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Leading Innovation

Self-Aligned Double and Quadruple Patterning-Aware Grid Routing with Hotspots Control

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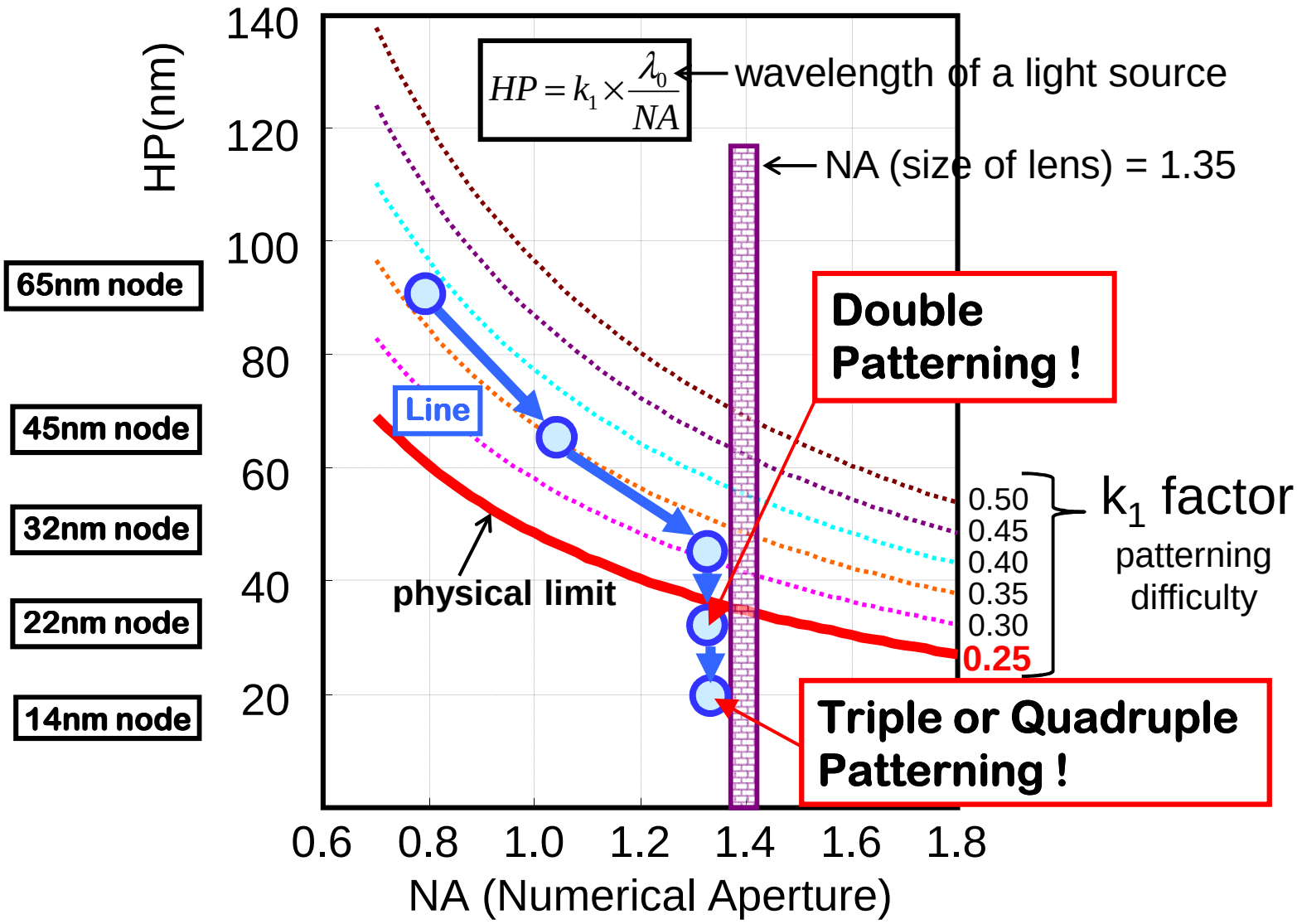
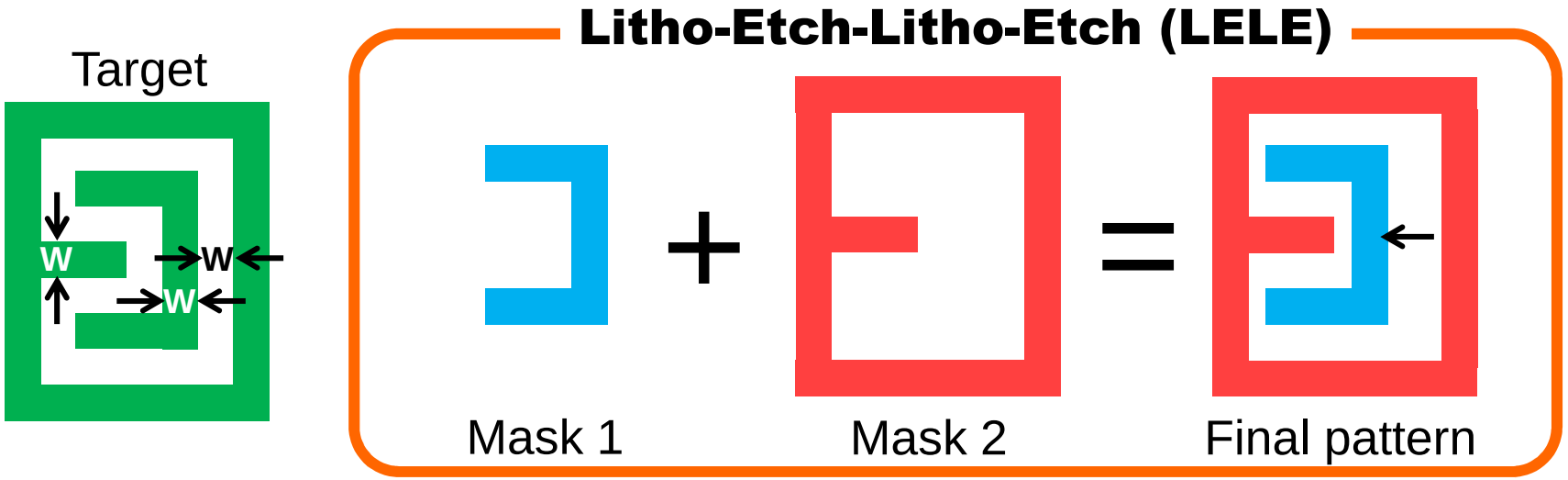
Outline

