The challenges of double patterning

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"Double, double, toil and trouble…"*

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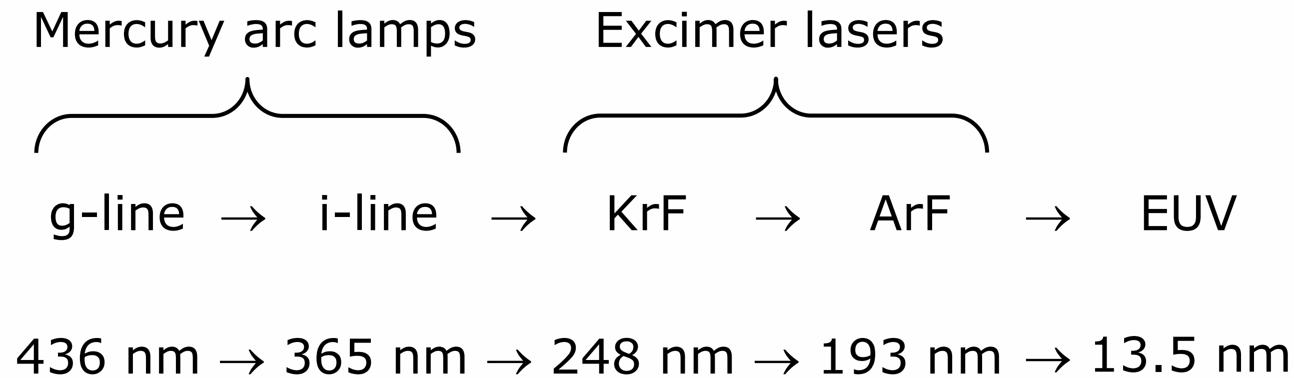
*_MacBeth_, Act 4, Scene 1

Why are we doing this?



"Who did strike out the light?"

MacBeth, Act 3, scene 3

Why are we doing this?

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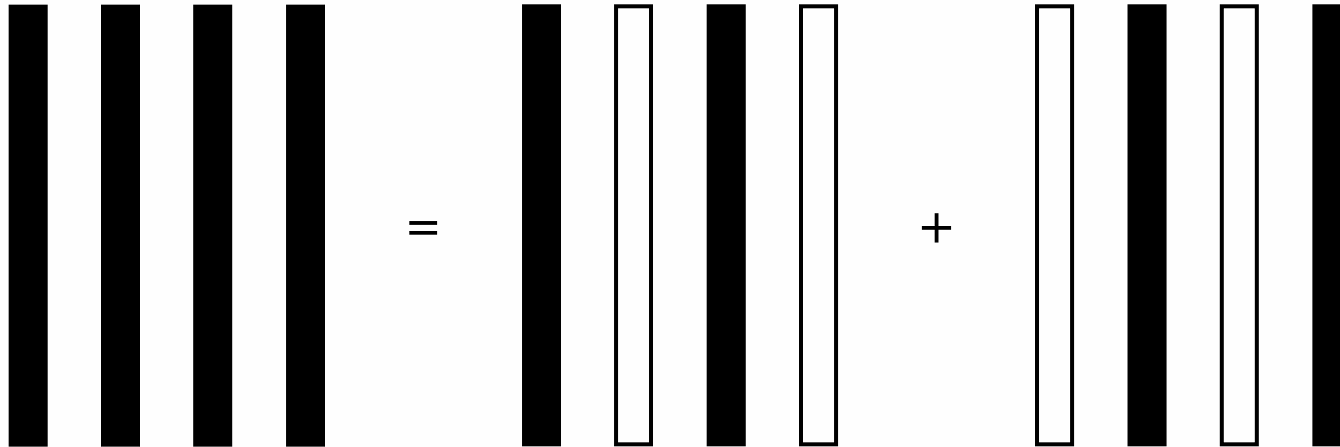

Pitches are limited by physics – minimum linewidths are not!

The challenges ahead

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- With single patterning, parameters scale ~0.7× node-to-node.
  - Overlay
  - CD control
  - LER

- Usually, we have an increase in resolution to assist with the transition.
  - Wavelength.
  - NA.

