E for Extension

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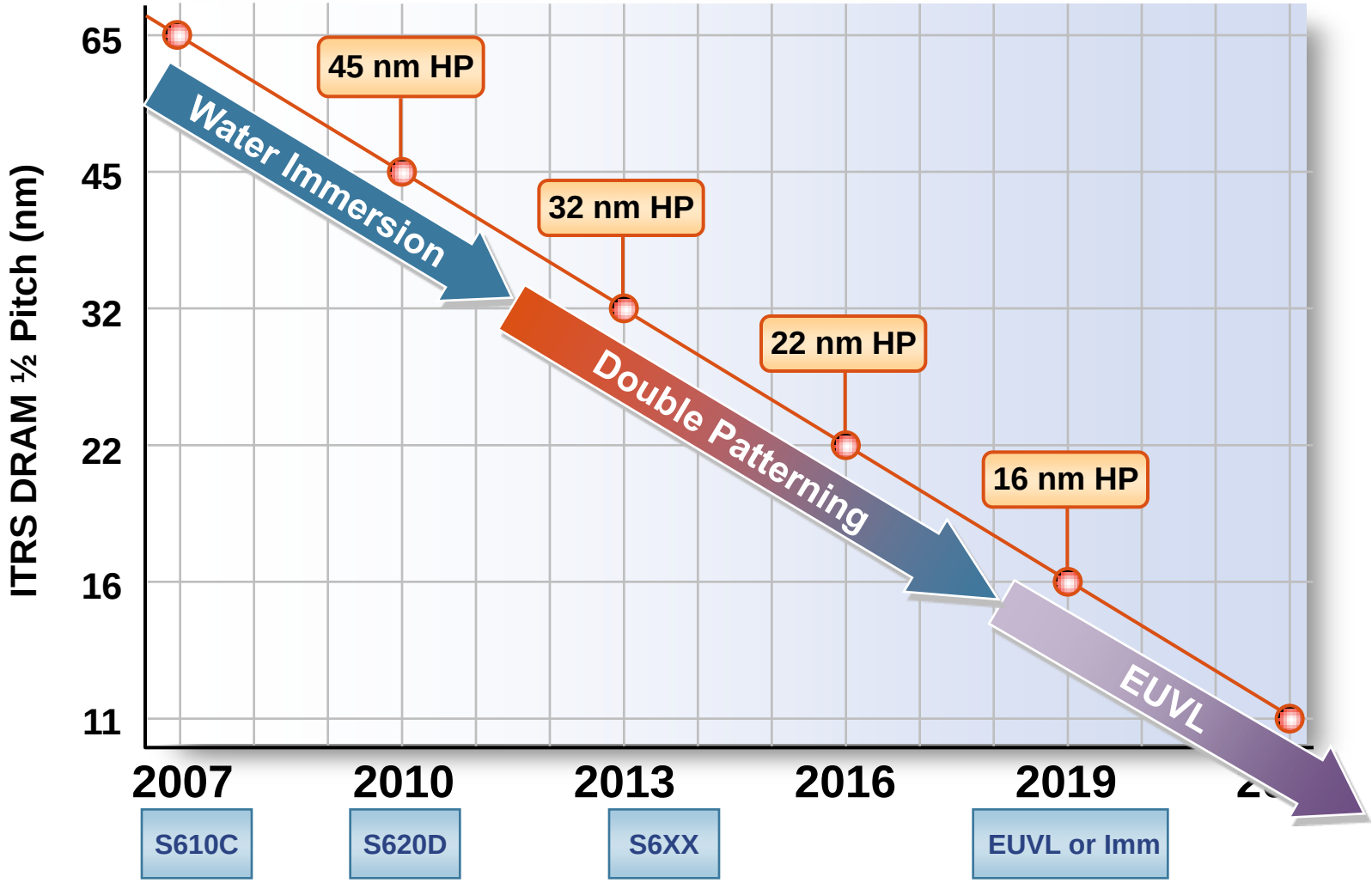
Engineering Development

Photo: J. Mabel

Photo: A. Pingstone

- Both of these were designed at the same time
- One appeared to be clearly superior
- One was more successful