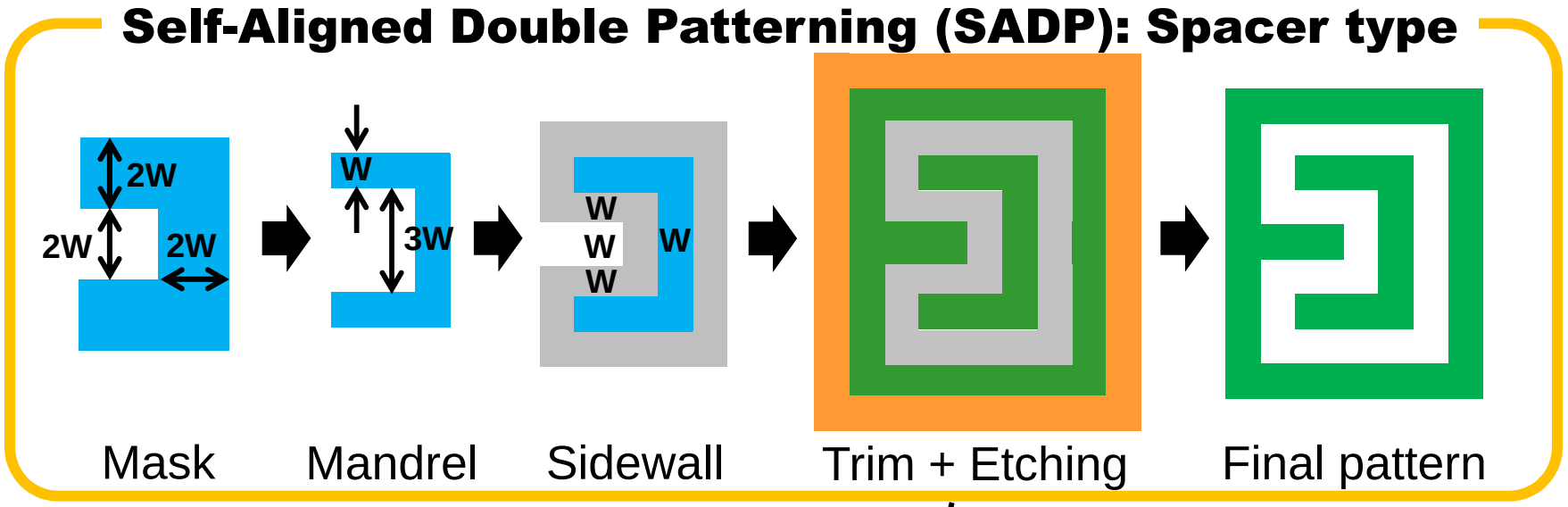
- Motivation
- SADP-aware Grid Routing
- Experiments and Results
- Expansion into SAQP-aware Grid Routing (digest)
- Conclusions and Future Works

