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Double Patterning and Hyper-Numerical Aperture Immersion Lithography

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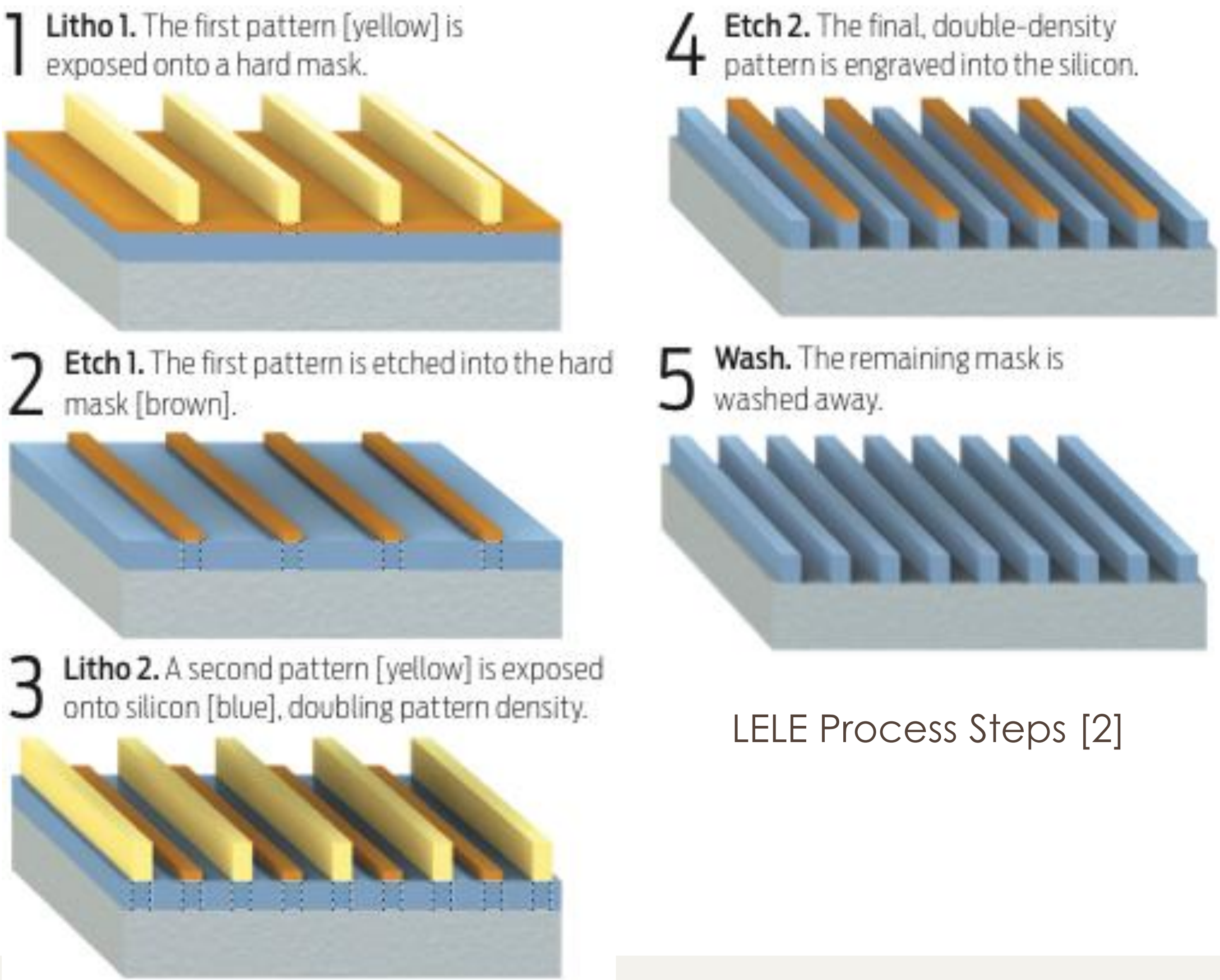
Introduction