Lithography Roadmap



ArFi extension takes us to 22 nm at least

EUVL and Optical Extensions

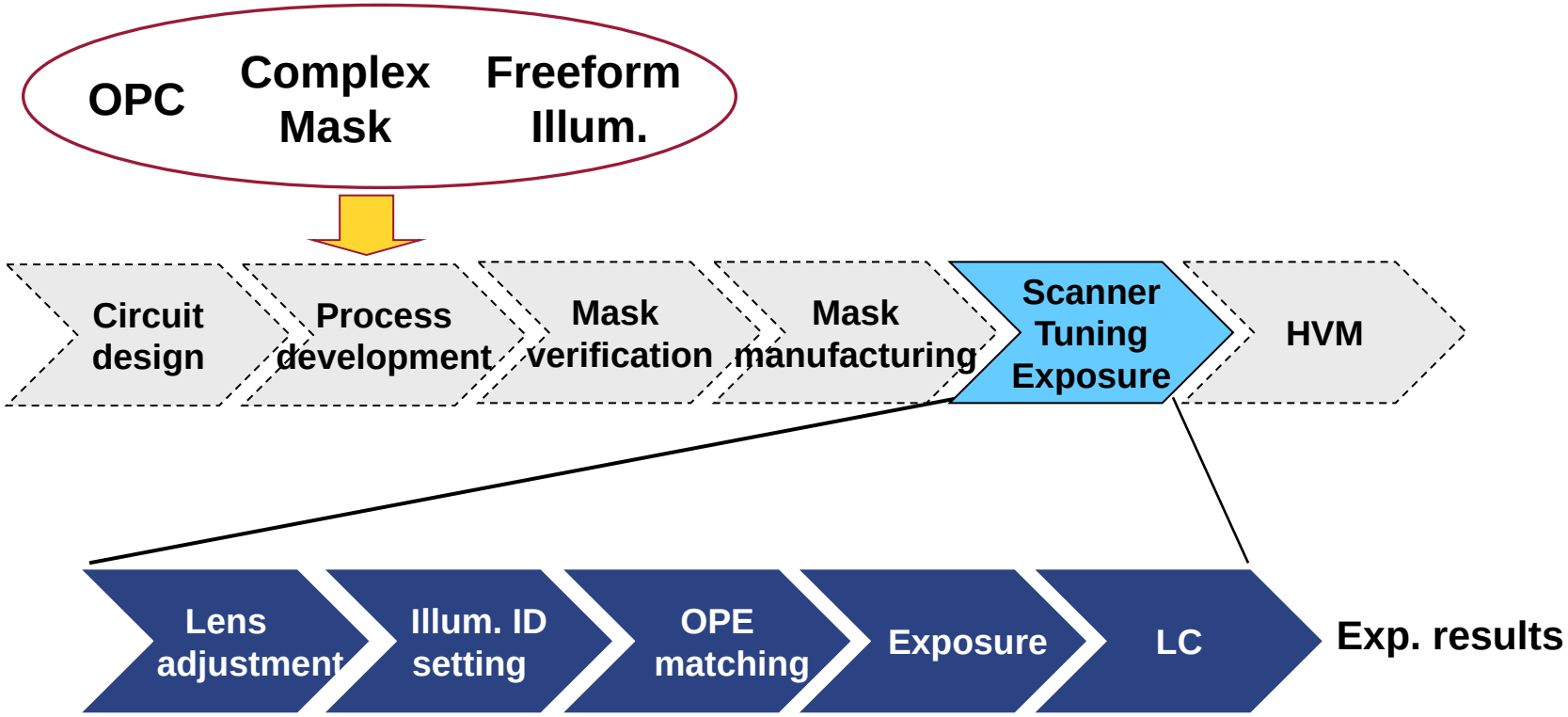
Photo: A. Pingstone

Successful technologies get extended

1. EUVL clearly offers unbeatable resolution, but its adoption has been delayed due to challenges in parts of the infrastructure or “ecosystem” including light sources and resist.
2. Nikon will support ArF extension to ~20 nm hp while continuing development of EUVL for possible use at 16 nm and beyond.

Today's Low k_1 System

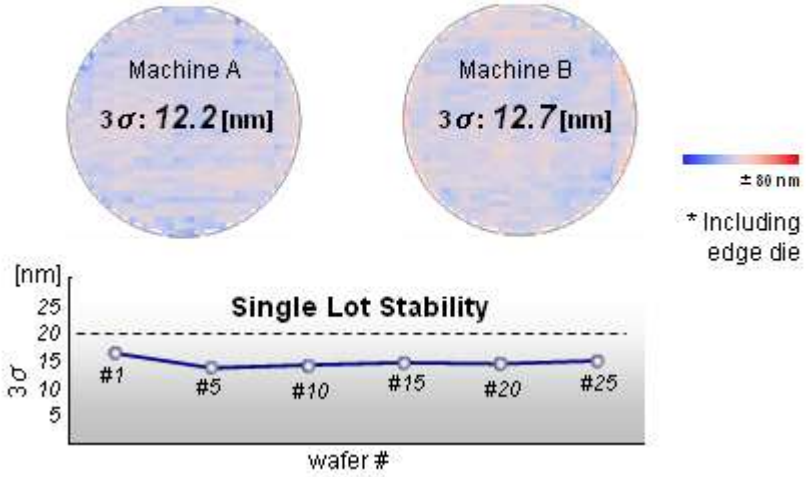
- Aircraft were extended by complicated aerodynamic calculations
- Similarly, ArFi is extended by computational lithography



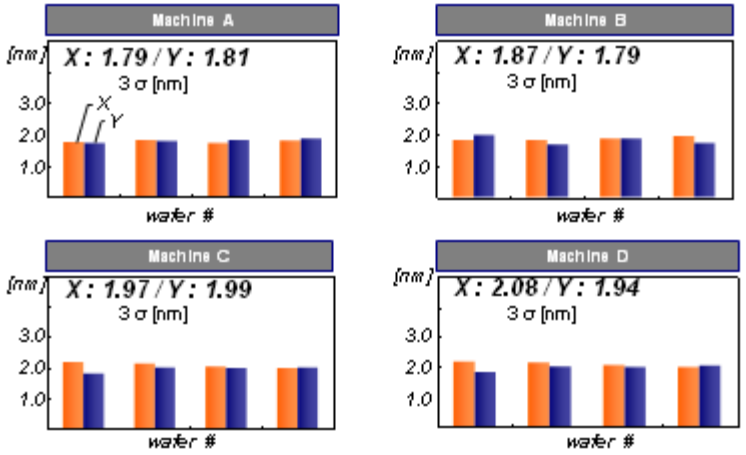
Systematic & automatic tool setting techniques are needed