- With double patterning.
  - Process control must scale faster than 0.7×.
  - Exposing (and perhaps etching) twice per layer doubles cost.

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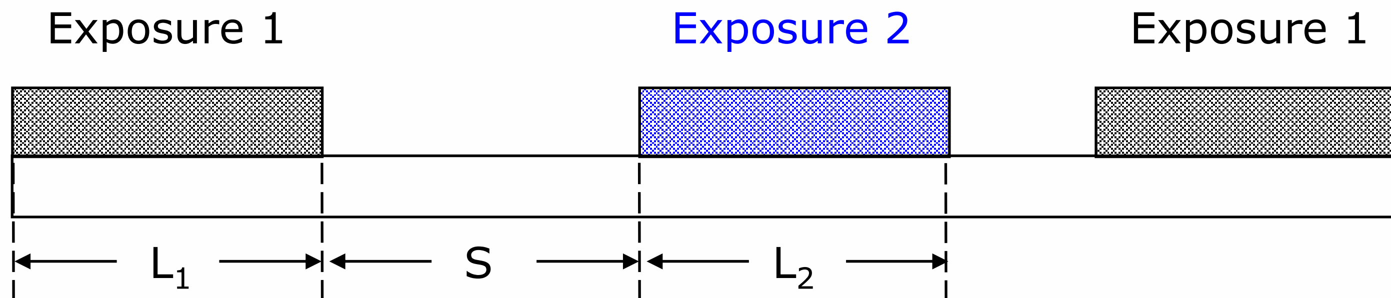
Overlay

Overlay requirements: metal layer



- To first order, lines will have the same CD variability as single exposures.
- For the space:

$$\Delta S = \frac{\Delta L_1}{2} + \frac{\Delta L_2}{2} + \Delta OL$$

$$\sigma_S = \sqrt{\frac{\sigma_L^2}{4} + \frac{\sigma_L^2}{4} + \sigma_{OL}^2}$$

$$= \sqrt{\frac{\sigma_L^2}{2} + \sigma_{OL}^2}$$

"But yet I'll make assurance double sure, And take a bond of fate…"*

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$$\sigma_S = \sqrt{\frac{\sigma_L^2}{2} + \sigma_{OL}^2}$$

**MacBeth*, Act 4, Scene 1

"But yet I'll make assurance double sure, And take a bond of fate…"*

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- In ITRS for 2012:
  - ITRS ½ pitch is 36 nm, so σ_S = 5.4 nm @ 15% CD control requirement.
  - Overlay requirement is 7.1 nm for single exposures.

**MacBeth*, Act 4, Scene 1

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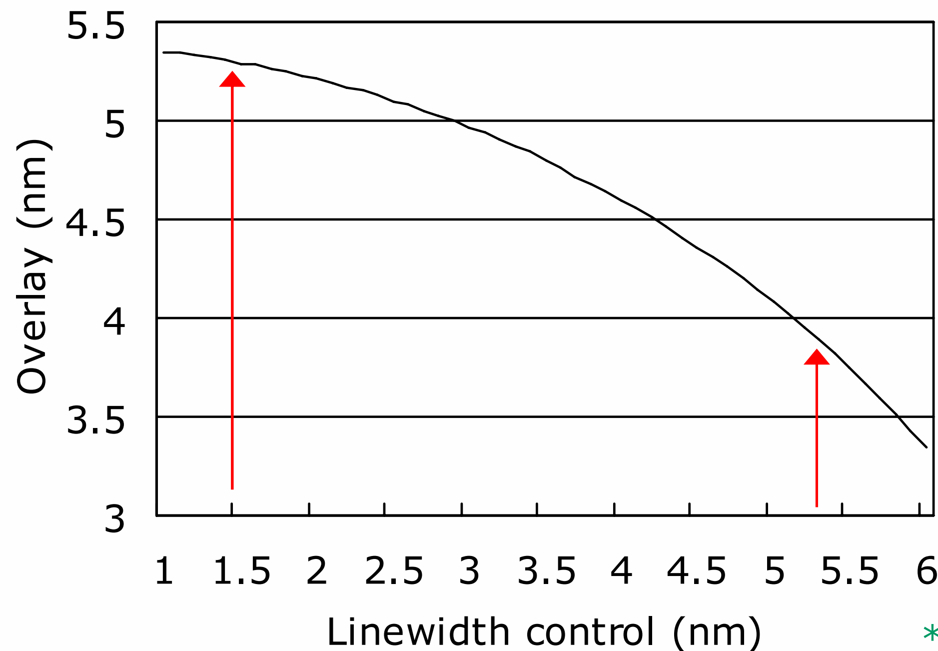