- Background
  - No new technology is introduced
  - Viewed as a short term solution to keep pace with Moore's Law
  - When used with immersion techniques it can produce feature sizes of 32nm and beyond [1]

- Techniques
  - Three main techniques
    - Lithography-Etch, Lithography-Etch (LELE)
    - Lithography-Freeze, Lithography Etch (LFLE)
    - Self-Alignment Double Patterning (SADP)

Litho-Etch, Litho-Etch (LELE)



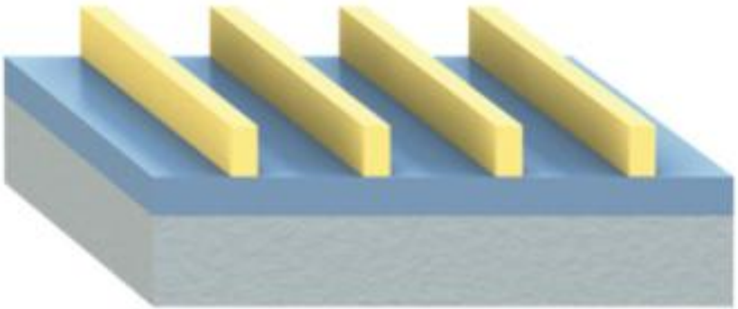
LELE Process Steps [2]

Advantages/Disadvantages

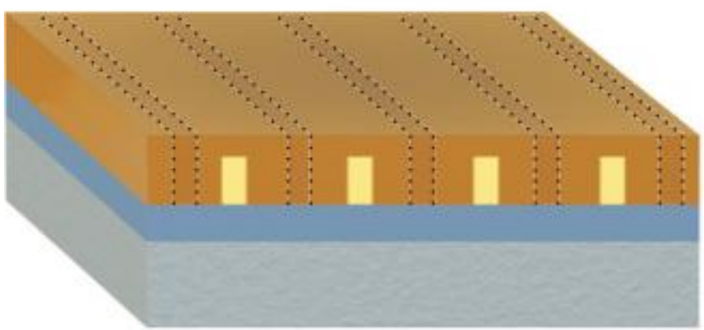
- Advantages
  - No new technology
  - Allows for greater resolution
  - Uses existing technology
  - Straightforward process
- Disadvantages
  - Requires 5 process steps
  - Expensive – litho-etch process twice
  - Low throughput
  - Small tolerance for pattern overlay

Litho-Freeze Litho-Etch (LFLE)

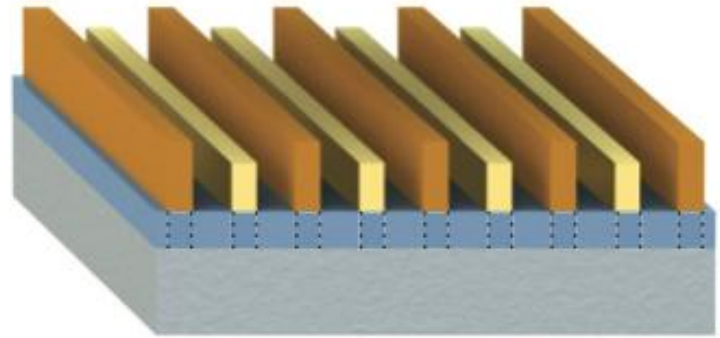
1 **Litho 1.** The first pattern [yellow] is exposed onto silicon [blue].



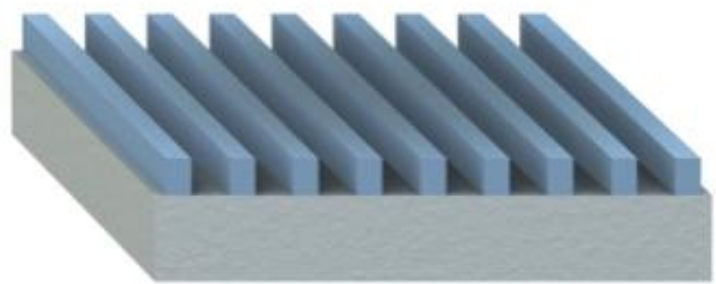
2 **Freeze, coat with new resist.** The already developed layer [yellow] is chemically frozen and coated with a second layer of resist [brown].



