UCLA

# Self Aligned Quadruple Patterning

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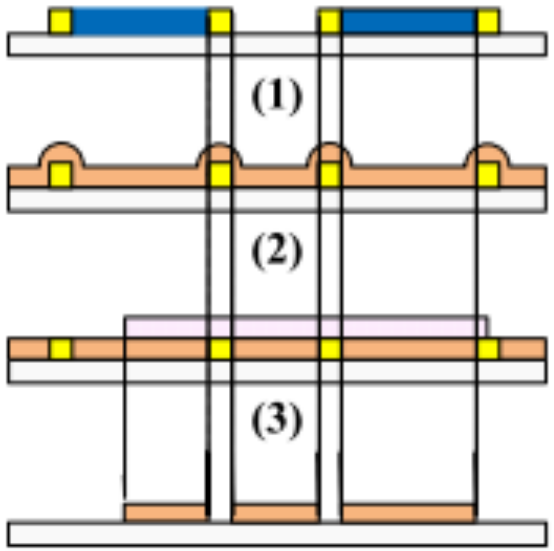
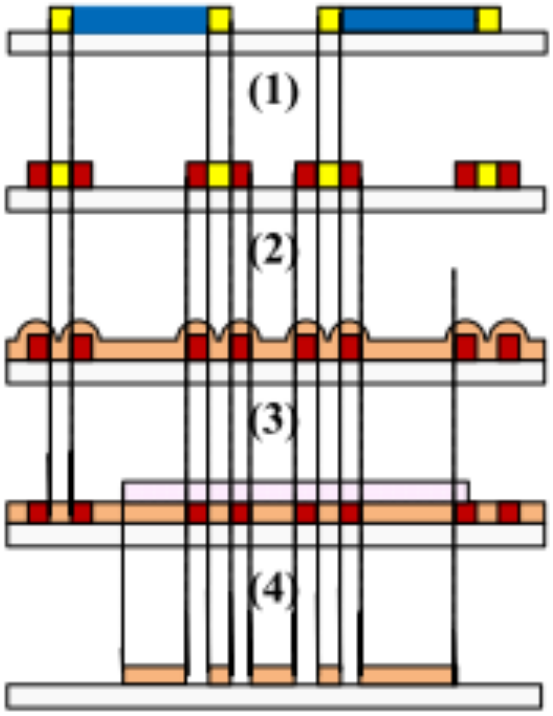
# SADP vs. SAQP [1]

