Outline

1. Ashing-Trimming
2. Dual Resist Process
3. Nanospacer Lithography for Nanowires and Nanogaps
4. Nanosphere Lithography
5. Nanoimprint
6. Conclusions
Map of Nanotechnology

- **Top-down approach**
- **Lithography**
- **Nanotechnology**
- **Chemistry**
- **Bottom-up**
- **Nanoland**

Dimension
- 100μm
- 10μm
- 1μm
- 100nm
- 10nm
- 1nm
- 0.1nm

YEAR
- 1940
- 1950
- 1960
- 1970
- 1980
- 1990
- 2000
- 2010

**Oxide Trimming in addition to Resist Ashing**

- **O₂ Plasma Ashing**
  - 500nm → 80nm
- **HF Trimming**
  - 80nm → 30nm

Ashing and trimming produces < 30nm patterns.
6.4nm Line Width
(Pattern Reduction by E-beam Lithography and Trimming)

- 6.4nm fin width is achieved

Metal Direct Patterning by Dual Resist

- High resolution by e-beam lithography
- High throughput by optical lithography
Spacer Lithography Technology

- Spacer lithography produces sub-lithographic pattern


Double-Gate FinFETs
(World Record Smallest Transistor!)

Y.-K. Choi et al., *IEDM*, p.421, 2001

15nm Double-Gate

\[ W_{\text{fin}} < \frac{3}{4}L_g \]
I-V Characteristics

![Graph showing I-V characteristics for PMOS and NMOS transistors.](image)

- NMOS $I_{on} = 850mA/\mu m$ and PMOS $I_{on} = 760\mu A/\mu m$ @ $|V_g - V_t| = |V_d| = 1V$.

Y.-K. Choi et al., Solid-State Electronics 46, p.1595, 2002

![Diagram showing different layers and spacers in a transistor structure.](image)

Y.-K. Choi et al., 47th EIPBN, p.77
Multiple Spacers for Nano-Wires

Sacrificial structures

1st Spacers

2nd Spacers

3rd Spacers

$2^n$ lines after $n$-times spacer lithography!

Poly-Si Nanogap by Spacer Lithography

Patterning

Spacer Deposition

Etch Back

Nano-Gap

2nd Poly-Si deposition

CMP and removal of spacer
Sub-8nm Gap of Poly-Si Electrodes

Detection of DNA Hybridization

J. Lee, Y.-K. Choi et al., MRS, p.185, April 2002
Detection of Protein Adsorption

- **Lysozyme**
- **Serum Albumin**
- **Fibrinogen**

High protein bulk concentration = 1mg/mL
Low protein bulk concentration = 0.008mg/mL

7nm Fluidic Channel

- 2nm fluidic channel is achievable due to accuracy of controllability of LPCVD.
**Nanometal Particles**

Cross-sectional View

- Nanobeads
- Metal Evaporation
- Metal Lift-off

Top View

- $g = 0.58D$
- $D = 2.3D$

**Carbon Nanotube Devices and NEMS**

- Carbon Nanotubes
- Nano-catalysts
- Porous Silicon
- Linear Actuator
Nano-Cylinders

- Nanobeads
- RIE Etch
- Nano-cylinders

Applications

- Filter
- Molecule Separator
- Molecule Amplifier
Metal Nanogap by Electromigration

- Metal nanogap electrodes are fabricated by electromigration.
- Electrical properties of biomolecules will be investigated.

Electromigration

Median time-to-failure (MTF) = $AJ^2 \exp(E_a/kT)$

Nanoimprint, Metal Evaporation, and Lift-off

- Nanoimprint, Metal Evaporation, and Lift-off
- Mold Separation and O$_2$ Ashing
- Pt nanowires and Metal Evaporation and Metal Lift-Off
Pt evaporation and Lift-Off

Si wires are changed to Pt wires by Imprinting and lift-off.

Ea = 13.0 +/- 0.3 kcal/mol

Ea is comparable to others’ result
Common Catalyst

Random distribution of particle size and position

Desired Catalyst

Precise control of particle size and position

Nano-Imprint Lithography (NIL)

Nano-wire mold

Stamp

90° Rotation

Well-ordered and high density nano-particles
Conclusions

1. Nanofabrication Technologies
   - Ashing-Trimming
   - Dual Resist Process
   - Nanospacer Lithography
   - Nanosphere Lithography

2. DNA and protein chip was demonstrated with nanogaps.

3. Nanoimprint technology was developed for chemical- and bio-sensors.

4. Fusion technologies would lead a cutting edge technology and open a new era.