3 **Litho 2.** A second pattern [brown] is exposed, doubling pattern density.



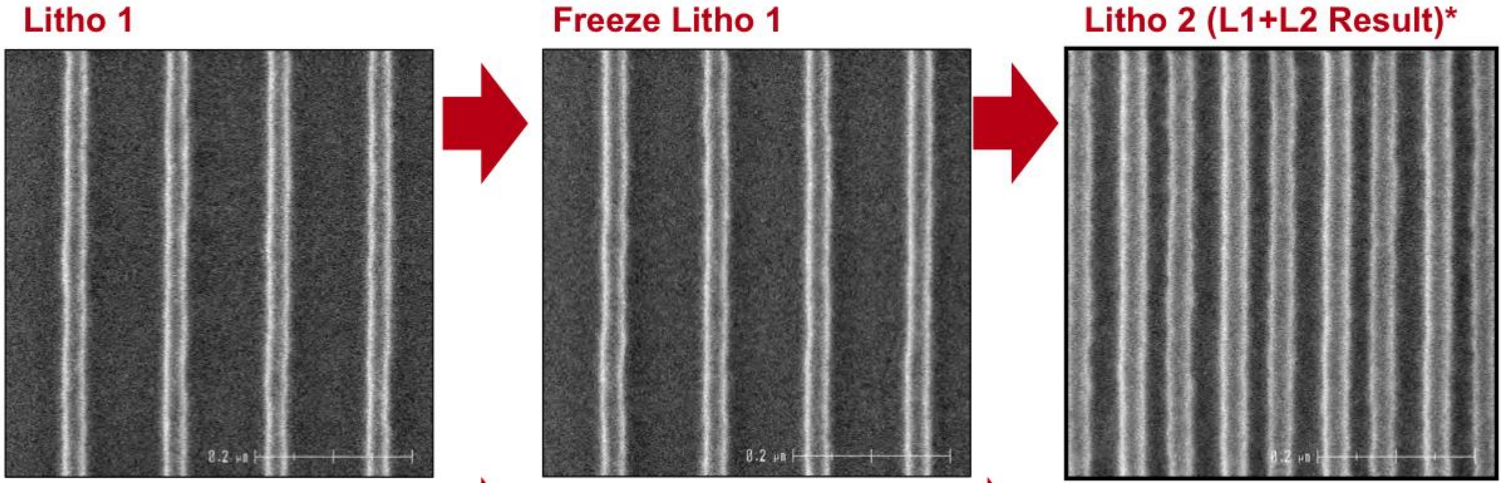
4 **Etch.** The unprotected silicon is engraved with the final, double-density pattern in a single etching operation.



LFLE Process Steps [2]

