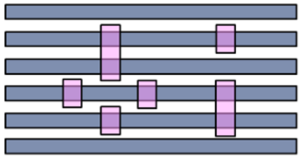




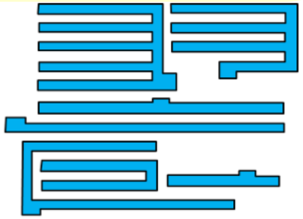
NAND flash



DRAM



Logic (MPU)



Random logic

Sub-10nm after 2020

Lithography for sub-10nm

- Extension of immersion lithography
  - 1D layout by SAxP + cut mask
    - L&S by SADP(19 nm)➔SAQP(10 nm)➔SAOP(sub-10 nm)
    - Cut mask by LE^8~ or NGL

Issues **Restrict design**
Complex process control
Long process steps
➔ **High cost**

- NGL
  - 2D layout by single exposure
    - High NA EUVL

Field size, Source, Optics, Resist

  - Bottom-up patterning
    - DSAL + EUVL

Overlay, Defectivity

We need NGL for sub 10nm with low cost!

EUV lithography for sub-10nm

The potential of EUVL is attractive.

$$\text{Resolution} = k1 \frac{\lambda}{NA}$$

λ : exposure wavelength
NA : Numerical Aperture
k1 : process constant[>0.25]

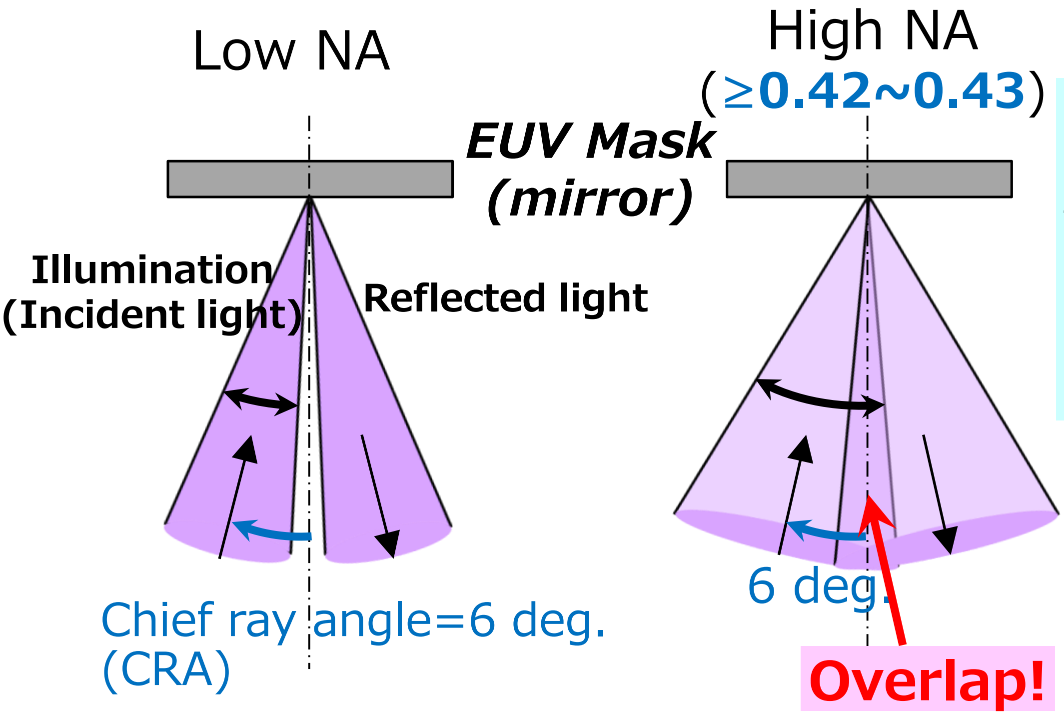
NA \ k1	0.40	0.35	0.30	0.25
0.25	21.6	18.9	16.2	13.5
0.30	18.0	15.8	13.5	11.3
0.33	16.4	**14.3**	12.3	10.2
0.35	15.4	13.5	11.6	**9.6**
0.40	13.5	11.8	10.1	**8.4**
0.45	12.0	10.5	**9.0**	**7.5**
0.50	10.8	**9.5**	**8.1**	**6.8**
0.55	9.8	**8.6**	**7.4**	**6.1**
0.60	9.0	**7.9**	**6.8**	**5.6**
[illegible]	[illegible]	[illegible]	[illegible]	**5.2**
0.70	7.7	**6.8**	**5.8**	**4.8**

NA ≥ 0.55 will be desirable.