State-of-the-Art Tooling – S620D

Focus Uniformity and Stability

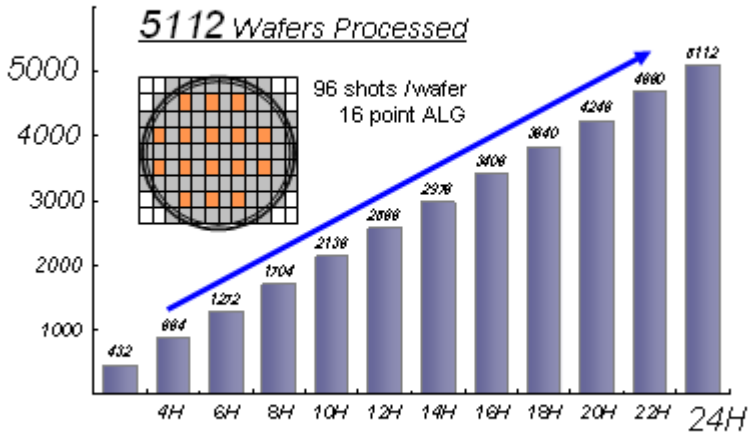


Single Machine Overlay



Overlay 2 nm at 700 mm/s

5000 wpd In-house Running



5000 wpd has been Demonstrated

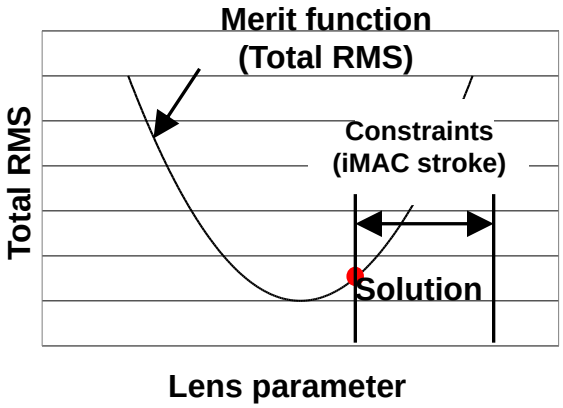
System Needs for ArFi Extension

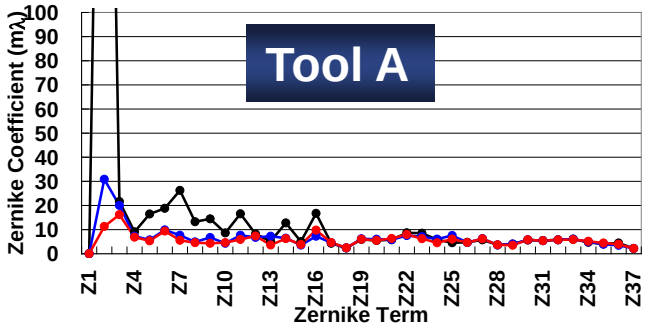
- Body:
  - Very precise overlay to support Double Patterning
  - Reduction of focus variation
- Optics:
  - Automatic lens setup
  - Custom illumination and software to support OPE signature matching
  - Programmable illumination for OPC/OPE control and for SMO
  - Tight control of thermally-induced lens aberrations
- General:
  - Reduction of CDU variation via scanner corrections
  - Support of other lithographic methods

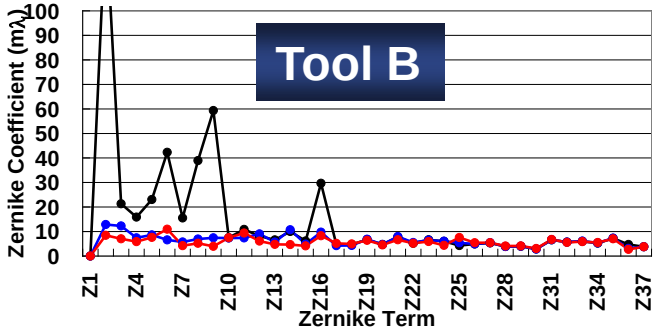
Lens Aberration Optimizer for Auto-Setup

- Global lens aberration optimization available
- Lens aberration customization (NA, Field, Pattern dependent)

Mathematical method





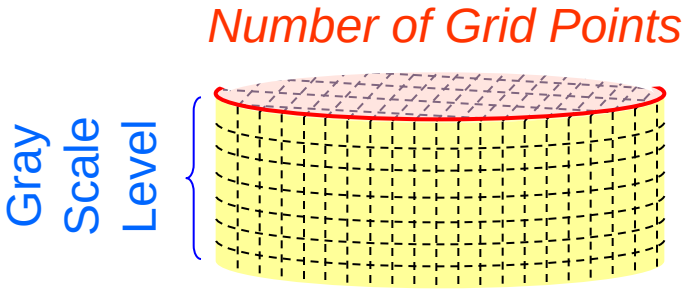


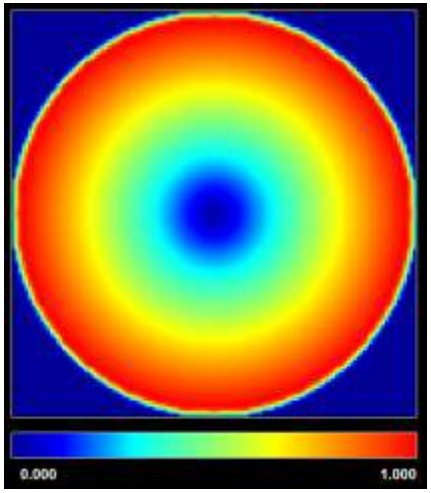
Pre Optimization
Expert Engineer
LFC

LAO automatically optimizes the lens just like a skilled human expert

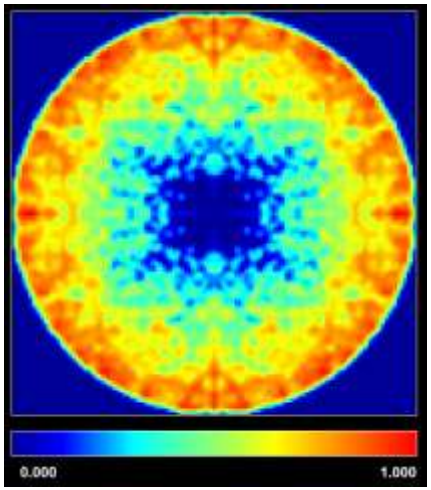
Pupilgram Control: Intelligent Illuminator

- Pupil fidelity vs. DPF
  - degree of pupilgram freedom:
    Gray scale level × number of grid points

