MEMS-based nanopatterning & NEMS

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Outline:

- Integration as sensors
- MHz resonance devices

Nanomechanics/NEMS

- Various implementation schemes (static/dynamic)
- Local deposition
- Thermo-mechanical indentation
- Molecular delivery

- New versatile methods (MEMS-based)

Emerging nanopatterning methods

Engineer's viewpoint of nanotechnology
# ITRS Roadmap 2002

http://public.itrs.net/

## Table: Lithography Technology Requirements

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</thead>
<tbody>
<tr>
<td><strong>DRAM</strong></td>
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<tr>
<td>DRAM ½ Pitch (nm)</td>
<td>130</td>
<td>115</td>
<td>100</td>
<td>90</td>
<td>80</td>
<td>70</td>
<td>65</td>
<td>45</td>
<td>32</td>
<td>22</td>
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<tr>
<td>Contact in resist (nm)</td>
<td>165</td>
<td>140</td>
<td>130</td>
<td>110</td>
<td>100</td>
<td>90</td>
<td>80</td>
<td>55</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>Contact after etch (nm)</td>
<td>150</td>
<td>130</td>
<td>115</td>
<td>100</td>
<td>90</td>
<td>80</td>
<td>70</td>
<td>50</td>
<td>35</td>
<td>25</td>
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<tr>
<td><strong>Overlay</strong></td>
<td>46</td>
<td>40</td>
<td>35</td>
<td>32</td>
<td>28</td>
<td>25</td>
<td>23</td>
<td>18</td>
<td>13</td>
<td>9</td>
</tr>
<tr>
<td>CD control (3 sigma) (nm)</td>
<td>15.9</td>
<td>14.1</td>
<td>12.2</td>
<td>11</td>
<td>9.8</td>
<td>8.6</td>
<td>8</td>
<td>5.5</td>
<td>3.9</td>
<td>2.7</td>
</tr>
</tbody>
</table>
Limits of photolithography for non-IC applications

- High cost of semiconductor processing tools
- Limited process flexibility
  - No rapid prototyping possible
  - Not applicable on fragile substrates
    - Mechanical (MEMS devices, cantilevers, membranes,…)
    - Chemical layers (SAMs, biosensors, polymer layers,…)
- Bottle-neck for progress in Micro/Nanotechnology (in research and application)
TopDown and BottomUp

Heini Rohrer
(1996)
All length-scale patterning

Emerging methods
- Scanning Probes (SPL)
- Micro-contact Printing (soft-lithography)
- Nanoimprint litho (NIL)
- NanoStencil (shadow mask membrane)

Self-organisation of material
(sub-lithography)
- Directed or “encoded” self-assembly
- Chemical/Physical

Pattern transfer
- Deposition
- Etching
- Lift-off

Lithography
- Optical/EBL/X-ray/Interference

Technology
- Engineering
### Emerging Nanopatterning Methods

<table>
<thead>
<tr>
<th>Molecule Delivery</th>
<th>Thermo-mechanical</th>
<th>Local Deposition</th>
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<tbody>
<tr>
<td>Wet, soft-contact, 100 nm scale</td>
<td>Nano-imprint, embossing, hard contact, 10 nm scale</td>
<td>Stencil, vacuum, no contact 10-100 nm scale</td>
</tr>
</tbody>
</table>

**Single & Scanning de novo**
- **Molecule Delivery**: DipPen
- **Thermo-mechanical**: Heated AFM
- **Local Deposition**: AFM Nanostencil

**Parallel & Static Replication**
- **Molecule Delivery**: Soft-lithography
- **Thermo-mechanical**: NIL
- **Local Deposition**: Membrane Nano-stencil

**Parallel & Scanning Adaptive mass-production**
- **Molecule Delivery**: Parallel DipPen
- **Thermo-mechanical**: Millipede
- **Local Deposition**: Smart Stencil
Dip-Pen Nanolithography

Writing >30 nm lines on Au surface using 1-othodecanethiol as ink

Chad A. Mirkin et al. Science 283, 661 (1999)
Nanoscale Dispensing (NADIS)

- pattern “liquids”
  - e.g. biomolecules, suspensions, “surface chemistry”
- versatile (ambient conditions)
- parallel probes
- integrated fluidic system

Soft-lithography/microcontact printing

- replication of a “master-pattern” using PDMS (stamp)
- inking the stamp with molecules (thiols, thioethers, alkoxy silanes, chlorosilanes, etc.)
- contact the stamp with the substrate surface
- monolayer formation at regions of contact
- dissolving unprotected gold sites

Transport Mechanisms during Printing:
1. displacement
2. spreading
3. diffusion
4. spreading, gas diffusion (surface)
5. gas diffusion (ambient)
6. displacement

From: www.research.ibm.com
Catalytic microcontact printing without ink
A focused laser beam propagates through the transparent PMMA sample and heats the optically absorbing AFM tip. The heated tip softens the substrate, and the local tip pressure creates an indentation. The sample is placed on a precision air-bearing spindle to allow for sample rotation.
Heated AFM tip

Reference: IBM Almaden
Nano-imprint Technology

Nanoimprint lithography patterns a resist by deforming the resist shape through embossing (with a mold), rather than by altering resist chemical structures through radiation (with particle beams). After imprinting the resist, an anisotropic etching is used to remove the residue resist in the compressed area to expose the underneath substrate. 10nm diameter holes and 40nm pitch in PMMA can be achieved on Si or a metal substrate and excellent uniformity over 1 square inch.

http://www.ee.princeton.edu/~chouweb/