some things to think about when doing evaporation liftoff of nanometer scale patterns

1/30/09
review fundamentals
$r_{\text{dep}} = \text{deposition rate (thickness/sec)}$

$r_{\text{evap}} = \text{evaporation rate (mass/sec)}$

- **sample**
- **sample holder**
- **crucible**
Evaporation Rate

\[ r_{\text{evap}} = \sqrt{\frac{M}{2\pi kT}} P_e \]

- \( r_{\text{evap}} \) = evaporation rate
- \( M \) = atomic mass
- \( k \) = Boltzmann’s constant
- \( T \) = temperature
- \( P_e \) = vapor pressure
Deposition Rate

• deposition rate depends on the location and orientation of the wafer in the chamber
Deposition Rate

\[ r_{dep} = \frac{r_{evap}}{\Omega d^2 \rho} \cos \theta \]

- \( r_{dep} \) = deposition rate (thickness/sec)
- \( r_{evap} \) = evaporation rate (mass/sec)
- \( \Omega \) = solid angle over which source emits (unit less steradians)
- \( d \) = source to substrate distance
- \( \rho \) = material density
- \( \theta \) = inclination of substrate away from direction to source
**Uniformity**

**Case 1:** $d \leq x$

- $d_1 < d_2$
- $r_{dep}(d_1) > r_{dep}(d_2)$

**Case 2:** $d \gg x$

- $d_1 \approx d_2$
- $r_{dep}(d_1) \approx r_{dep}(d_2)$
\[ \Delta r_{dep} = \frac{1}{(\Delta d)^2} \]

if \( \Delta d = 2 \), then \( \Delta r_{dep} = \frac{1}{4} \)
example
Detecting DNA with Carbon Nanotube Arrays
Prabhu Arumugam, NASA Ames Research Center
Devin Brown, Georgia Tech Nanotechnology Research Center
Bruce Gale, University of Utah
Neil Gordon, Early Warning Inc.

Below is a 4 inch wafer with 30 chips.

Each pad has 100nm nickel dots spaced at 1 micron, shown below.

Each chip has a 3 x 3 array of 200 micron pads shown above.

Multi-walled carbon nanotubes are grown on each nickel dot.

At left is an artist’s conception of an ultrasensitive multiplex electronics biosensor based on a carbon nanotube nanoelectrode array. The insets on the right represent applications in DNA (top) and antigen detection (bottom).

Carbon nanotubes offer a wide electrochemical window, flexible surface chemistry, and biocompatibility. By placing a thousand nanotube probes in the space of one of today’s metal electrodes, DNA sequences can be detected from less than a thousand strands. This is sensitive enough to directly measure mRNAs in a drop of blood or a piece of tiny tissue sample. It matches the upper limit of sensitivity of conventional laser-based fluorescence techniques, but doesn’t require time-consuming sample preparation and expensive and bulky analytical equipment.
Carbon nanotube catalyst pattern
130nm diameter on 1um pitch
100A Cr + 300A Ni
### Process Flow

<table>
<thead>
<tr>
<th>step</th>
<th>description</th>
<th>equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>spincoat PMMA A4 at 2000RPM, 1000RPM/s, 60sec</td>
<td>CEE Brewer 100CB spincoater</td>
</tr>
<tr>
<td>2</td>
<td>hotplate bake 180C, 90sec</td>
<td>CEE Brewer 100CB spincoater</td>
</tr>
<tr>
<td>3</td>
<td>resist thickness measurement</td>
<td>Woolam ellipsometer (180nm), Tencor P15 profilometer (230nm)</td>
</tr>
<tr>
<td>3</td>
<td>EBL expose requires prealignment 100kV, 2nA, 1950uC/cm², shot pitch = 4nm</td>
<td>JEOL JBX-9300FS EBL system</td>
</tr>
<tr>
<td>4</td>
<td>develop 1:1 MIBK:IPA 2min immersion, IPA immersion 30sec</td>
<td>wet bench</td>
</tr>
<tr>
<td>5</td>
<td>optical microscope inspection</td>
<td>Leitz Ergolux</td>
</tr>
<tr>
<td>6</td>
<td>e-beam evaporate 10nm Cr @ 1A/s, 30nm Ni @ 2A/s</td>
<td>CVC E-beam evaporator</td>
</tr>
<tr>
<td>7</td>
<td>acetone liftoff (2 to 3 hrs)</td>
<td>wet bench</td>
</tr>
<tr>
<td>8</td>
<td>SEM inspection (Hitachi full die inspection)</td>
<td>Zeiss Ultra 60 FESEM, or Hitachi 3500 Thermionic SEM</td>
</tr>
</tbody>
</table>
Problem

😊 want this but often get this
nanodot diameters for uu27 / slot 8

all die measured

Legend

diameter

- <= 100
- <= 105
- <= 110
- <= 115
- <= 120
- <= 125
- <= 130
- <= 135
- > 135
wafer point of view to incoming metal evaporation

\[
\tan \theta = \frac{x_2}{y}
\]

\[
x_2 = \tan \theta \times y
\]
The diagram illustrates the wafer point of view to incoming metal evaporation, focusing on the nanodot size and its top-down and side-view shapes at various angles. The table below summarizes the nanodot size and shapes for different angles:

<table>
<thead>
<tr>
<th>angle (degrees)</th>
<th>nanodot size (nm)</th>
<th>top down shape</th>
<th>side view shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>130</td>
<td>![top down shape 0]</td>
<td>![side view shape 0]</td>
</tr>
<tr>
<td>1</td>
<td>128</td>
<td>![top down shape 1]</td>
<td>![side view shape 1]</td>
</tr>
<tr>
<td>3</td>
<td>123</td>
<td>![top down shape 3]</td>
<td>![side view shape 3]</td>
</tr>
<tr>
<td>6</td>
<td>116</td>
<td>![top down shape 6]</td>
<td>![side view shape 6]</td>
</tr>
<tr>
<td>9</td>
<td>109</td>
<td>![top down shape 9]</td>
<td>![side view shape 9]</td>
</tr>
<tr>
<td>12</td>
<td>80</td>
<td>![top down shape 12]</td>
<td>![side view shape 12]</td>
</tr>
</tbody>
</table>

The diagram also shows the thickness of PMMA (235 nm) and silicon (80 nm). The PMMA layer is directly above the silicon layer.
in order to limit incoming angle to 3 degrees or less across entire wafer, the sample would have to be placed almost 1m away from crucible, however this would decrease evaporation rate by 1/16.
6” wafer
Cr + Ni thickness measured on this mark of each chip
CVC1 evaporator

crucible not centered relative to sample holder
AFM measurement of nanodots
AFM measurement of nanodots
follow up points for next time
thicker resist is worse
characterize your resist (dose vs. feature size)