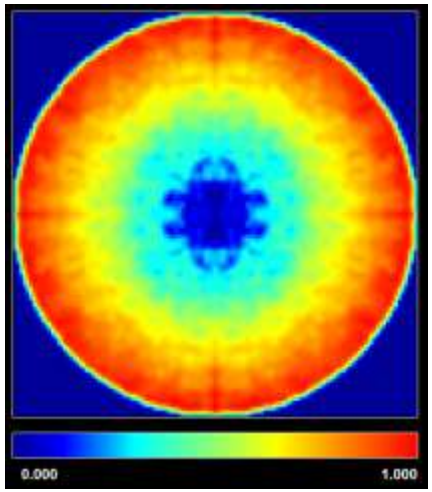




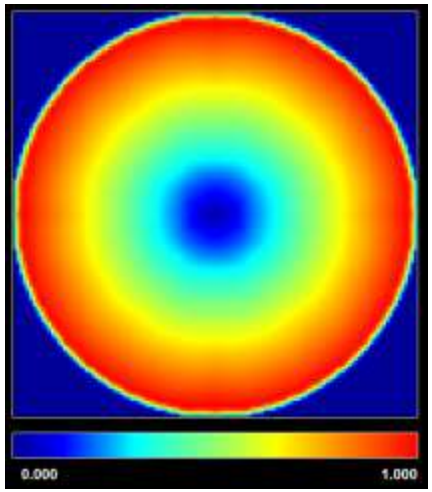
Target



DPF = 4000



DPF = 10,000

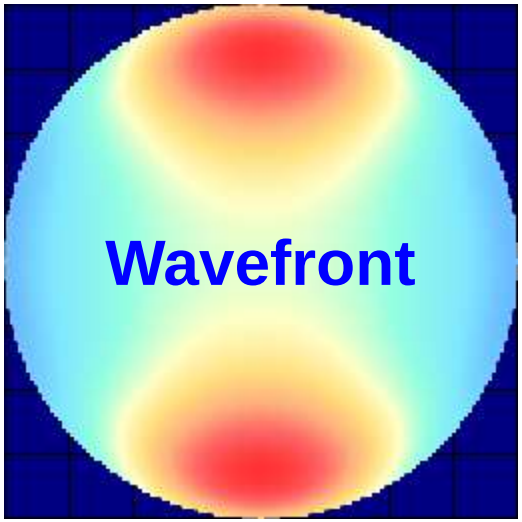


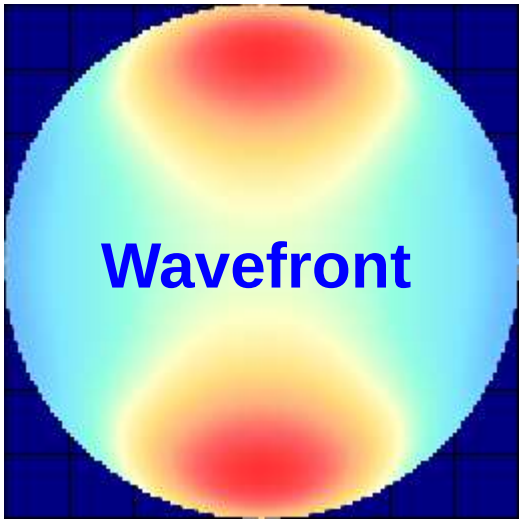
DPF = 100,000

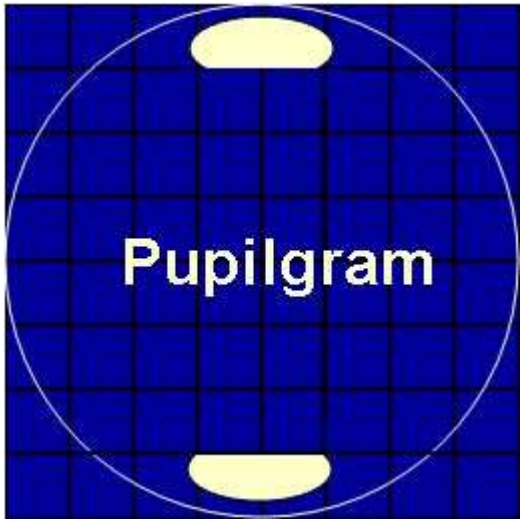
The Nikon intelligent illuminator can support 10,000 - 100,000 DPF

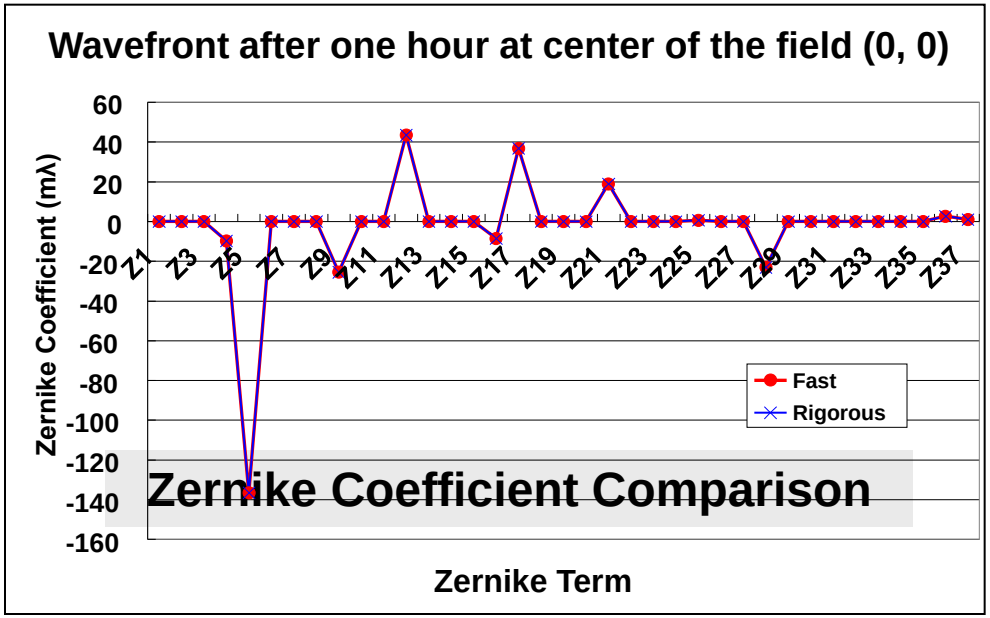
Fast Thermal Aberration Prediction

Rigorous simulation **Fast prediction**





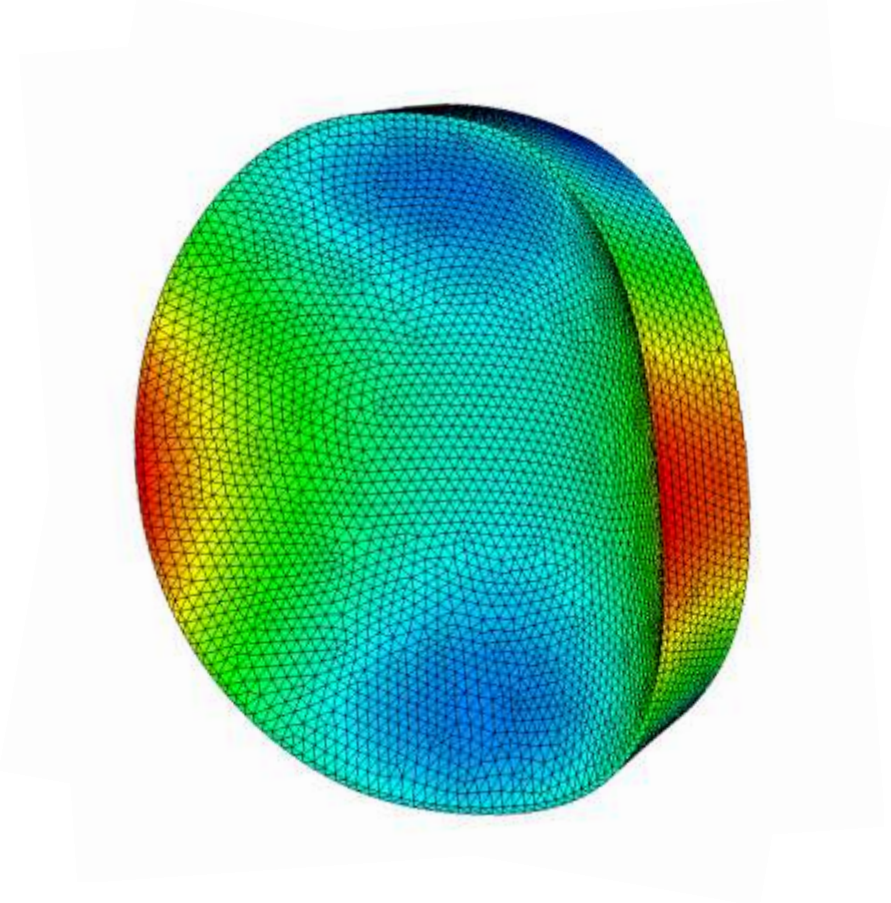




- Accurate thermal aberration prediction available in a few seconds for any shape of diffracted pupilgram