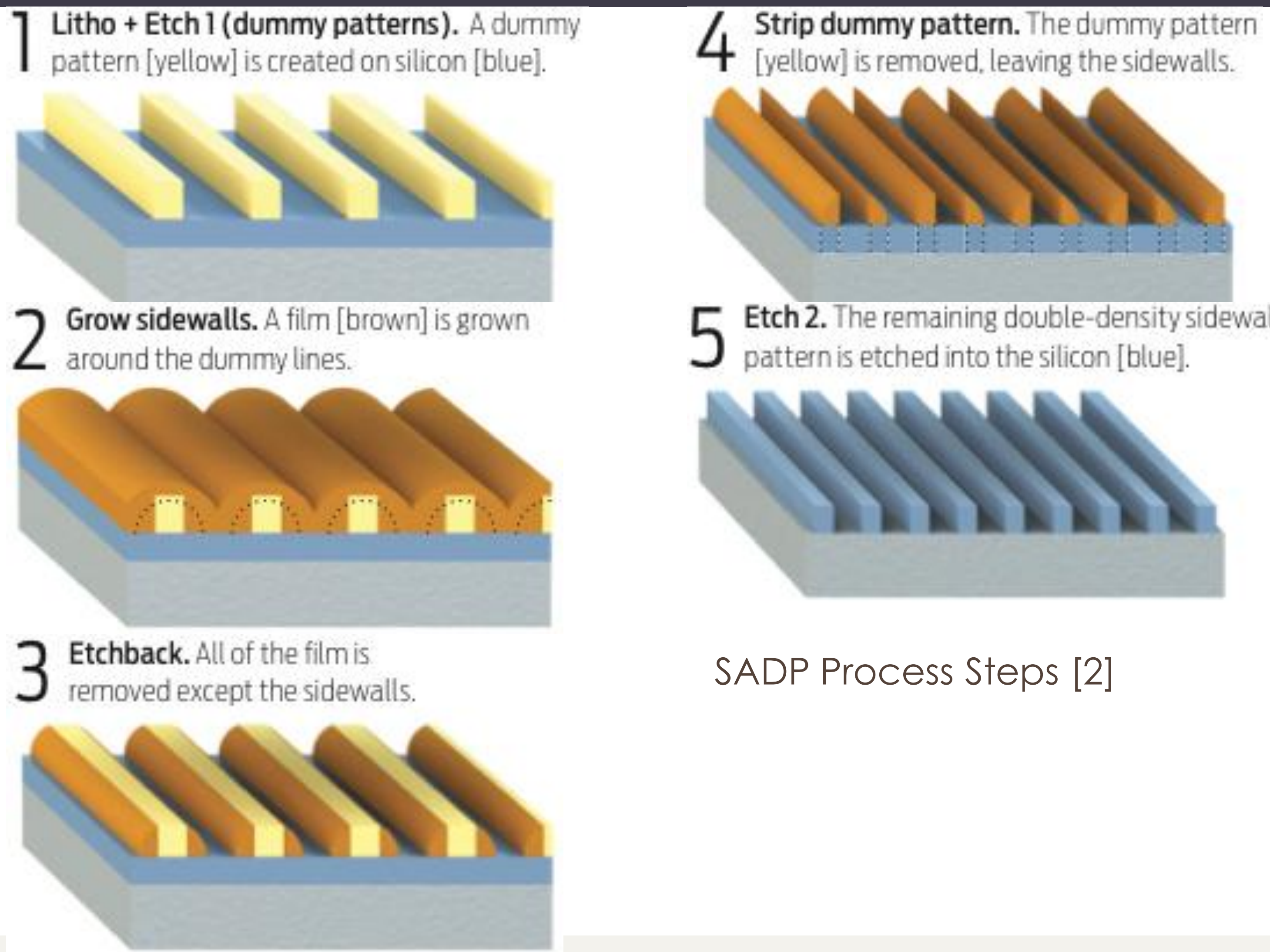
Advantages/Disadvantages

- Advantages
  - Four process steps (five for LELE)
  - Reduced cost
  - Increased throughput
- Disadvantages
  - Faces same issues with small overlay tolerance



LFLE Example [3]