**MacBeth*, Act 4, Scene 1

Overlay control

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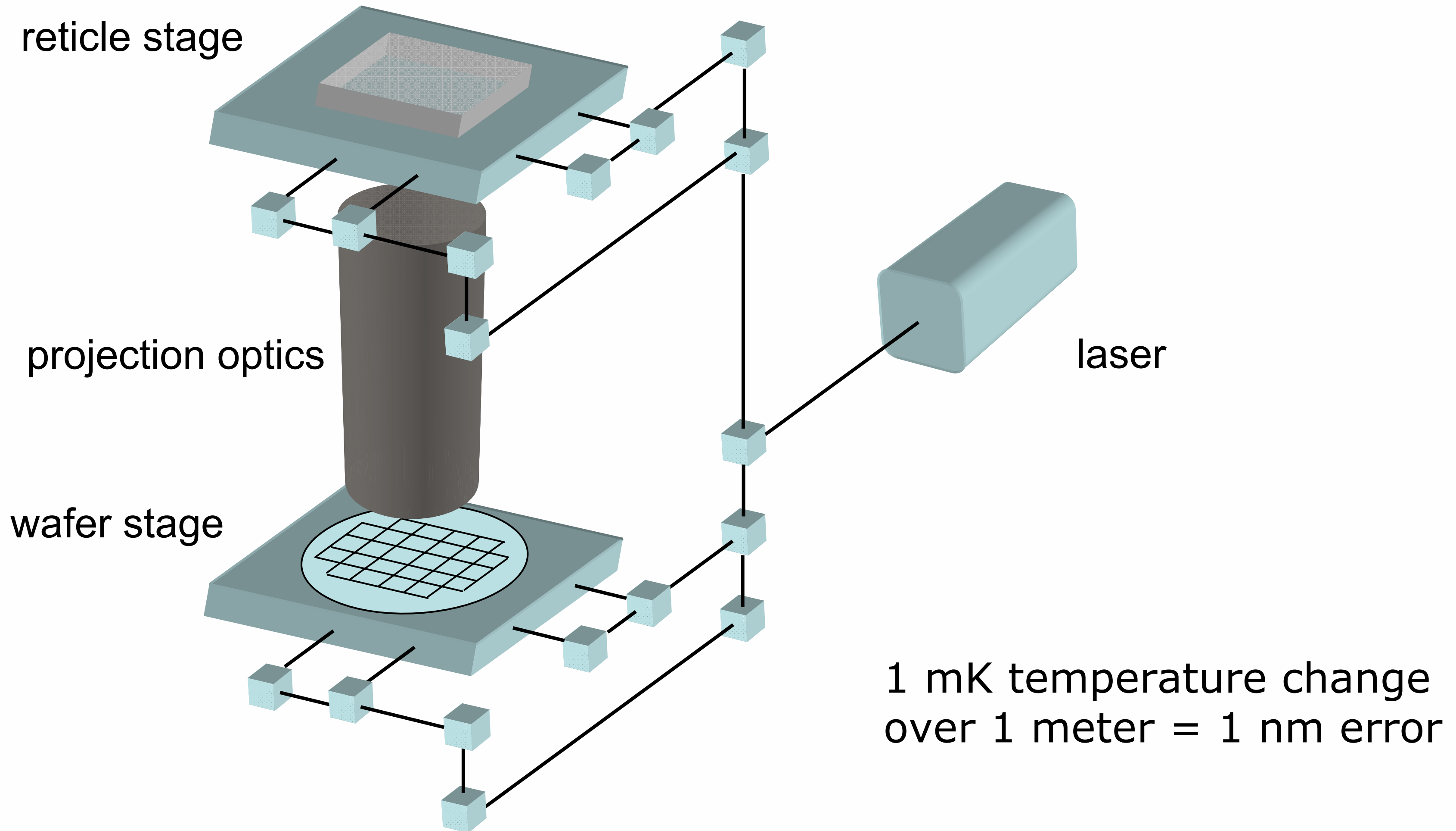