Concerns for high NA EUVL

- **High NA EUV tradeoff**
  - Resolution(high NA) / full field (throughput)/ 6 inch mask
- **High power source**
  - Power loss by increasing in mirror number and pellicle
  - Low sensitivity resist
- **Optics for high NA and high power**
  - Increase in NA (> 0.5)→ Tighter mirror roughness and aberration specification for larger mirror
  - Damage due to high power EUV light
    - ML mirror, mask and Pellicle durability
- **Resist for high NA**
  - RLS tradeoff: Resolution / LER / Sensitivity ~shot noise issue

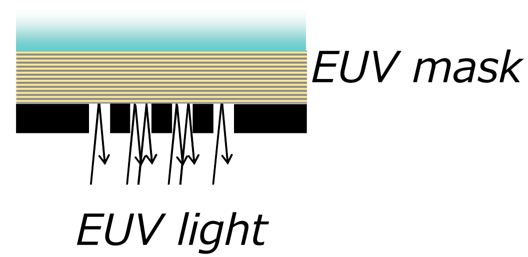
High NA EUV trade-off : EUV optics



Countermeasure

<u>1) Increasing CRA :</u> <u>Difficult</u>

Because of pattern shift in defocus due to mask 3D effect



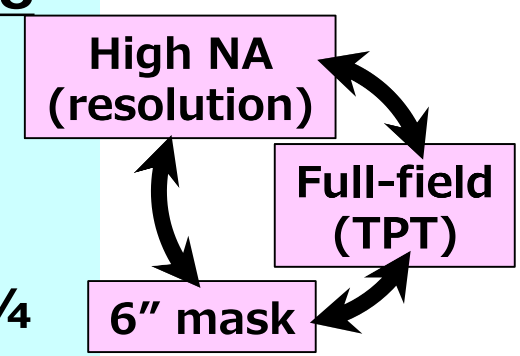
<u>2) Reduction ratio change from 1/4 to 1/6 ~ 1/8 with keeping CRA=6 deg.</u>

2-1) Increasing mask size to 9 inch . : Difficult

Because of the renewal of mask infrastructure

2-2) Decreasing of exposure field size to ½ or ¼

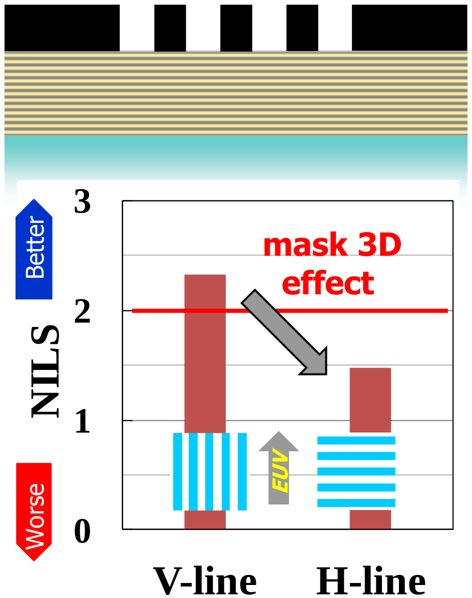
Challenge for TPT (concern about CoO)



Etched ML pattern for high NA EUVL

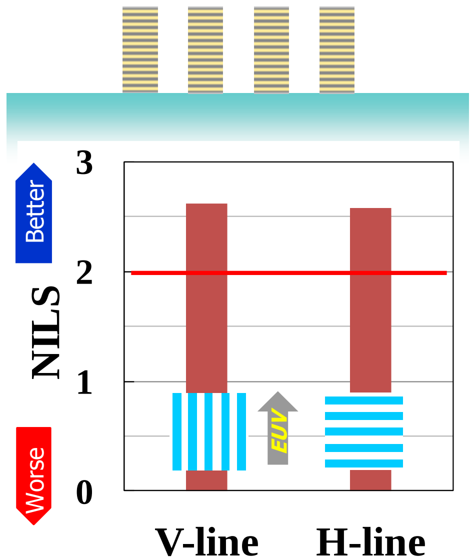
In order to overcome the tradeoff of high NA EUVL, mask structure is optimized.