Thermal Aberration Control

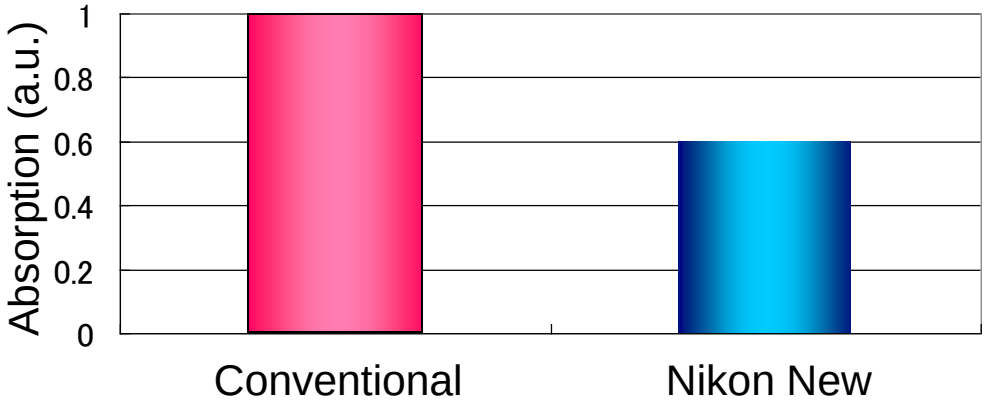
- New adaptive optics = Deformable mirror