Resolution Limit on Arf Lithography



Double Patterning

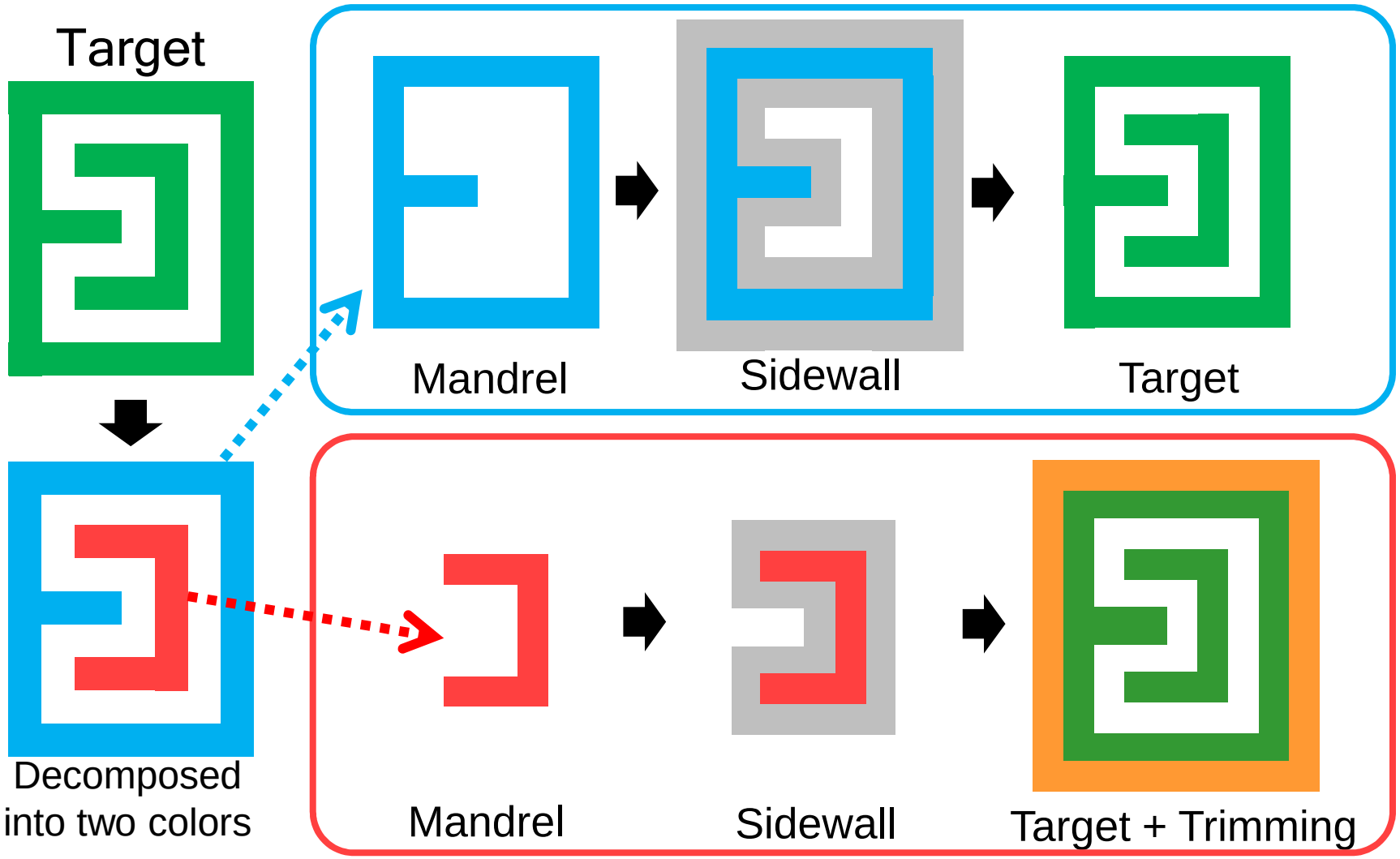




Mask (Mandrel) Pattern ≠ Final Pattern

Difficult to design intuitively

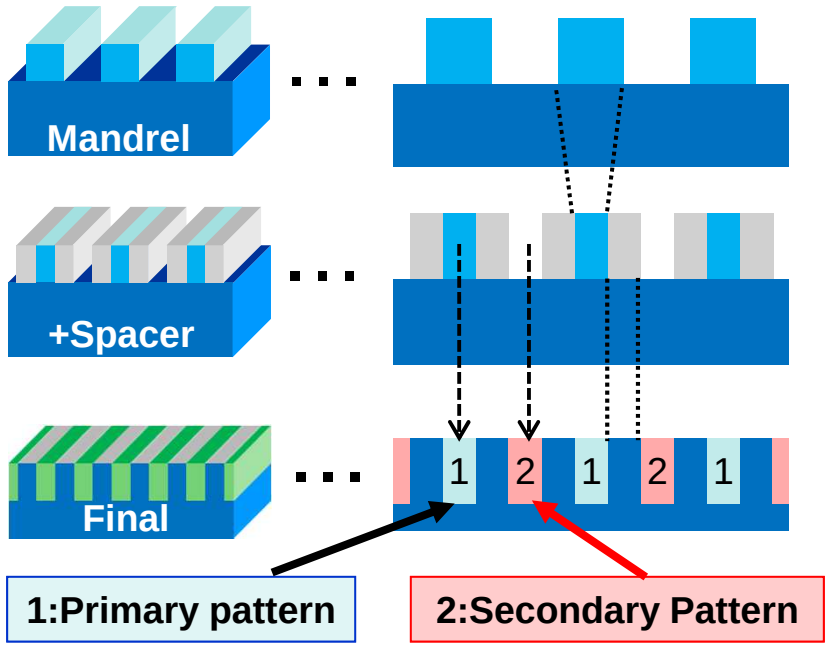
SADP Spacer Process overview