Ta based absorber

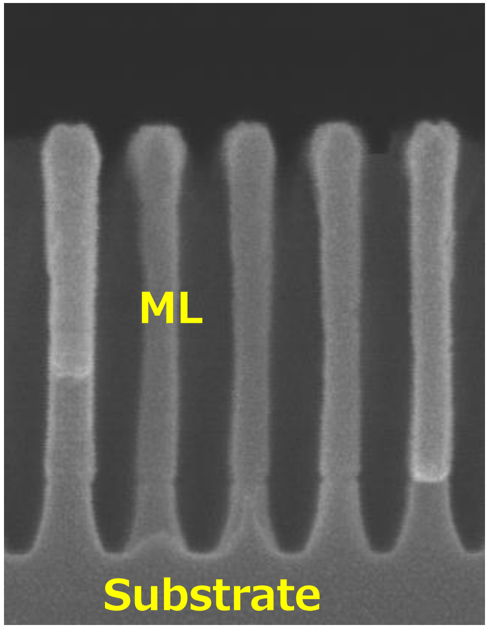


lower mask 3D effect

Etched Multilayer



After HM/Ta removal



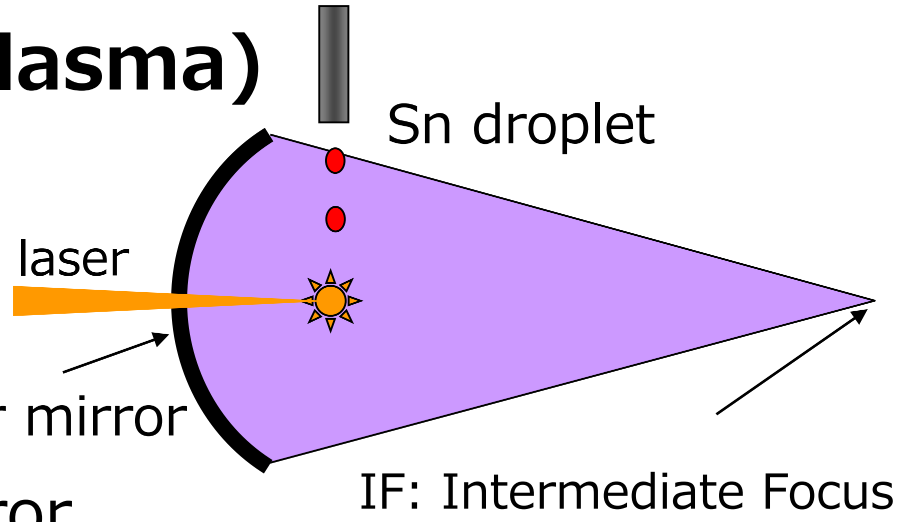
Takashi Kamo, et al, 2013 International Symposium on Extreme Ultraviolet Lithography

Etched multilayer L/S pattern of 40 nm hp on mask (10 nm hp on wafer using 4X optics) is achieved.