1 mK temperature change over 1 meter = 1 nm error

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Spacer processes

Frequency doubling with spacers

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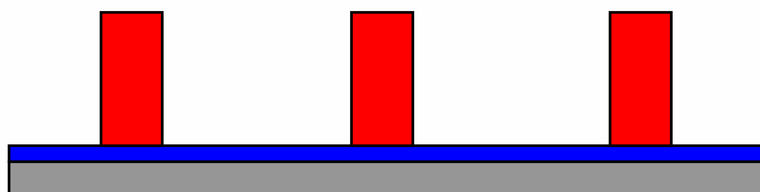
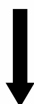
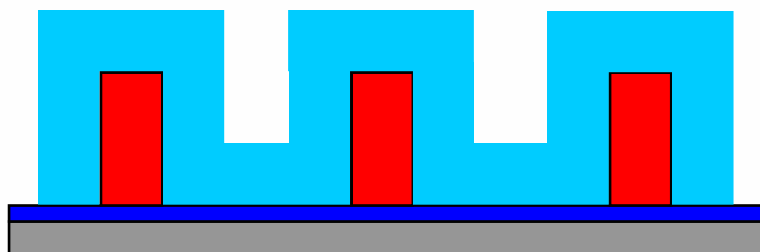
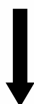
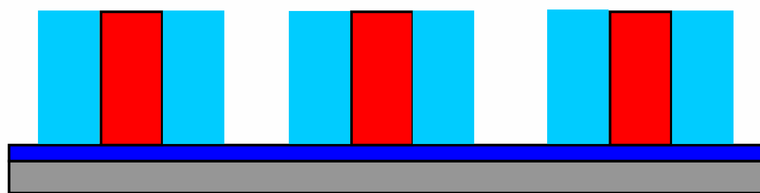

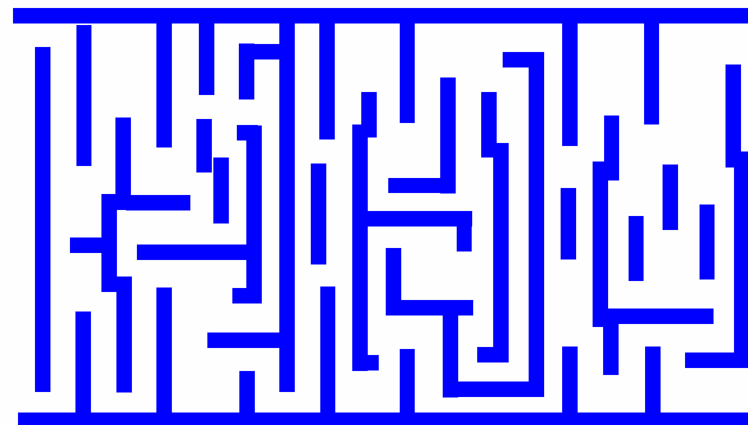

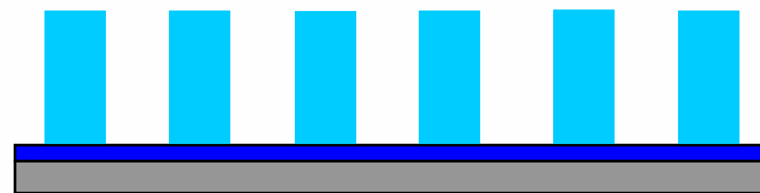

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Resolution

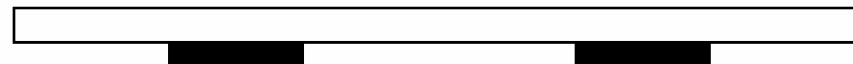
Dark field versus bright field patterning

Dark field

Positive resist

$4 \times 45 \text{ nm} = 180 \text{ nm} < 193 \text{ nm}$

Bright field



Resist types

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- High resolution negative resists will relieve the resolution burden.
- Challenges:
  - Immersion compatibility.
  - Aqueous developers.