Negative tone





(a) 2-mask nSADP

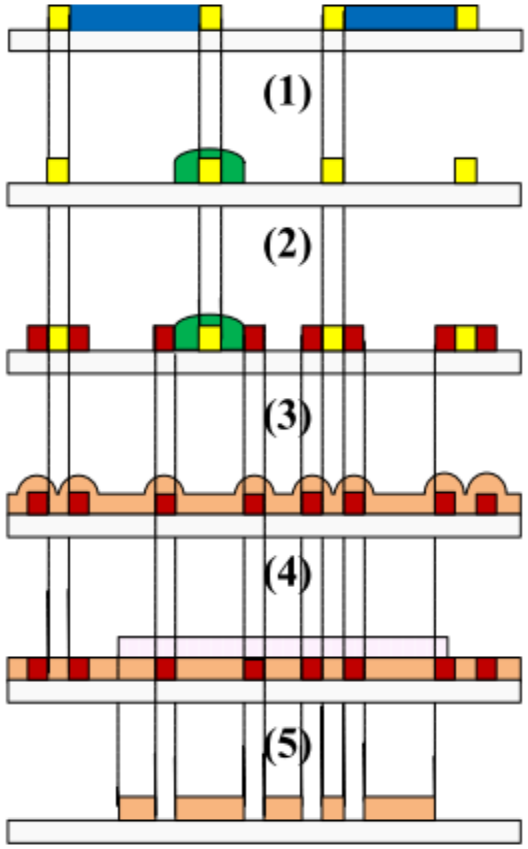
Trim and NOT Spacer 1

(b) 2-mask nSAQP

Trim and NOT Spacer 2

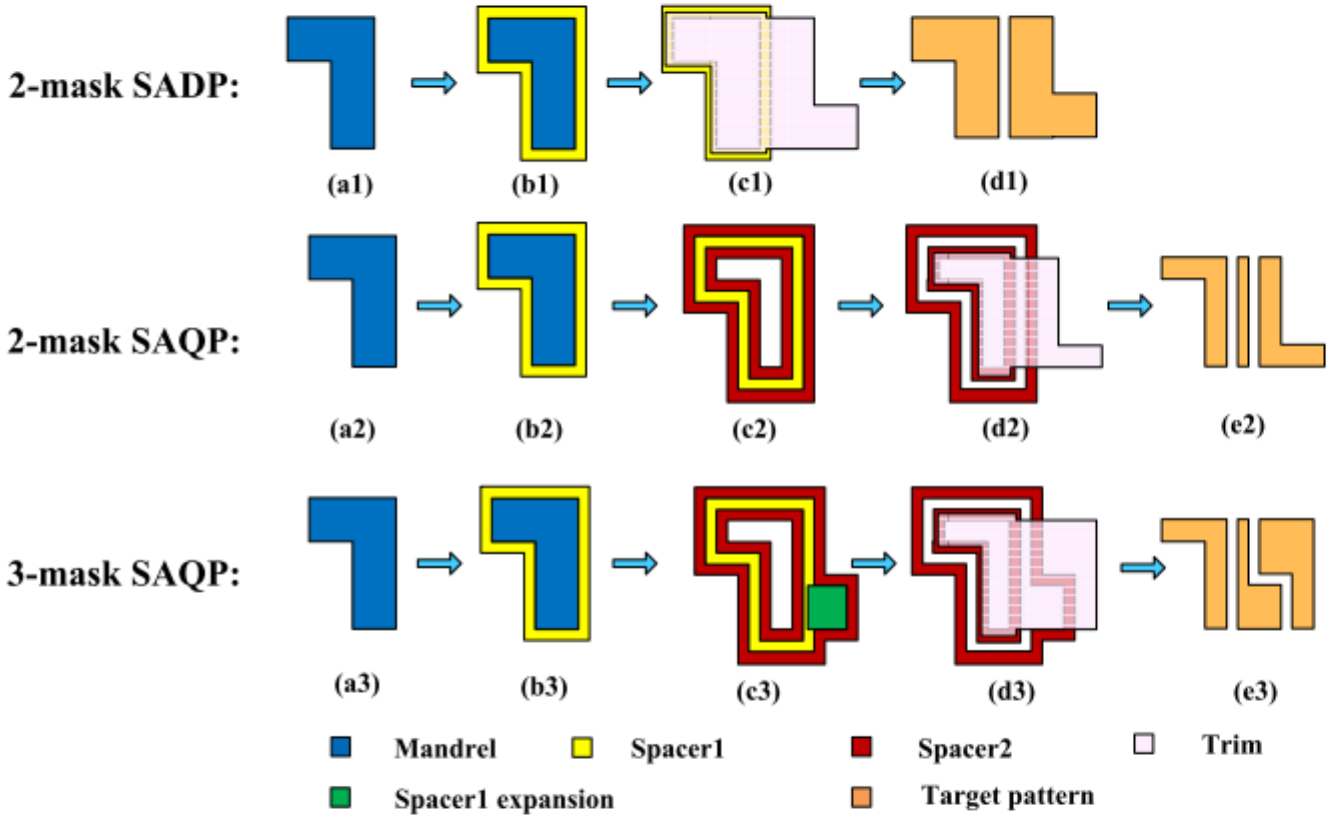
# Spacer Expansion➔3 mask SAQP

- Proposed in this paper
- To form additional 2-D patterns ➔ more flexibility
  - Patterns formed by S1 are const 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