→**Enabler of high NA, 4X full-field and 6 inch mask**

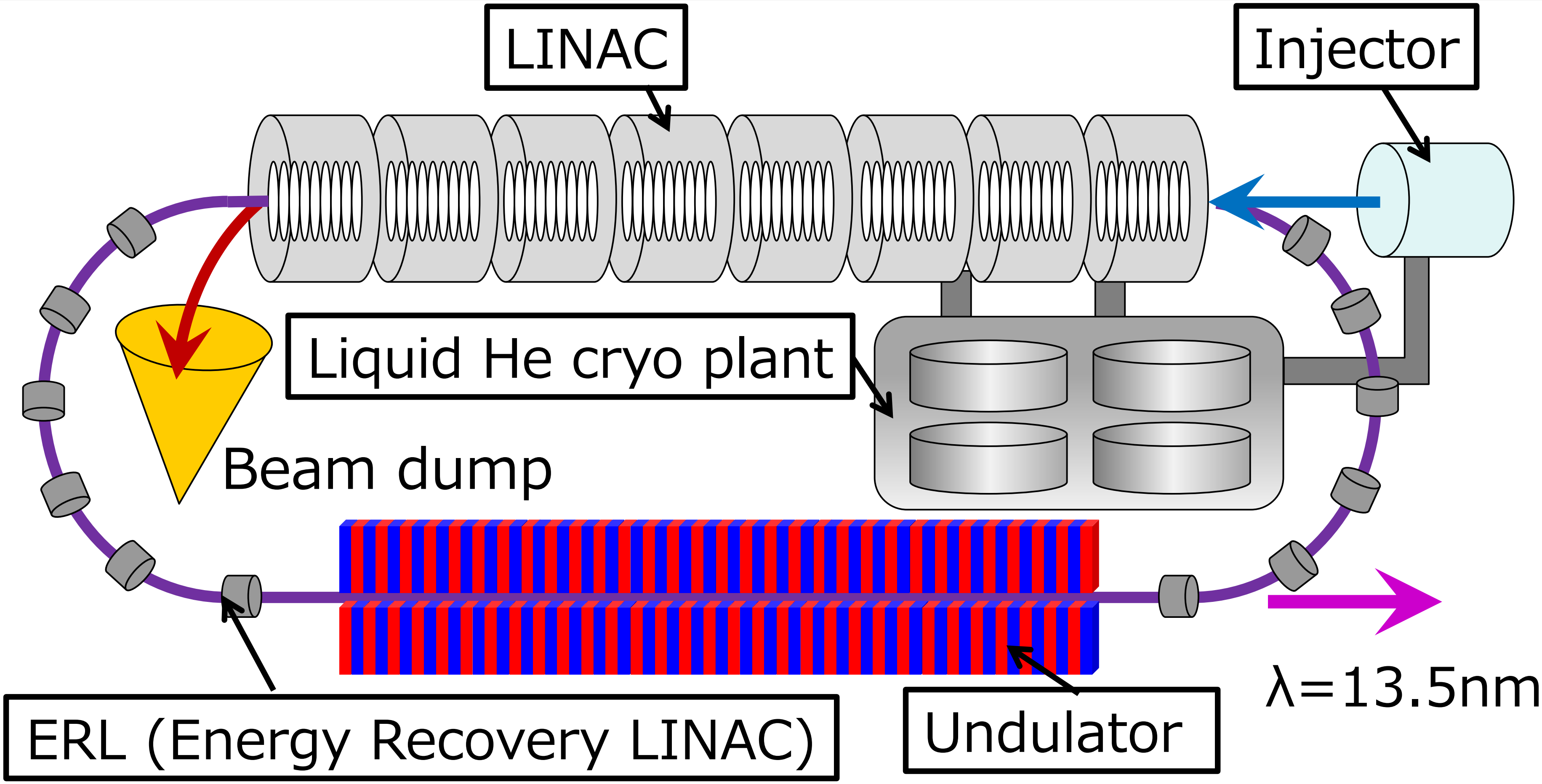
High power EUV source

- **LPP(Laser Produced Plasma)**
  - **Current level: 40~60W**
  - Challenges
    - Heat treatment
    - Debris
    - Lifetime of collector mirror
    - Running cost



- **Target of source power: 250 W in 2015**