Cost

Cost issue

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- The basic problem with double patterning is cost.
- It doubles the number of critical layers.
    - 10 critical layers $\rightarrow$ 20 critical layers.

Difficulties

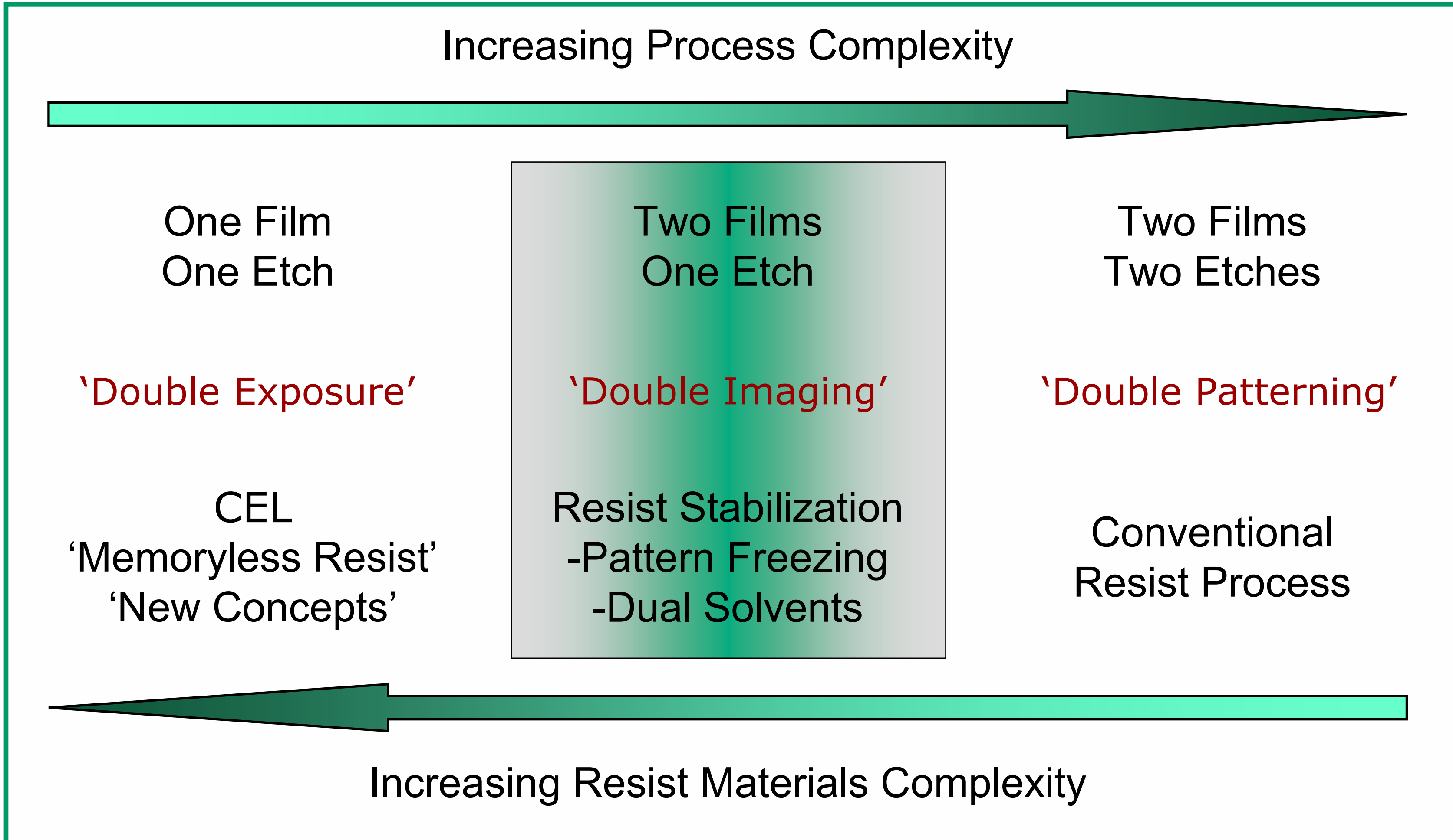

Figure courtesy of Dr. Tom Wallow

Can appropriate materials be devised?