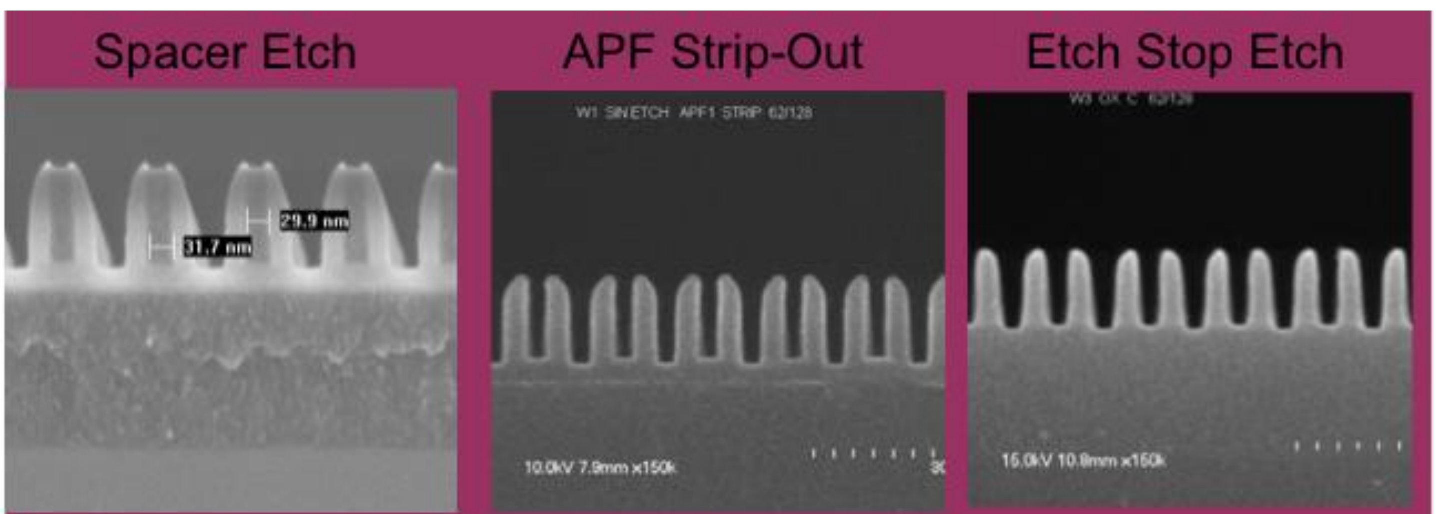
Self-Aligned Double Patterning (SADP)



SADP Process Steps [2]

Advantages/Disadvantages

- Advantages
  - Eliminates trouble with pattern overlay tolerance
- Disadvantages
  - Increased process steps – increased cost
  - Optimized for processes with uniform patterns



SADP Example[3]

Applications

- Memory Devices
  - Self-Aligned Double Patterning (SADP)
    - Used because these devices typically have uniform patterns
    - Used by Hynix, Micron, Renesas, and Samsung
- Logic Devices
  - Litho-Etch, Litho-Etch (LELE) and Litho-Freeze, Litho-Etch (LFLE)
    - Used because these devices typically have non-uniform patterns
    - Used by Intel, Sony, TI, Toshiba, and TSMC

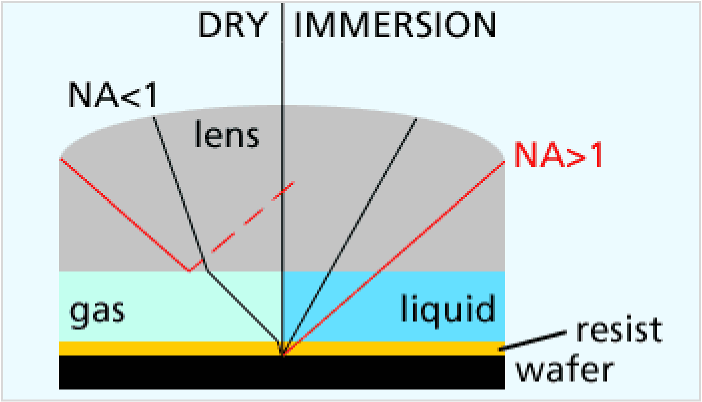
Hyper-Numerical Aperture Immersion Lithography

- Background
  - Similar to conventional projection lithography
  - Currently viable method to keep up with Moore's Law
  - Enhances resolution