- **Big gap between target and current level**
- **High NA EUVL will need higher power**
- **Scalability of LPP source to >> 250 W ?**

FEL for EUV source



An FEL has the potential of high power source, for example over 10kW to multiple scanners.

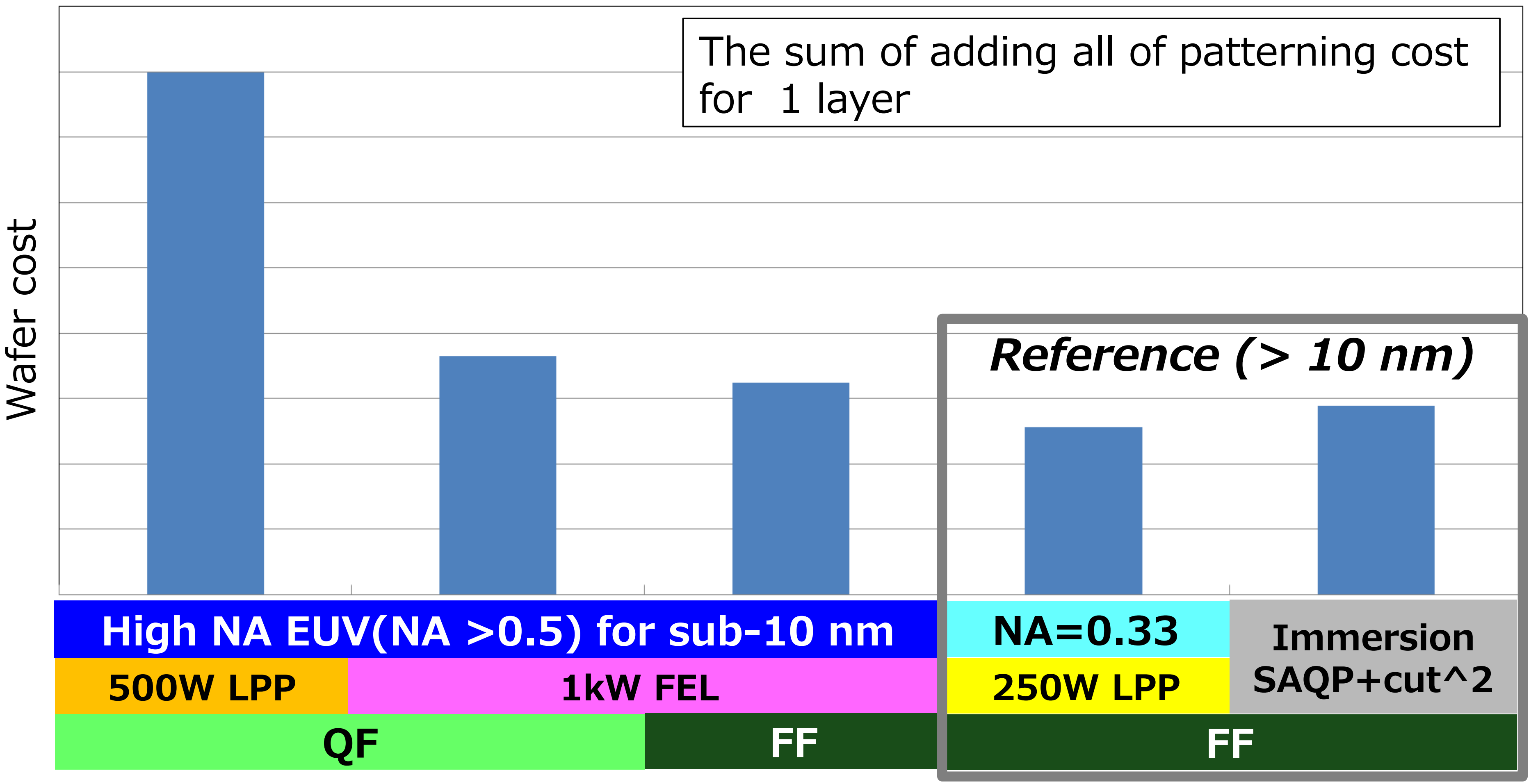
But FEL for EUV source is still in the conceptual stage.