Accurate & Quick motion

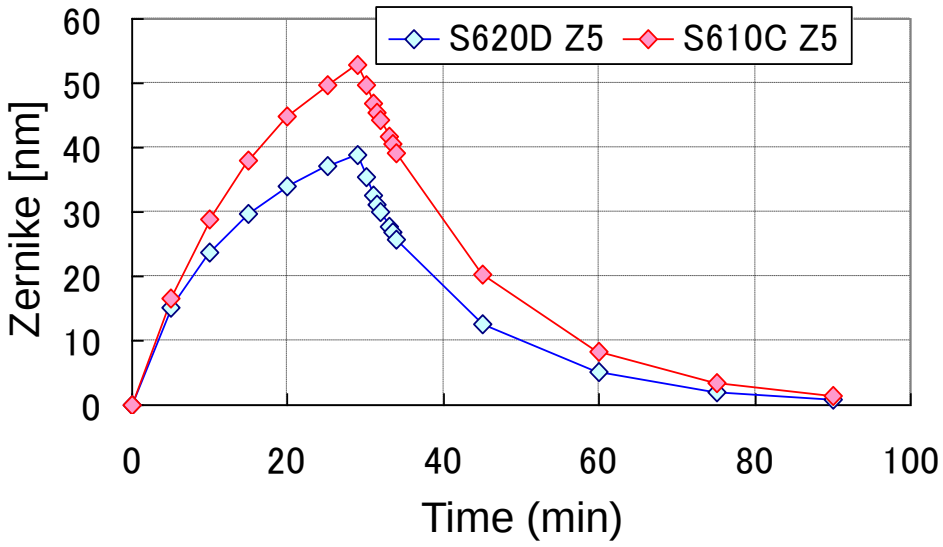
Lens Heating Reduction

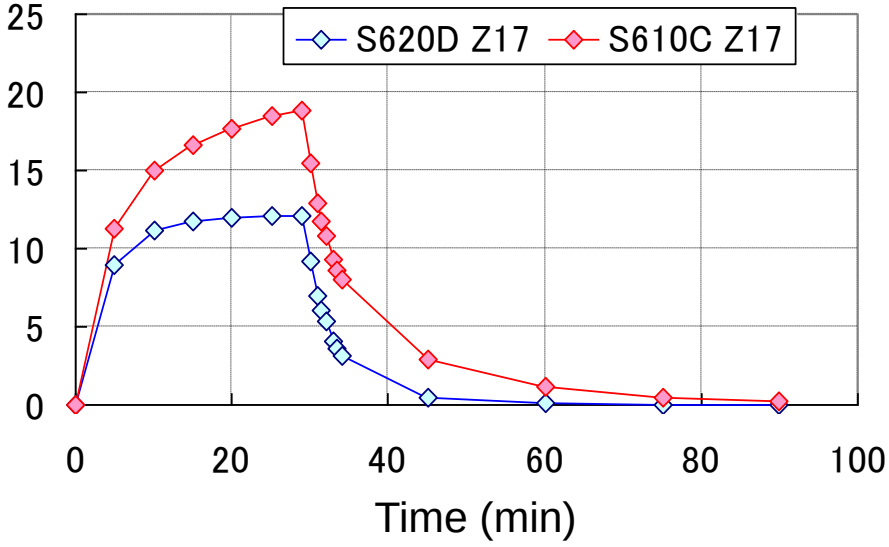
- Lens material absorption is reduced



40% reduction in absorption achieved with in-house materials development

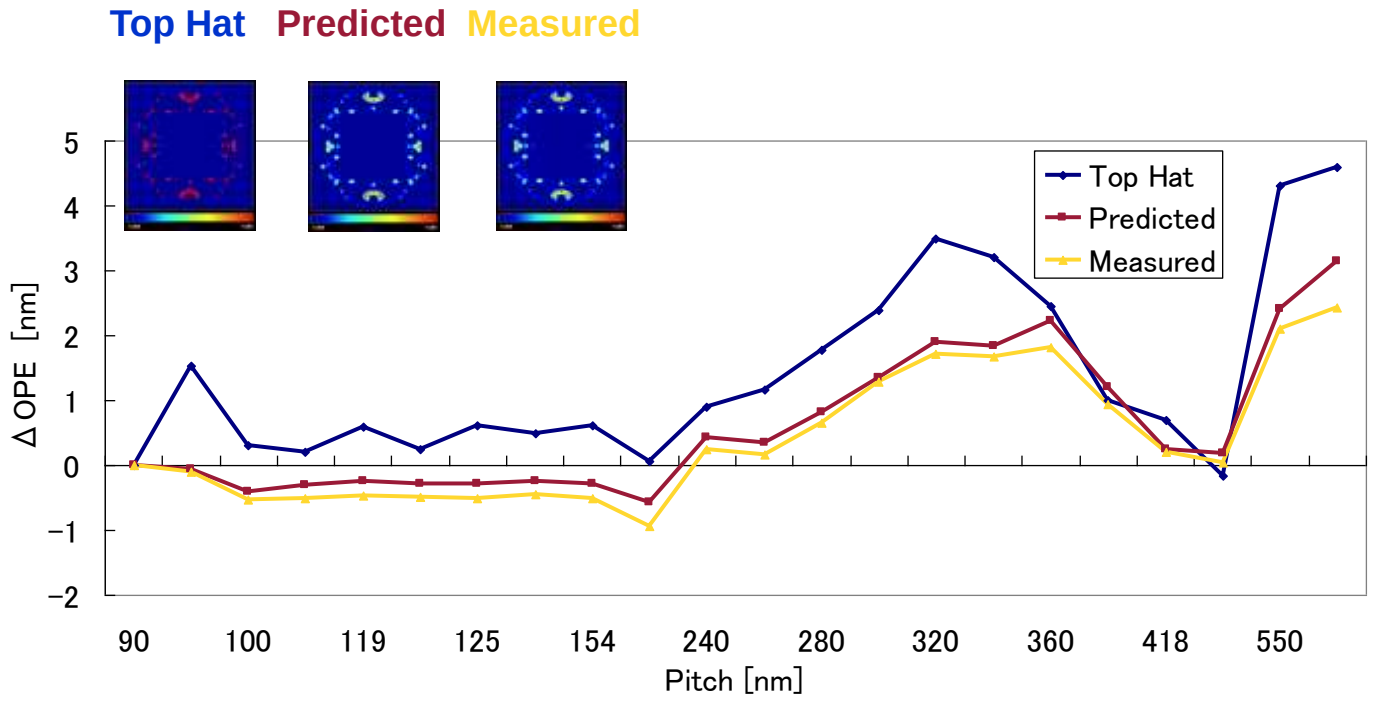
- Thermal aberration has been reduced





OPE Matching Software

- Adjusts tool parameters (NA, iNA, A.R., etc) to minimize OPE error from reference
- Freeform-illuminator capable
- Nikon-to-Nikon and Nikon-to-Other



Experimental result of OPE matching accuracy < 1.0 nm RMS

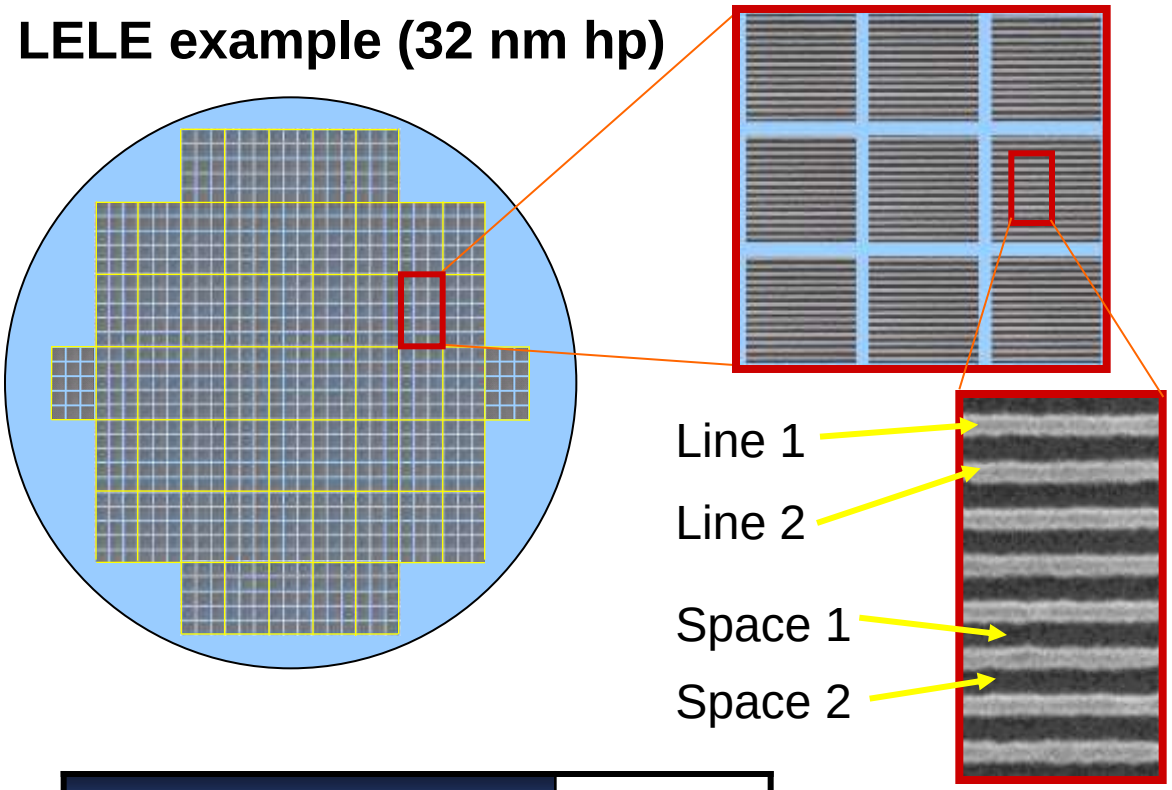
Breaking the k_1 Barrier

- The scanner enables computational lithography via those automatic adjustments
- We can't break the k_1 barrier... but we can cheat it using extensions in the litho process
- Extensions include:
  - double patterning
  - spacer process
  - spacer and cutting
  - integration with block copolymer self-assembly