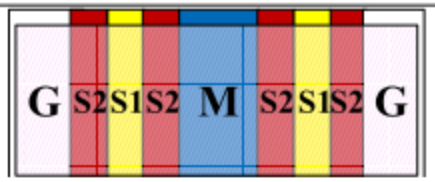
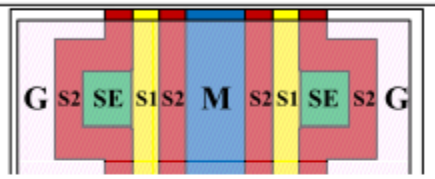
- **1D**: features with a single minimum (spacer1 width) CD, **not necessarily** straight
- **2D**: other types of features

# Definitions(cont'd)

| | |
|---|---|
| M | Feature generated in mandrel region |
| G | Feature generated in gap (space) region between mandrels |
| MG | Feature generated in mandrel or gap region |
| S1 | Feature generated in spacer1 region |
| SE | Feature generated in spacer1-expansion region |
| S1-SE | Feature generated in spacer1 or spacer1-expansion region |

- 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

| Process Type | Composition | Line Types | Line Arrangement |
|---|---|---|---|
| 2-mask nSADP |   | M(2-D or 1-D)<br>G(2-D or 1-D) | G\|\|M |
| 2-mask nSAQP |   | M(2-D or 1-D)<br>G(2-D or 1-D)<br>S1(1-D) | G\|\|S1\|\|M\|\|S1 |
| 3-mask nSAQP |   | M(2-D or 1-D)<br>G(2-D or 1-D)<br>S1(1-D)<br>SE(2-D) | G\|\|S1-SE\|\|M\|\|S1-SE |

| Process Type | Dimensional characteristics |
|---|---|
| 2-mask nSADP | 2-D\|\|2-D |
| 2-mask nSAQP | 2-D\|\|1-D\|\|2-D\|\|1-D |
| 3-mask nSAQP | 2-D\|\|2-D\|\|2-D\|\|2-D |