Concerns for FEL

- Proof of concept; FEL of λ=13.5 nm with high power of > 10 kW
- Availability for 365D/24H
- Impact for wafer cost
- Electrical power consumption
- Facilities size
- Timely readiness; long lead items

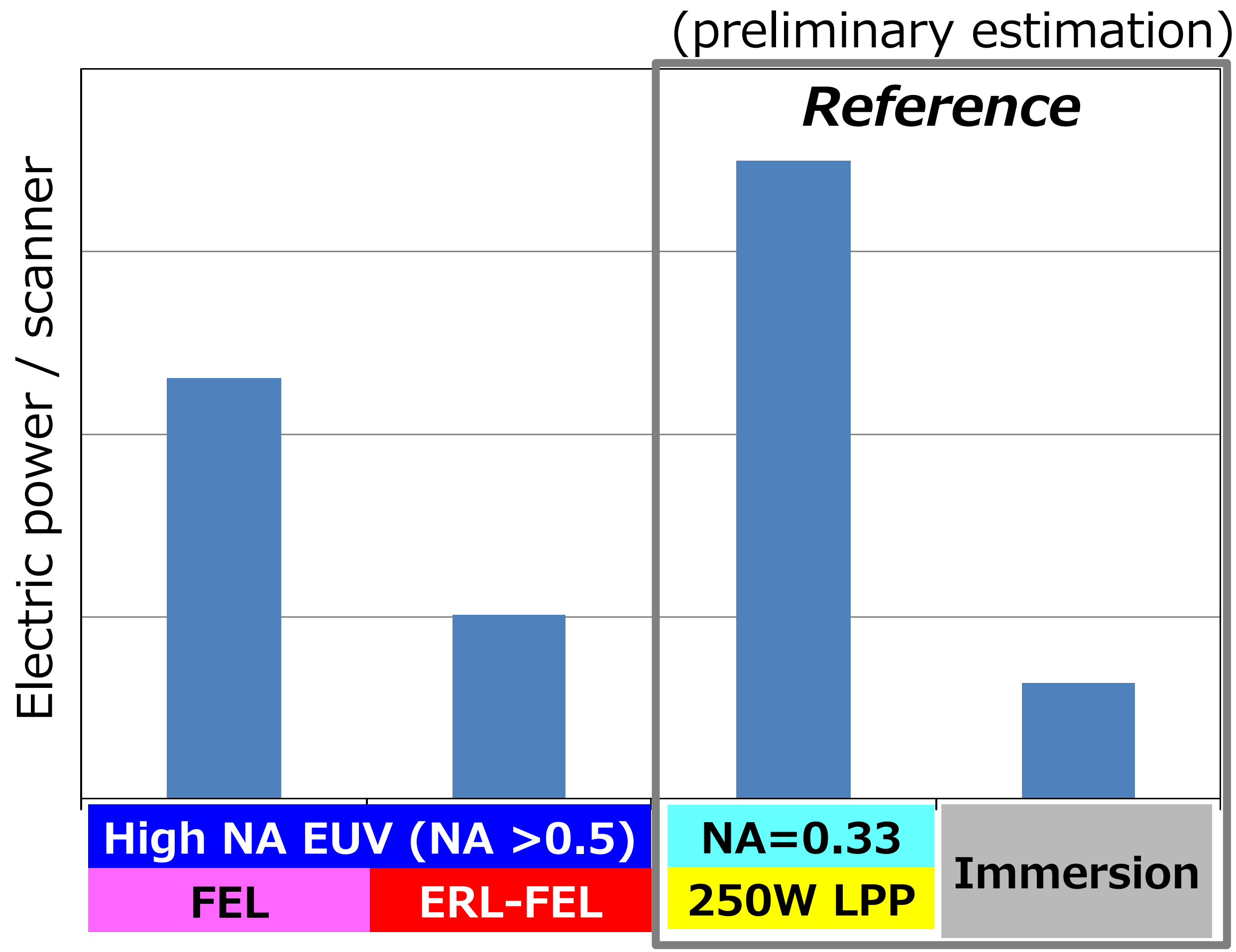
Comparison of wafer cost

(preliminary estimation)



Wafer cost of FEL is expected to be lower than LPP.

Electric power consumption



ERL will reduce the electric power consumption of FEL.

Concerns for FEL

- **Proof of concept; λ=13.5 nm / > 10 kW**
  - ***?? Need research and development***
- **Availability for 365D/24H**
  - **Redundancy system**
- **Impact for wafer cost**

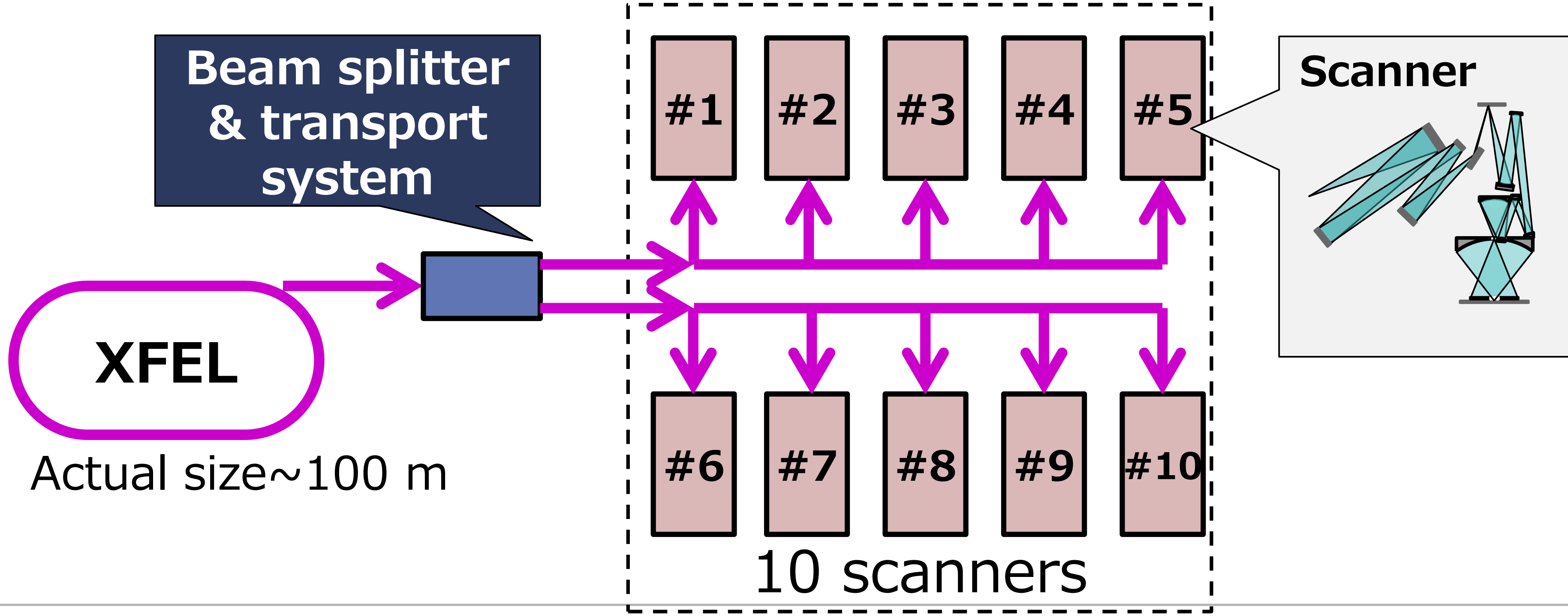
There are many challenges for high power EUV-FEL.
But nothing will be a show stopper, technically.
Careful and sufficient optimization will be required.