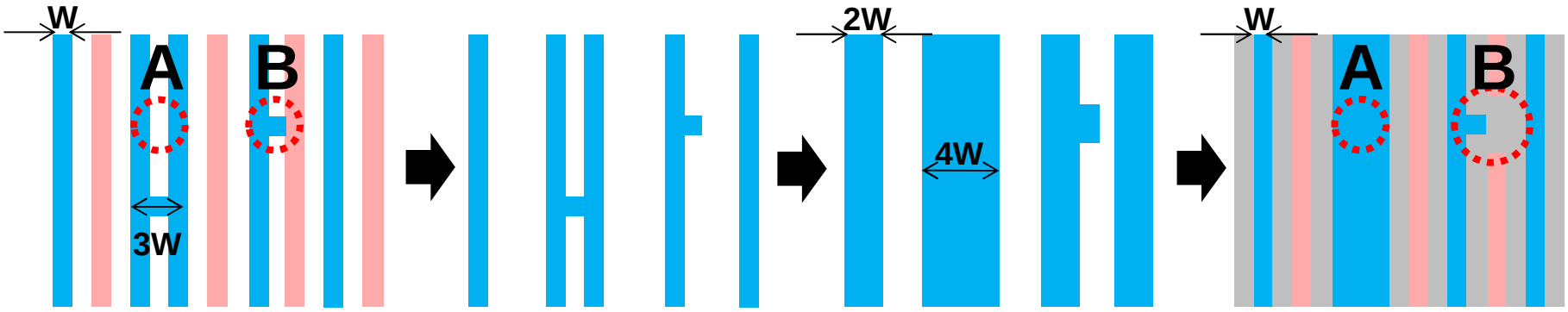
Layout design by two colors is effective!!

[DAC2011] Y. Ban, K. Lucas and D. Z. Pan,
"Flexible 2D layout decomposition framework for spacer-type double pattering lithography".

