Self Aligned Quadruple Patterning

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SADP vs. SAQP [1]

(a) 2-mask nSADP
(b) 2-mask nSAQP

Trim and NOT Spacer 1
Trim and NOT Spacer 2

Negative tone
Spacer Expansion $\rightarrow$ 3 mask SAQP

- Proposed in this paper
- To form additional 2-D patterns $\rightarrow$ more flexibility
  - Patterns formed by S1 are constant width (W1)
- CD of SE pattern is larger than spacer1 width (W1)
  - because patterned by optical lithography

(c) 3-mask nSAQP
Generation of 2D patterns

- Notice final patterns formed by mandrel are smaller than original mandrel patterns
  - because spacer2 is formed right next to spacer1 consuming some areas of the original mandrels.
Definitions

- **1D**: features with a single minimum (spacer1 width) CD, *not necessarily* straight
- **2D**: other types of features
Definitions (cont’d)

<table>
<thead>
<tr>
<th>M</th>
<th>Feature generated in mandrel region</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>Feature generated in gap (space) region between mandrels</td>
</tr>
<tr>
<td>MG</td>
<td>Feature generated in mandrel or gap region</td>
</tr>
<tr>
<td>S1</td>
<td>Feature generated in spacer1 region</td>
</tr>
<tr>
<td>SE</td>
<td>Feature generated in spacer1-expansion region</td>
</tr>
<tr>
<td>S1-SE</td>
<td>Feature generated in spacer1 or spacer1-expansion region</td>
</tr>
</tbody>
</table>

- M and G patterns can be either 1-D or 2-D,
- S1 patterns are 1D
- S1-SE and SE patterns in 3-mask nSAQP process can only be 2-D features.
# Line arrangements

<table>
<thead>
<tr>
<th>Process Type</th>
<th>Composition</th>
<th>Line Types</th>
<th>Line Arrangement</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-mask nSADP</td>
<td><img src="image1" alt="Diagram" /></td>
<td>M(2-D or 1-D) (\oplus) G(2-D or 1-D)</td>
<td>G(\parallel)M</td>
</tr>
<tr>
<td>2-mask nSAQP</td>
<td><img src="image2" alt="Diagram" /></td>
<td>M(2-D or 1-D) (\oplus) G(2-D or 1-D)</td>
<td>G(\parallel)S1(\parallel)M(\parallel)S1</td>
</tr>
<tr>
<td>3-mask nSAQP</td>
<td><img src="image3" alt="Diagram" /></td>
<td>M(2-D or 1-D) (\oplus) G(2-D or 1-D)</td>
<td>G(\parallel)S1-SE(\parallel)M(\parallel)S1-SE</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Process Type</th>
<th>Dimensional characteristics</th>
</tr>
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<tbody>
<tr>
<td>2-mask nSADP</td>
<td>2-D(\parallel)2-D</td>
</tr>
<tr>
<td>2-mask nSAQP</td>
<td>2-D(\parallel)1-D(\parallel)2-D(\parallel)1-D</td>
</tr>
<tr>
<td>3-mask nSAQP</td>
<td>2-D(\parallel)2-D(\parallel)2-D(\parallel)2-D</td>
</tr>
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</table>

[Image -573x-90 to 1049x885]
Dimensions [2]

Spacer1 width: W1
Spacer2 width: W2
Final layout = Trim and not S2

- Min feature width: W1
  - formed by S1
- Min feature space: W2
  - formed by S2
- Min feature pitch: W1+W2
2-Mask SAQP Decomposition [1] based on SADP

1. Construct conflicting graph and assign colors to S1 and MG patterns
   - Non-W1 width polygons are MG
   - Connect each pair of polygons separated by W2

2. Generate assisting MG on both sides of S1 patterns
2-Mask SAQP Decomposition [1] (cont’d)

3. MG patterns at a distance less than CDmin
   \[\Rightarrow\] MERGE to form a new MG polygon

4. Generate Spacer2 next to Spacer1 patterns

5. Create virtual “equivalent spacer” by grouping S1 and S2 features together

6. Do SADP Layout decomposition \[\Rightarrow\] M & G
2-Mask SAQP Decomposition [1] RECAP

1. Construct graph
2. Color MG and S1
3. Generating assisting MG patterns
4. Merging MG patterns
5. Generating spacer2
6. SADP layout decomposition
7. Forming closed-loop spacers and generating trim pattern.
8. Trim mask hot spot detection
3-Mask SAQP Decomposition

- Types of features: M, G, S1 and SE
3-Mask SAQP: Allowed and Disallowed Combinations

| Combinations | 1-D||2-D | 2-D||1-D | 2-D||2-D | 1-D||1-D |
|--------------|-------|-------|-------|-------|-------|
| Assign color | S1||MG | MG||S1 | MG||S1-SE | S1-SE||MG | S1||MG | MG||S1 |

Examples

- S1 (1D)|||S1-SE (2D)

These configurations are assumed to be prohibited because of process limitation and overlay.

Also, S1-SE(2-D) || MG(1-D) replaced by MG(2-D) || S1(1-D) for simplification.
3-Mask SAQP Decomposition [1]

1. Construct Conflicting graph
2. Identify all pairs of 1-D || 2-D and 2-D || 1-D features ➔ assign MG color to the 2-D nodes and S1 color to the 1-D nodes
3. Now any uncolored 1-D node can only be connected to 1-D node(s), and similarly any uncolored 2-D node can only be connected to 2-D node(s)
   ➔ Same type of uncolored nodes groups to form subgraphs
   ➔ Use 2-coloring on each subgraph
3-Mask SAQP Decomposition [1] RECAP

(1) Target layout and conflicting graph

(2) Assign colors for 2D||1D pattern pairs

(3) Using 2-coloring algorithm to decompose 1D||1D and 2D||2D patterns
3-Mask SAQP based on SADP [1]

(a) Construct graph
(b) Color S1(1D)/MG(2D), and S1-SE(2D)
(c) Separate S1 and SE
(d) Remove SE pattern

(e) Generating assisting MG patterns
(f) MG complement
(g) Equivalent SADP layout decomposition
(h) Forming closed-loop spacers and generating trim pattern
References

1. Mask Strategy and Layout Decomposition for Self-Aligned Quadruple Patterning; SPIE; 2013
2. Characterization and Decomposition of Self-Aligned Quadruple Patterning Friendly Layout; SPIE 2012
QUESTIONS?
ALGORITHM FLAWS?