- **Facility size**
  - **Very large underground facilities (~100 m)**
- **Timely readiness; long lead time items**
  - **Long term project management**

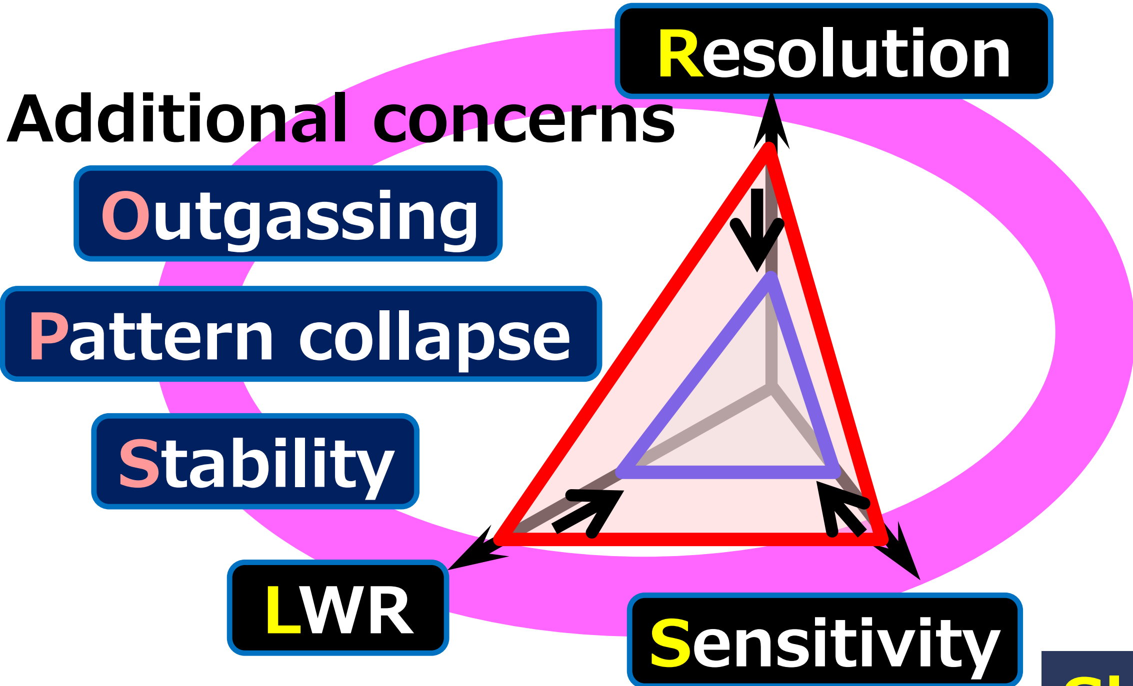
Optics for high NA and high power

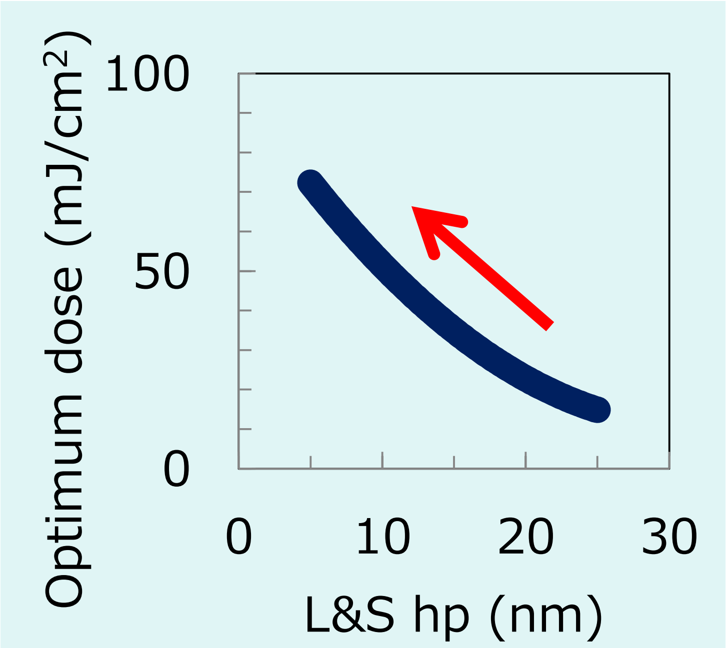
- Increase in NA (≥ 0.6) leads the specification of mirror roughness and aberration tighter.
- Damage due to high power EUV light for all optics (e. g. beam splitter and transport system, ML mirror, mask and pellicle)

