Double Patterning and Hyper-Numerical Aperture Immersion Lithography

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Double Patterning Lithography

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]**

1. **Litho 1.** The first pattern [yellow] is exposed onto a hard mask.
2. **Etch 1.** The first pattern is etched into the hard mask [brown].
3. **Litho 2.** A second pattern [yellow] is exposed onto silicon [blue], doubling pattern density.
4. **Etch 2.** The final, double-density pattern is engraved into the silicon.
5. **Wash.** The remaining mask is washed away.
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
Double Patterning Lithography

**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

**Litho-Freeze Litho-Etch (LFLE)**

**LFLE Example [3]**
Self-Aligned Double Patterning (SADP)

1. **Litho + Etch 1 (dummy patterns).** A dummy pattern [yellow] is created on silicon [blue].

2. **Grow sidewalls.** A film [brown] is grown around the dummy lines.

3. **Etchback.** All of the film is removed except the sidewalls.

4. **Strip dummy pattern.** The dummy pattern [yellow] is removed, leaving the sidewalls.

5. **Etch 2.** The remaining double-density sidewall pattern is etched into the silicon [blue].

SADP Process Steps [2]
Self-Aligned Double Patterning (SADP)

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]

Schematic diagram of the optics of a projection exposure lithography system.
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 without 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 distortions.

- 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 achievable feature sizes.

- Allows companies to keep up with Moore’s Law. Able to create nodes of 32nm and 22nm.