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"Eye of newt, and toe of frog,
Wool of bat, and tongue of dog,
Adder's fork, and blind-worm's sting,
Lizard's leg, and owlet's wing,—"*

**MacBeth*, Act 4, Scene 1

Difficulties

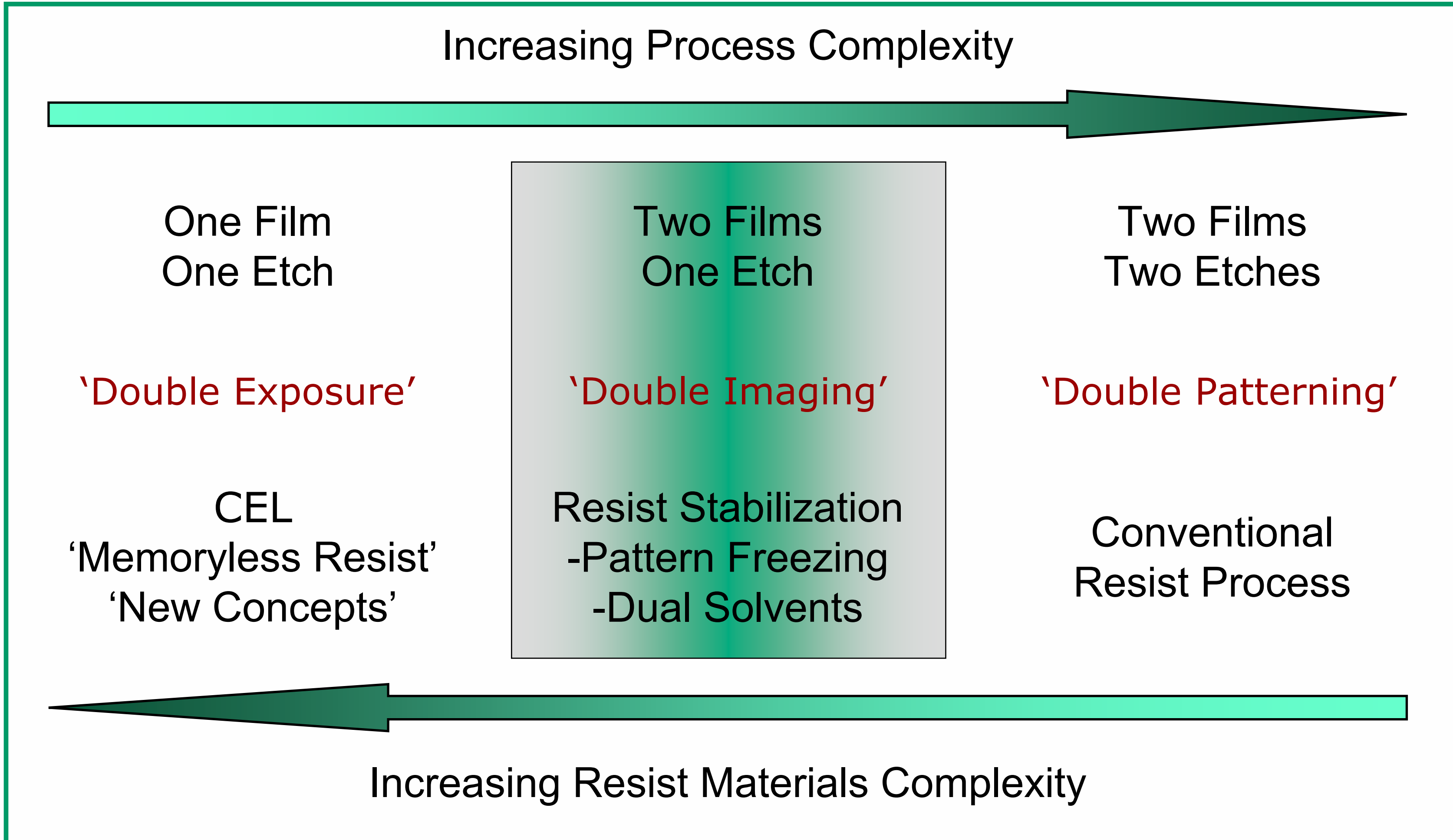
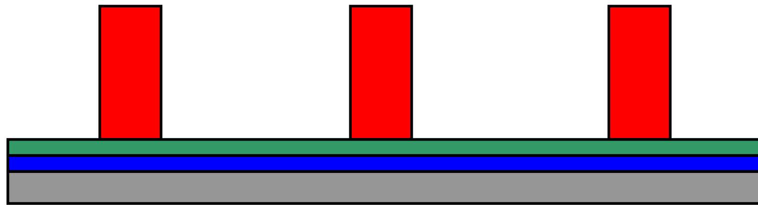
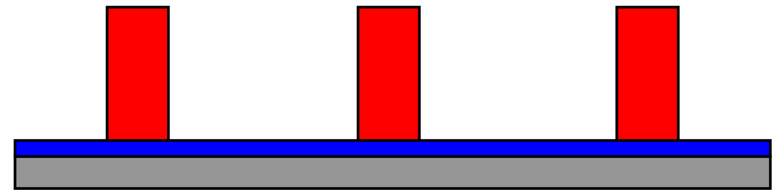