Photo: U.S. Navy

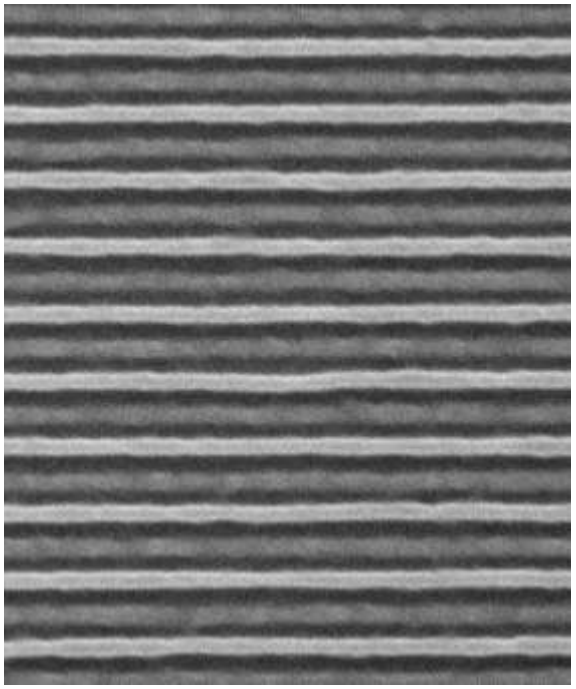
Optical Litho: Pitch Splitting DP

LELE example (32 nm hp)



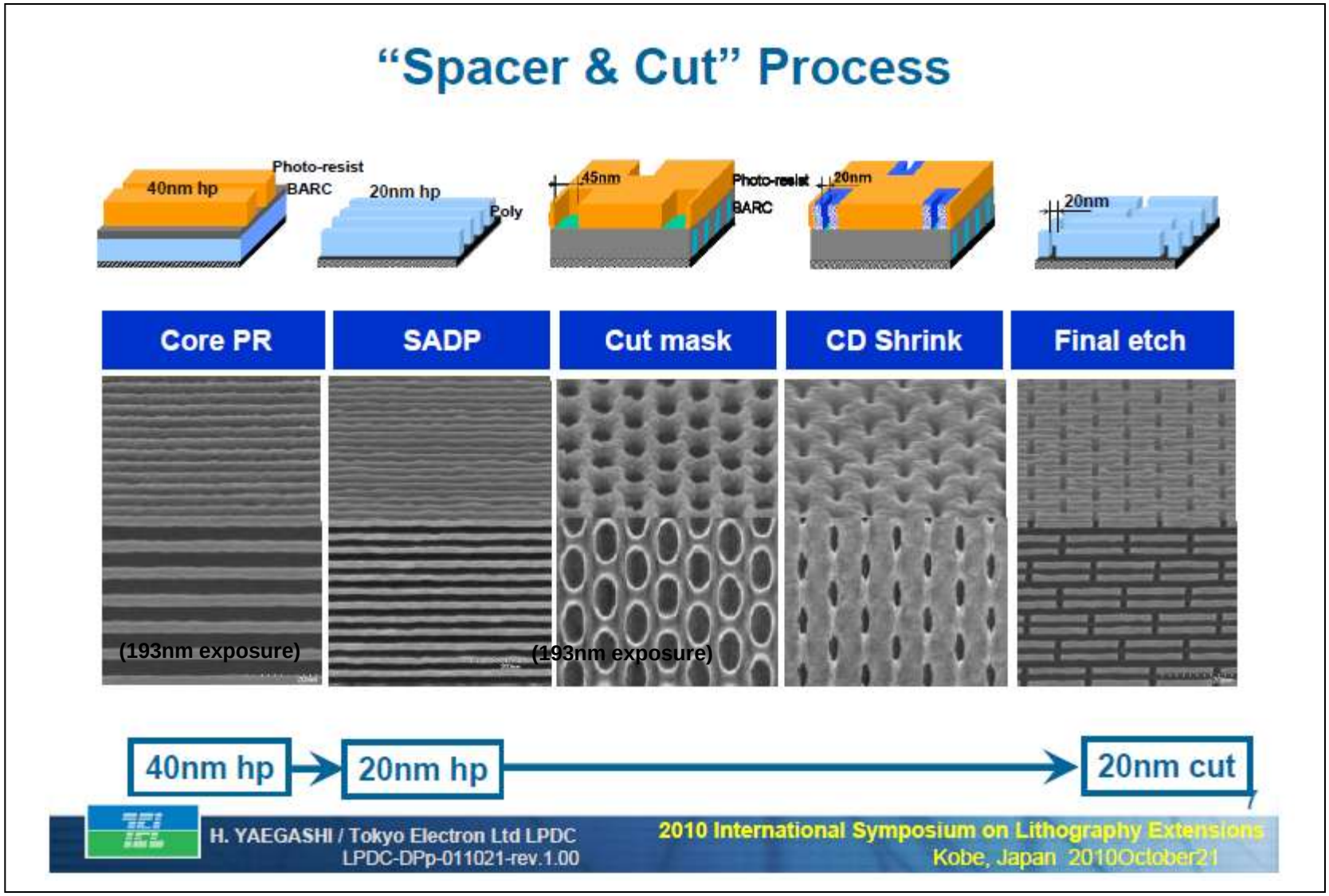
Line CDU (3σ)	2.5 nm
Space CDU (3σ)	3.3 nm