# Dimensions [2]

Spacer1 width: W1

Spacer2 width: W2

Final layout = Trim and not S2

➔Min feature width:  W1

- formed by S1

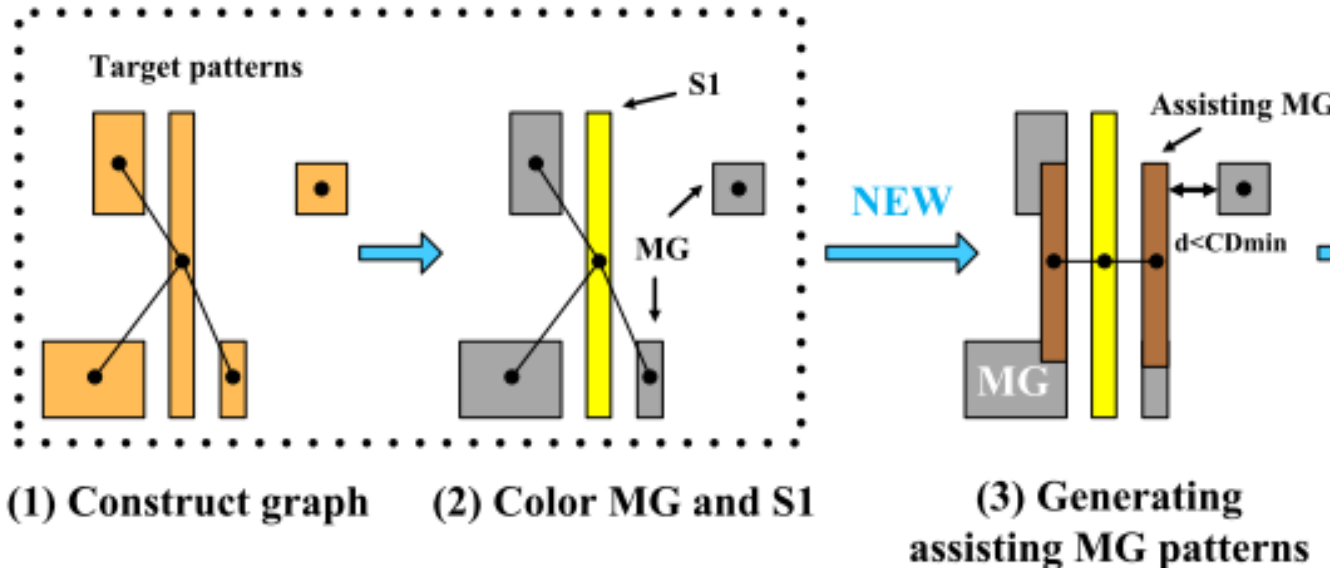
➔Min feature space: W2

- formed by S2

➔Min feature pitch: W1+W2

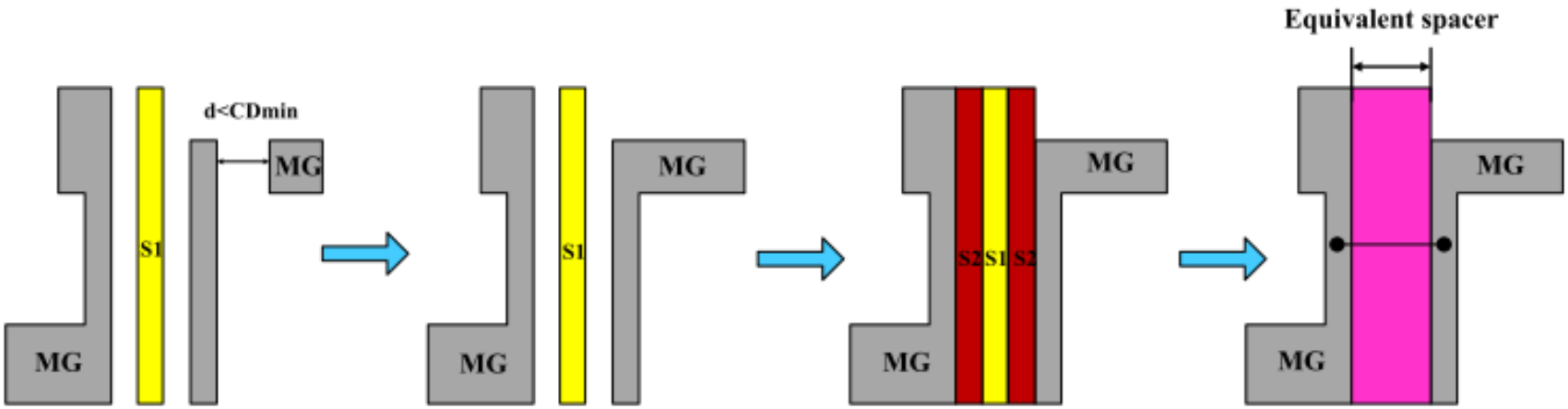
# 2-Mask SAQP Decomposition [1] based on SADP