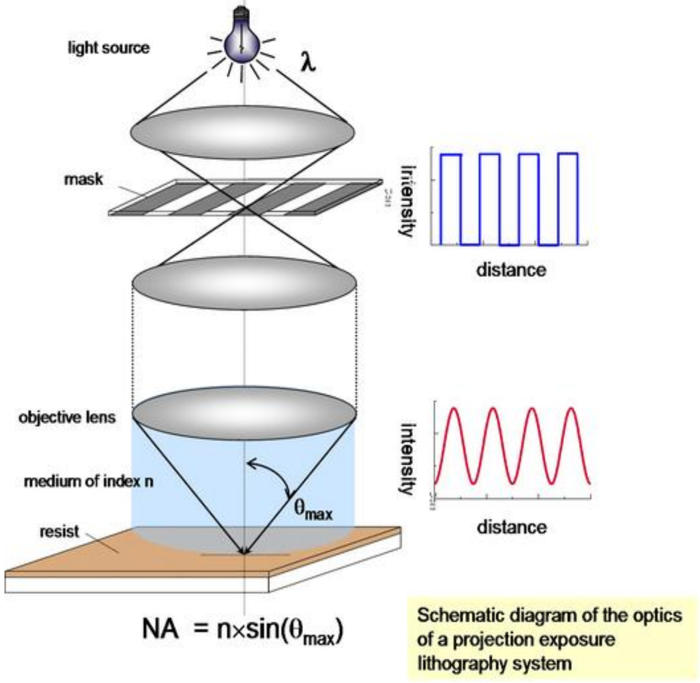
Process Details

- Light source: 193 ArF excimer laser
- Similarity to conventional projection lithography seen in presence of mask and lens.
- However, air-gap present between the wafer and lens is replaced by liquid medium. Most common medium is highly purified deionized water.
- Liquid medium will have higher refractive index than 1.
- Liquid in direct contact with lens and photoresist on wafer. Optimal processing done with water-resistant photoresist.

Immersion Lithography Set-up



Zeiss [5]



IBM [4]

Why a liquid medium?

- Acheivable resolution for devices is directly related to the Numerical Aperture of the lithography equipment.
- NA = sin(max. refraction angle) * (refractive index of liquid)
- With a liquid medium refractive index of greater than 1, there is a larger depth of focus and minimal reflection of the projected laser light, resulting in higher resolution of patterns exposed onto the photoresist on the wafer.
- Increases in resolution can range between 30-40% depending on the liquid used.
- By using immersion lithography, we can achieve smaller feature sizes withouth having to overhaul all equipment to costly x-ray lithography systems, for example.

Disadvantages

- Bubbles in the fluid as well as thermal and pressure variations in the fluid can lead to processing disortions.
- Possibility of 193nm ArF laser ionized the liquid medium and promoting reaction with photoresist, thus altering the accuracy of desired features.
- When wafer is removed from apparatus, residual moisture might remain due to direct contact with liquid. Moisture will impede optimal device performance and processing.
- More expensive than conventional dry lithography.

Applications

- Industry leaders using immersion lithography:
  - Intel
  - Texas Instruments
  - Nikon
  - IBM
  - ASML
  - Toshiba
- Purpose: to achieve feature sizes around 25nm without having to shift to inordinately expensive equipment such as x-ray systems.
- Immersion lithography combined with double patterning results in even finer acheivable feature sizes.
- Allows companies to keep up with Moore's Law. Able to create nodes of 32nm and 22nm.

References

[1] P. Zimmerman, "Double patterning lithography: double the trouble or double the fun," SPIE Newsroom, [Online]. Available: http://spie.org/documents/Newsroom/Imported/1691/1691_5999_0_2009-06-24.pdf

[2] "All Double-Patterning Variations Lead to Rome," IEEE Spectrum, [Online]. Available: http://spectrum.ieee.org/images/nov08/images/doub03.pdf

[3] "Litho-Freeze-Litho-Etch (LFLE) enabling coat/develop track process," Applied Materials, [Online]. Available: http://www.sematech.org/meetings/archives/litho/8715/pres/O-DPMP-03_Pieczulewski_SOKUDO.pdf

[4] "Immersion Lithography," IBM, [Online]. Available: http://www.almaden.ibm.com/st/chemistry/lithography/immersion/

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[6] B.W. Smith, Y. Fan, M. Slocum, L. Zavyalova, "25nm Immersion Lithography at a 193nm Wavelength," Rochester Institute of Technology, Proceedings of SPIE, SPIE Microlithography, Optical Microlithography XVIII, Immersion Lithography, 5754, San Jose, California, United States, pp. 141-147 (2005).