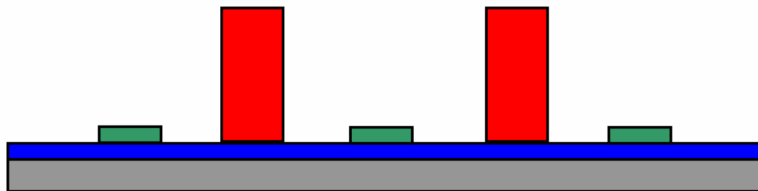
Figure courtesy of Dr. Tom Wallow

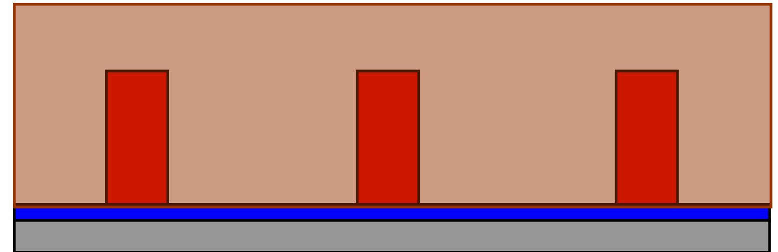
Cost reduction

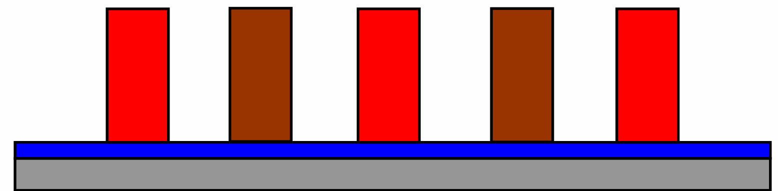
- What if we can eliminate an etch step?











Properties

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- Properties of films.
    - Solvent of second resist does not dissolve underlayer resist.
    - Second exposure does not cause underlayer resist to dissolve in developer.
    - High resolution, low LER, immersion compatibility,...

Early AMD resist-on-resist work

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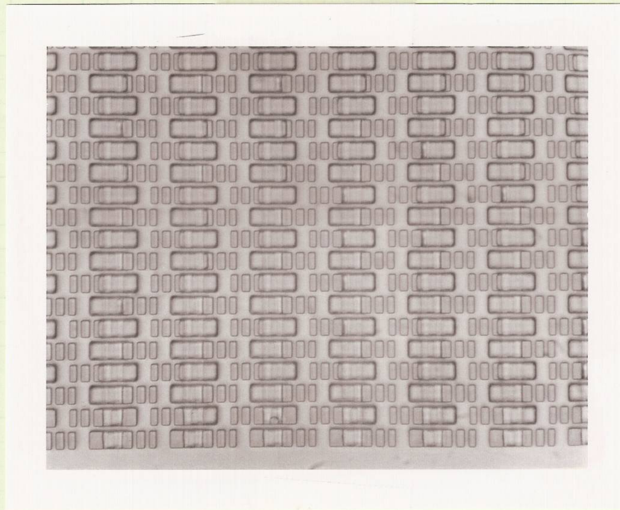
Resist on resist self-aligned masking