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

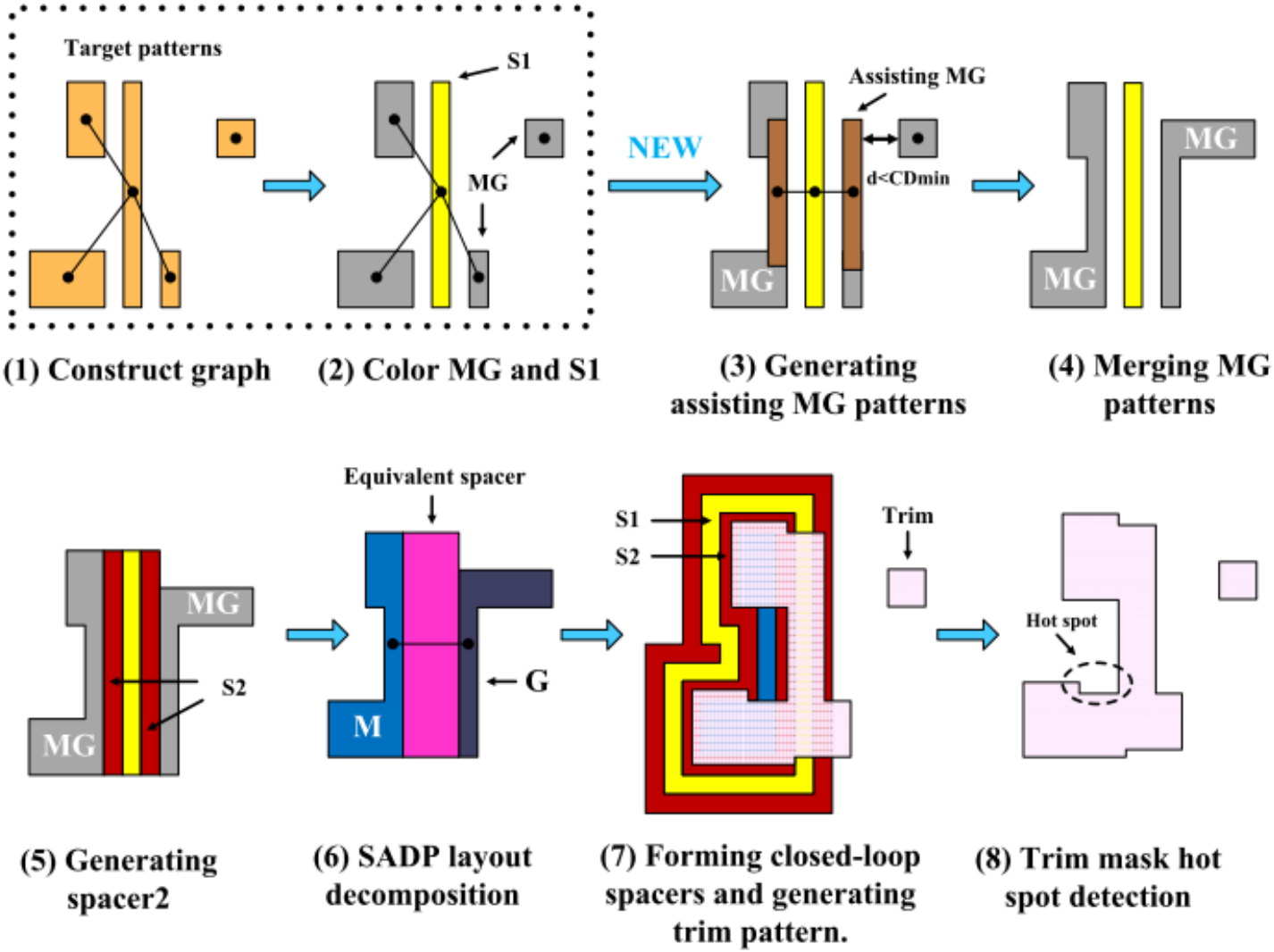


# 2-Mask SAQP Decomposition [1] (cont'd)

3. MG patterns at a distance less than CDmin
   ➔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➔ M & G

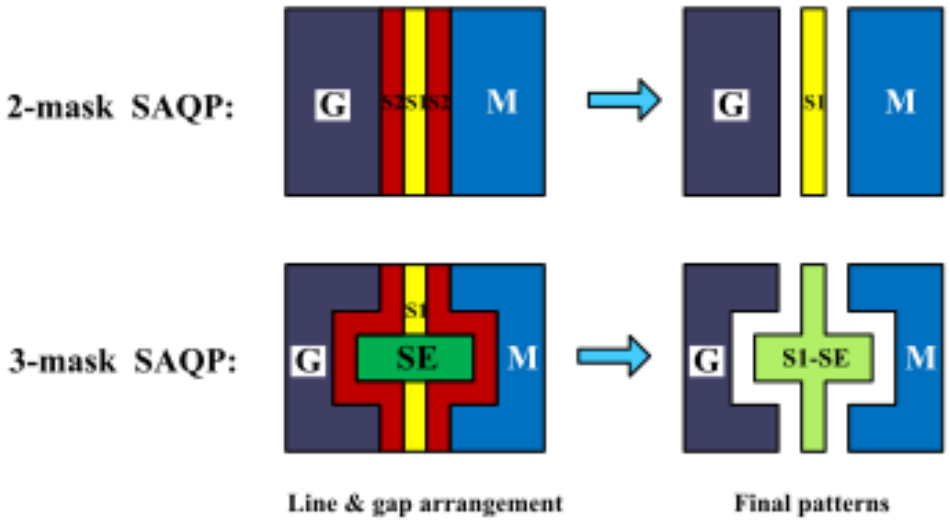


# 2-Mask SAQP Decomposition [1] RECAP

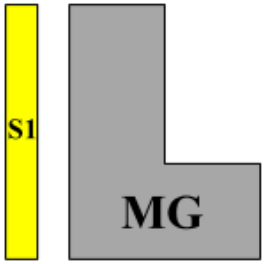
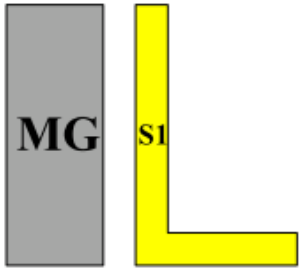
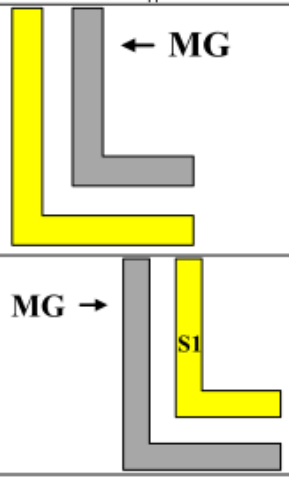


# 3-Mask SAQP Decomposition

- Types of features: M, G, S1 and SE