LFLE 22 nm hp



The S620 has already supported double patterning

Spacer + Cutting by 193 nm Exposure

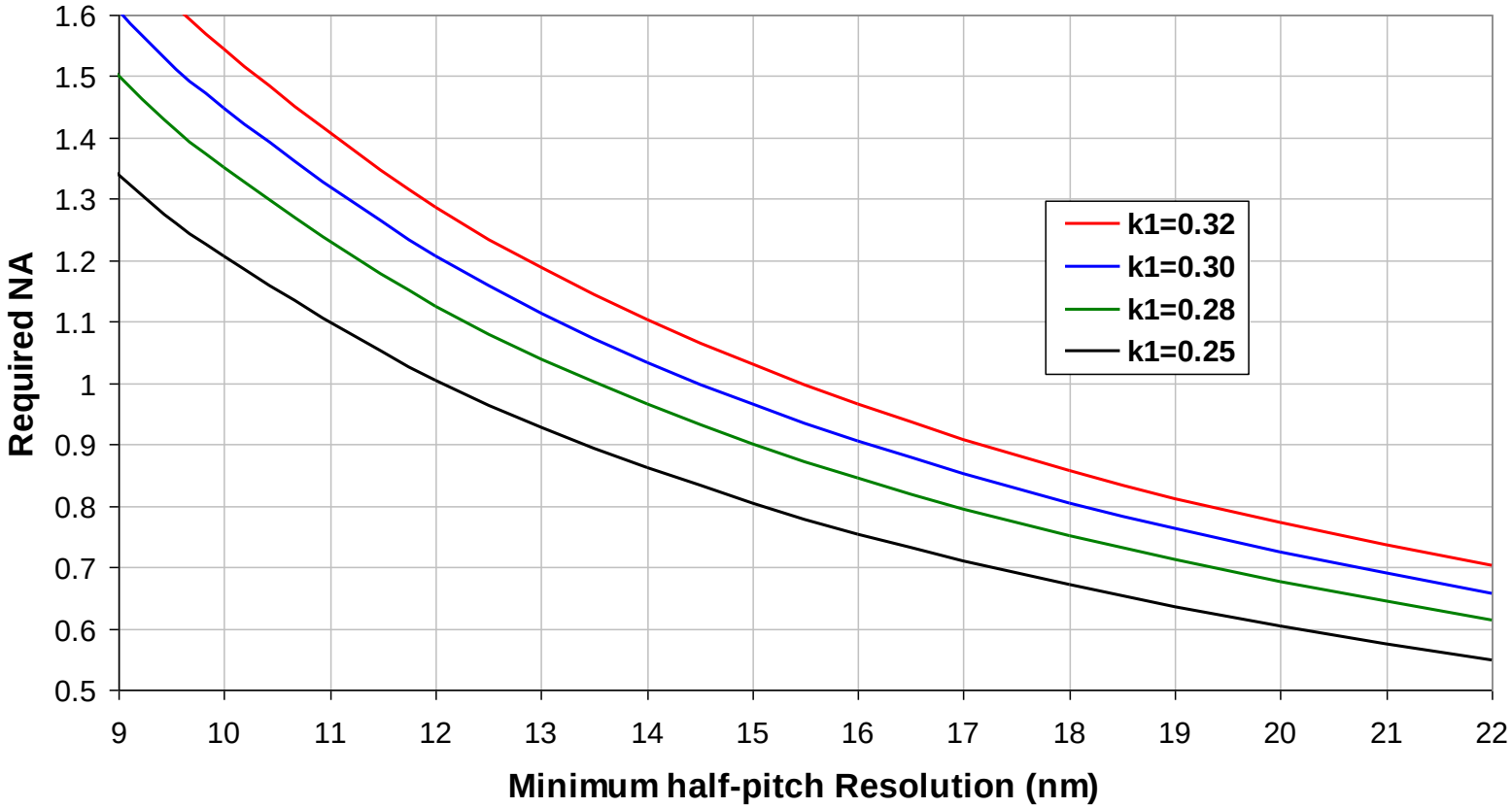


H. Yaegashi (Litho Extensions Symposium, 2010)

Required NA for Double Spacer

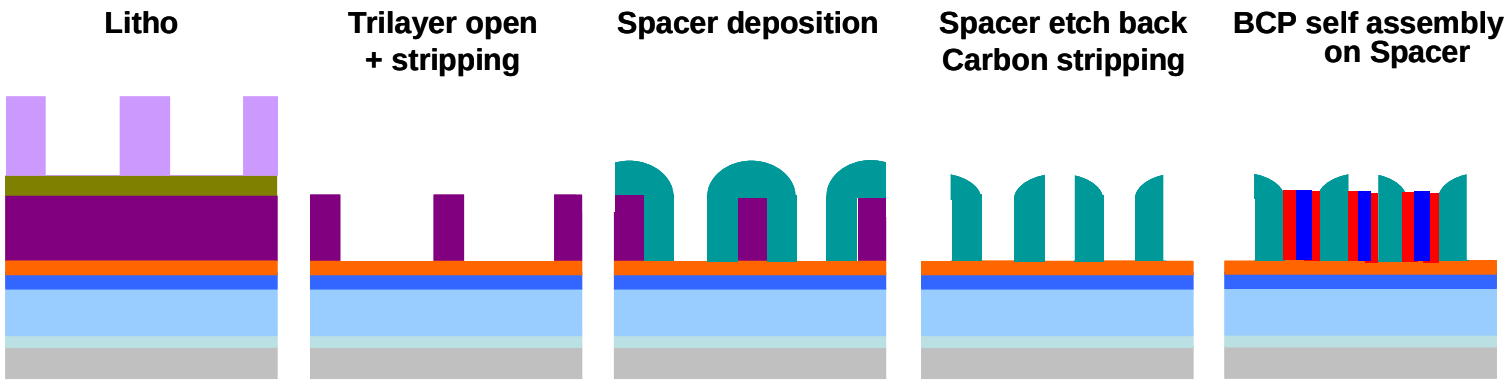
Required NA given by: NA = $k_1 \frac{\lambda}{4d}$,

where d is the minimum resolution defined by deposition

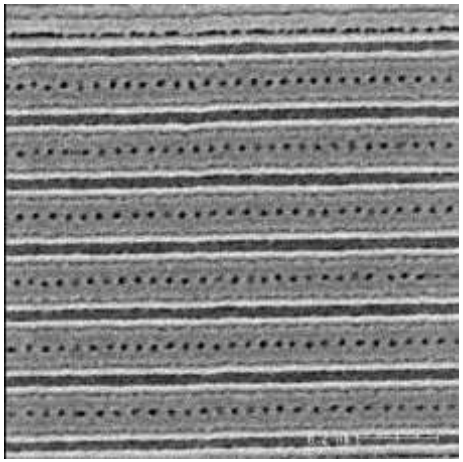


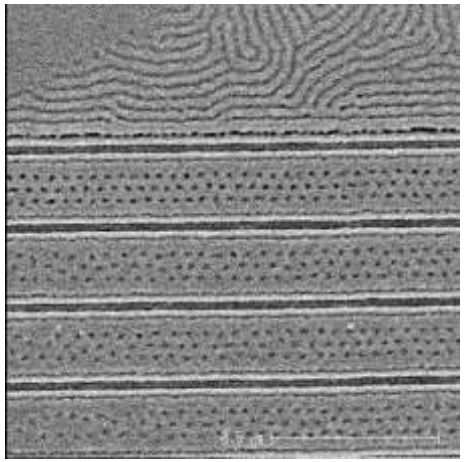
D. Flagello, NRCA

Extension of 193 nm with BCP



PSbPMMA 70/30 BCP spacer patterns





BCP self assembly compatible with spacer technology

Courtesy of R.Tiron, et al. Directed self assembly program in LETI

Summary

- Nikon will support ArFi extension prior to EUVL
- Advanced tool control and matching will be key enablers, and the S620 has that technology in place
- Work is ongoing to combine other lithography techniques with conventional optical litho
  - Achieving 1X nm lithography with optical litho may be possible with more ‘tools’ added to the core techniques

NIKON PRECISION INC.