→ Concern for durability



EUV resist tradeoff

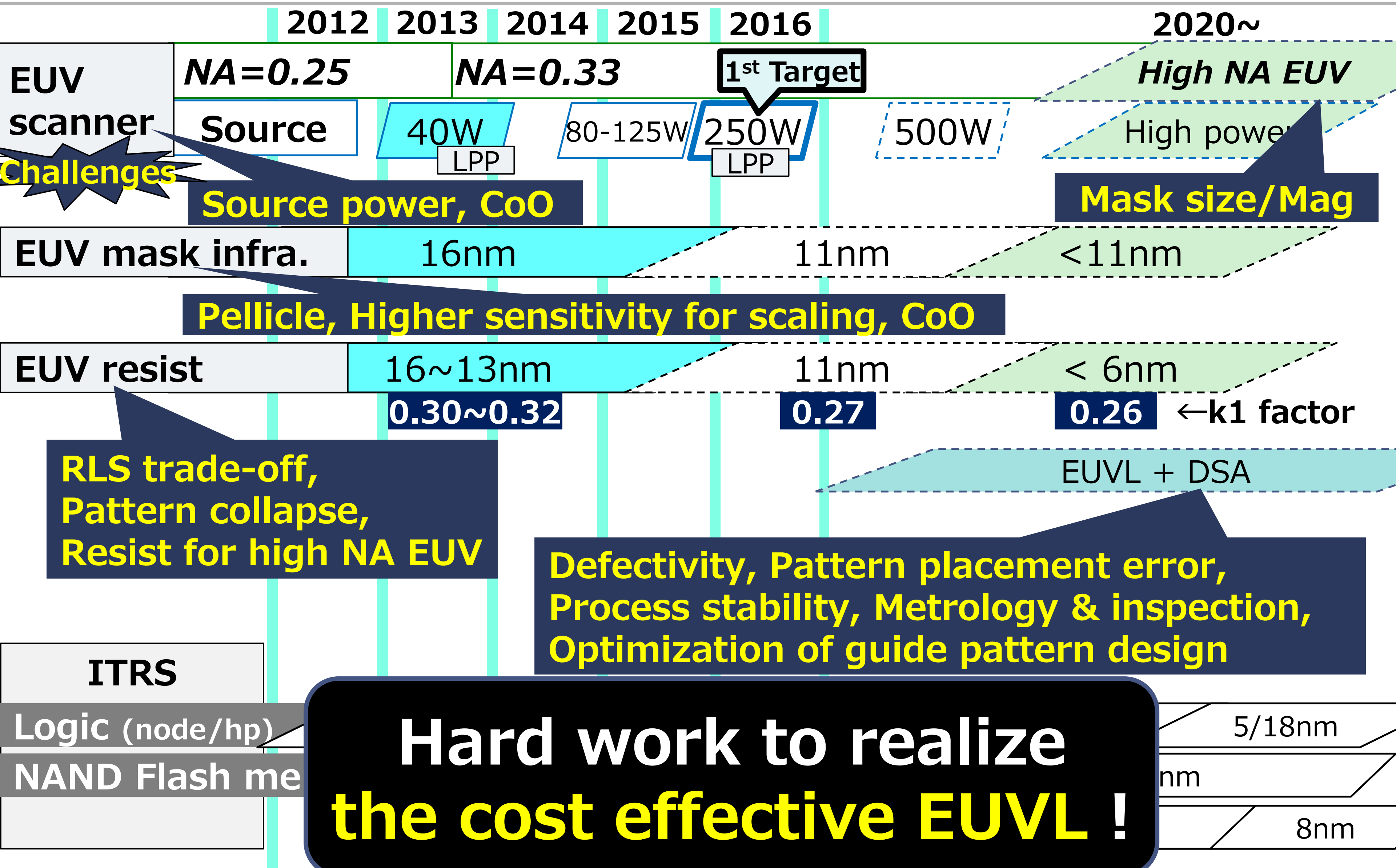




Shot noise!
➔ Higher dose for smaller hp

Difficult to overcome RLS tradeoff.
We need high resolution 1st for sub-10 nm.
Not only CAR but also alternative platform resist such as inorganic resist should be considered more.

Trend of EUV lithography



Summary

Summary

- **High NA EUVL** is the most promising candidate for sub-10 nm lithography, because of its patterning potential.

- We should take our best effort to establish **cost effective** high NA EUVL.

- There are many **concerns** for high NA EUVL.
  - Etched ML mask will enable **4X full-field 6 inch mask**.
  - **Higher power source** will be required for sub-10 nm. An FEL is one of the candidates for future high power EUV source.
  - **Damage** due to high power EUV light for all optics is concern for durability.
  - Alternative platform **resist** should be considered more for sub-10 nm.