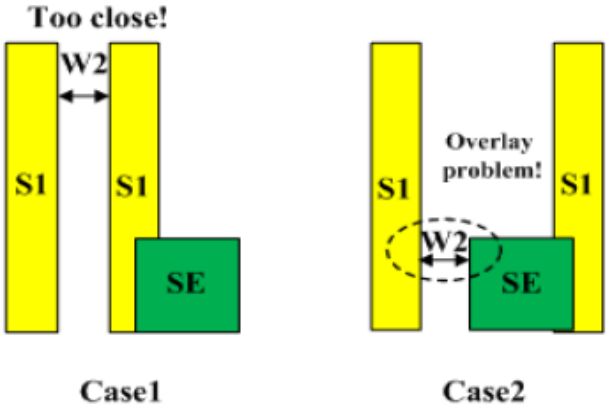


# 3-Mask SAQP: Allowed and Disallowed Combinations

| 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<br>S1-SE\|\|MG | S1\|\|MG<br>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.

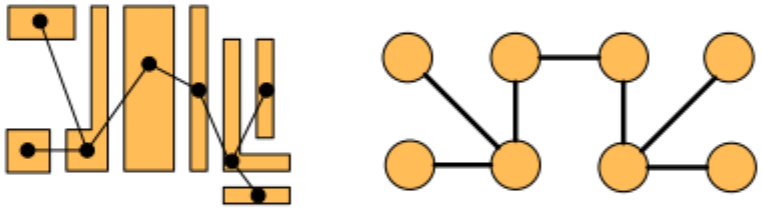
# 3-Mask SAQP Decomposition [1]

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)

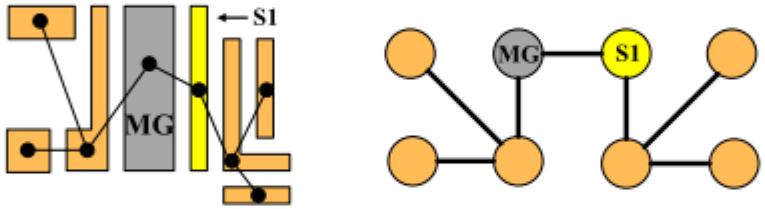
➔Same type of uncolored nodes groups to form subgraphs