Experimental conditions:

KTI 747 negative resist, 0.5 μm; exposure tool: Perkin Elmer 341

Kodak 820 positive resist, 1.5 μm; exposure tool: GCA 6300, g-line, 0.3 NA

More recent AMD resist-on-resist work

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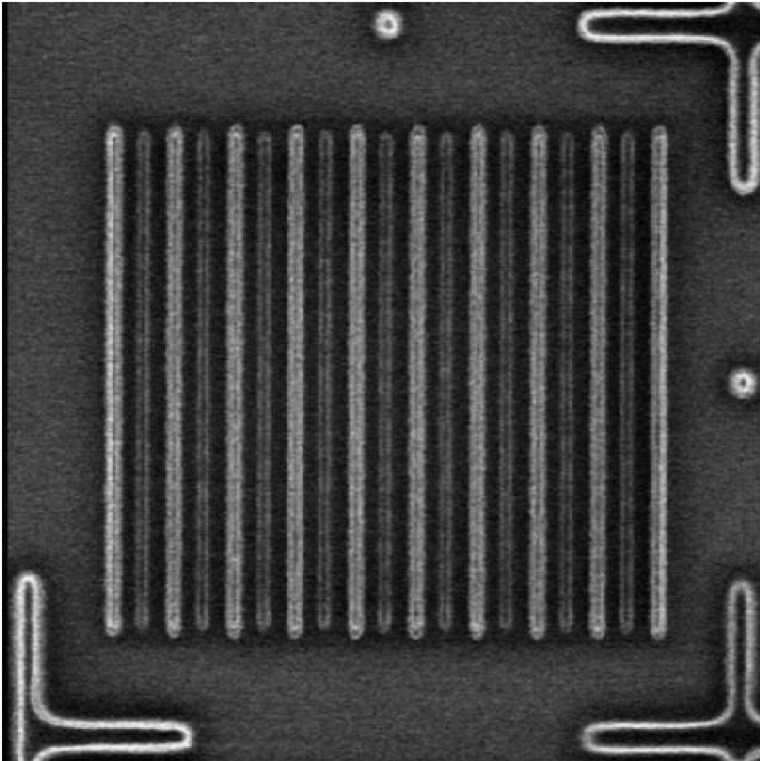
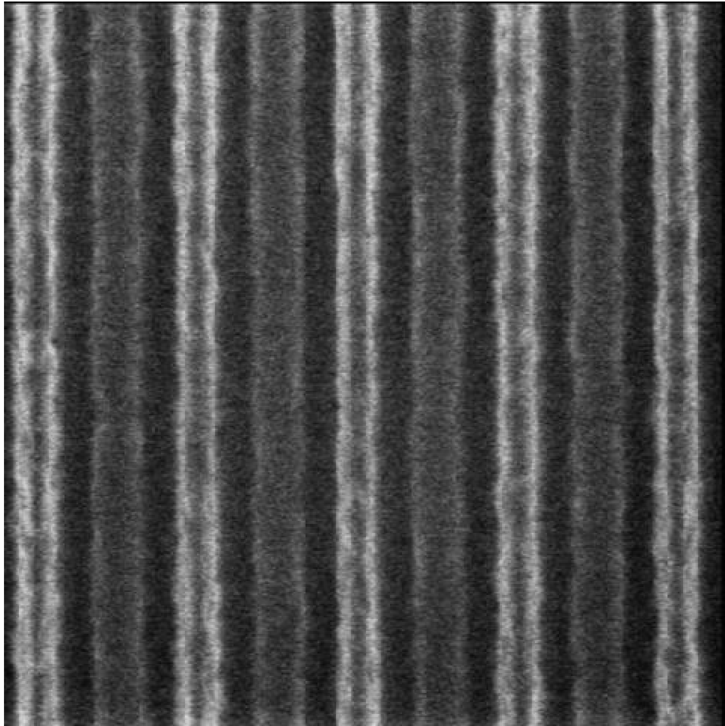


Radiation hardened



Chemically treated

Summary

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- There are many challenges!

- There are many opportunities for creative solutions!

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