➔Use 2-coloring on each subgraph

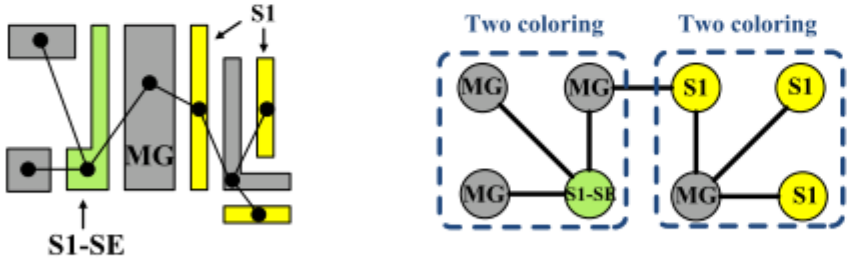
# 3-Mask SAQP Decomposition [1] RECAP



(1) Target layout and conflicting graph

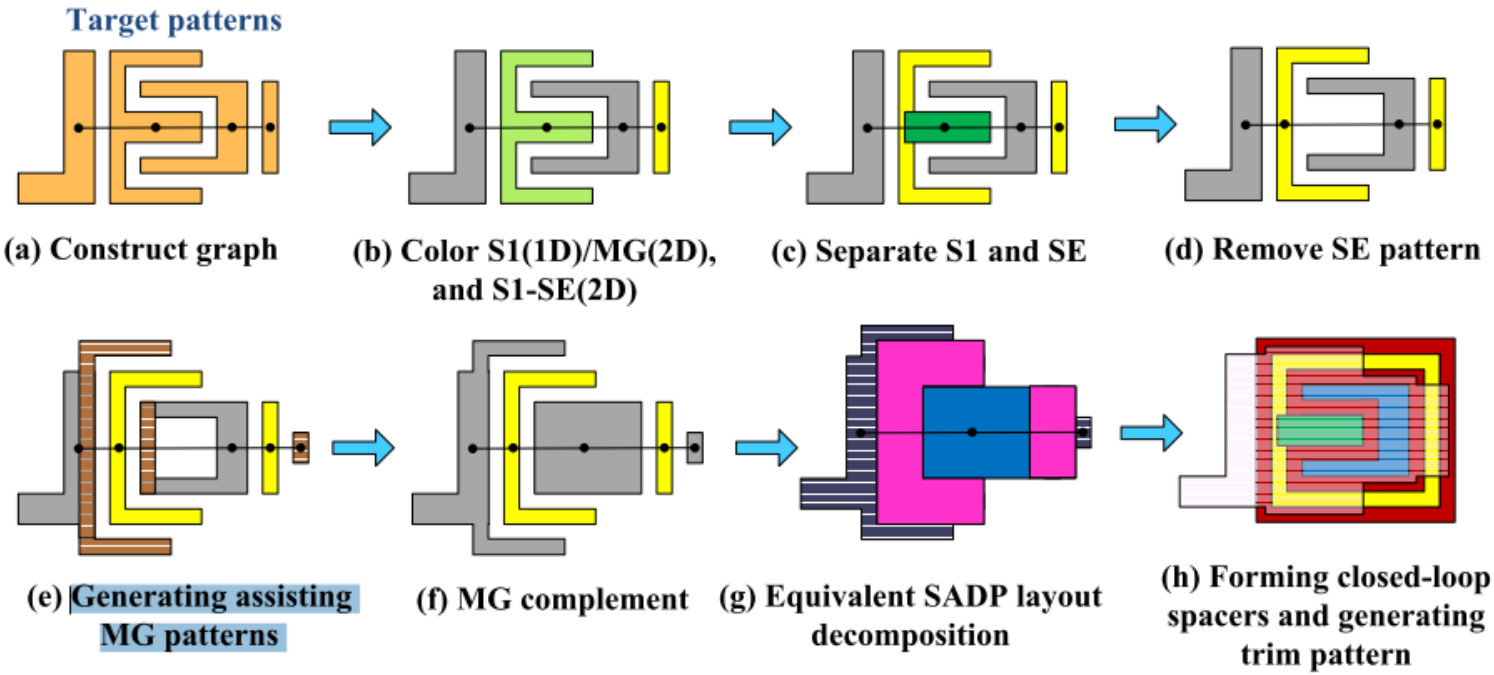



(2) Assign colors for 2D||1D pattern pairs




(3) Using 2-coloring algorithm to decompose 1D||1D and 2D||2D patterns

# 3-Mask SAQP based on SADP [1]



# 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?