Feasible SADP Layout

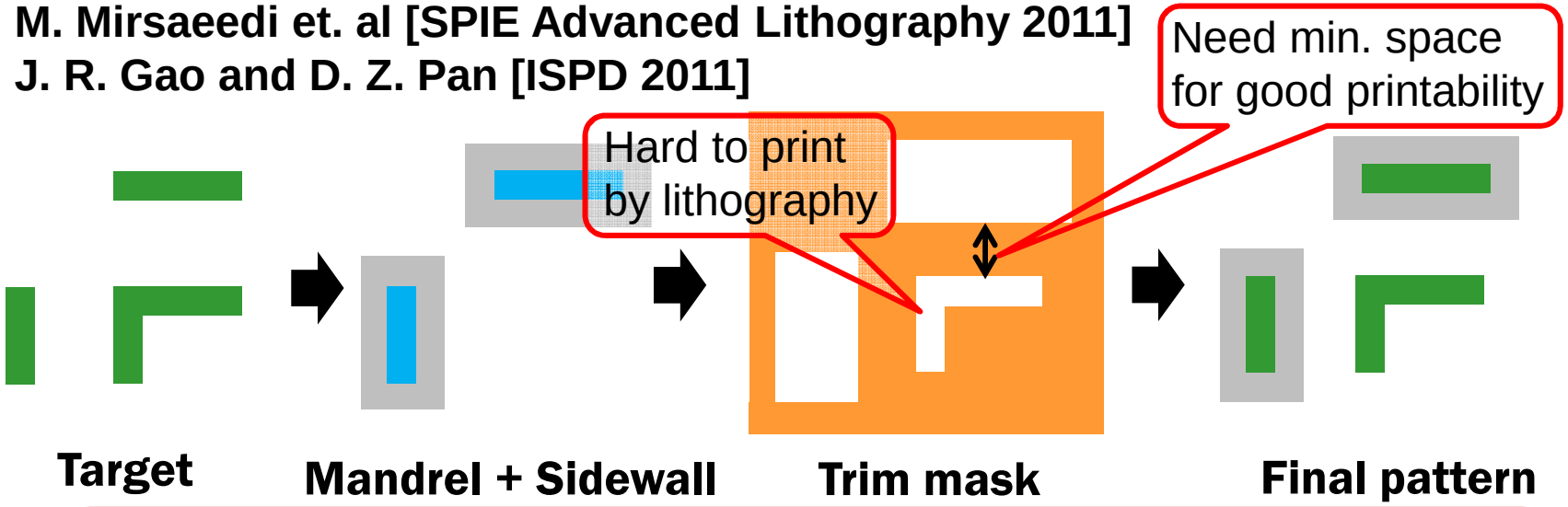


- Spaces of the final pattern are constant.
- Patterns can be painted into two groups, primary and secondary.
- The primary and secondary patterns are separated by spacer.
  → The different color patterns cannot “connect”.

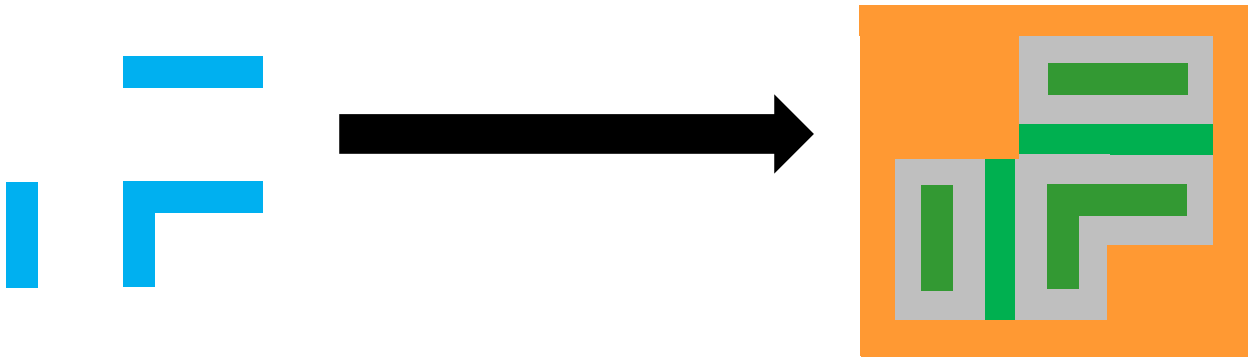


Previous Works

M. Mirsaeedi et. al [SPIE Advanced Lithography 2011]
J. R. Gao and D. Z. Pan [ISPD 2011]



- All patterns should be formed by sidewall.
- Trim mask should be used only for trimming unnecessary patterns.

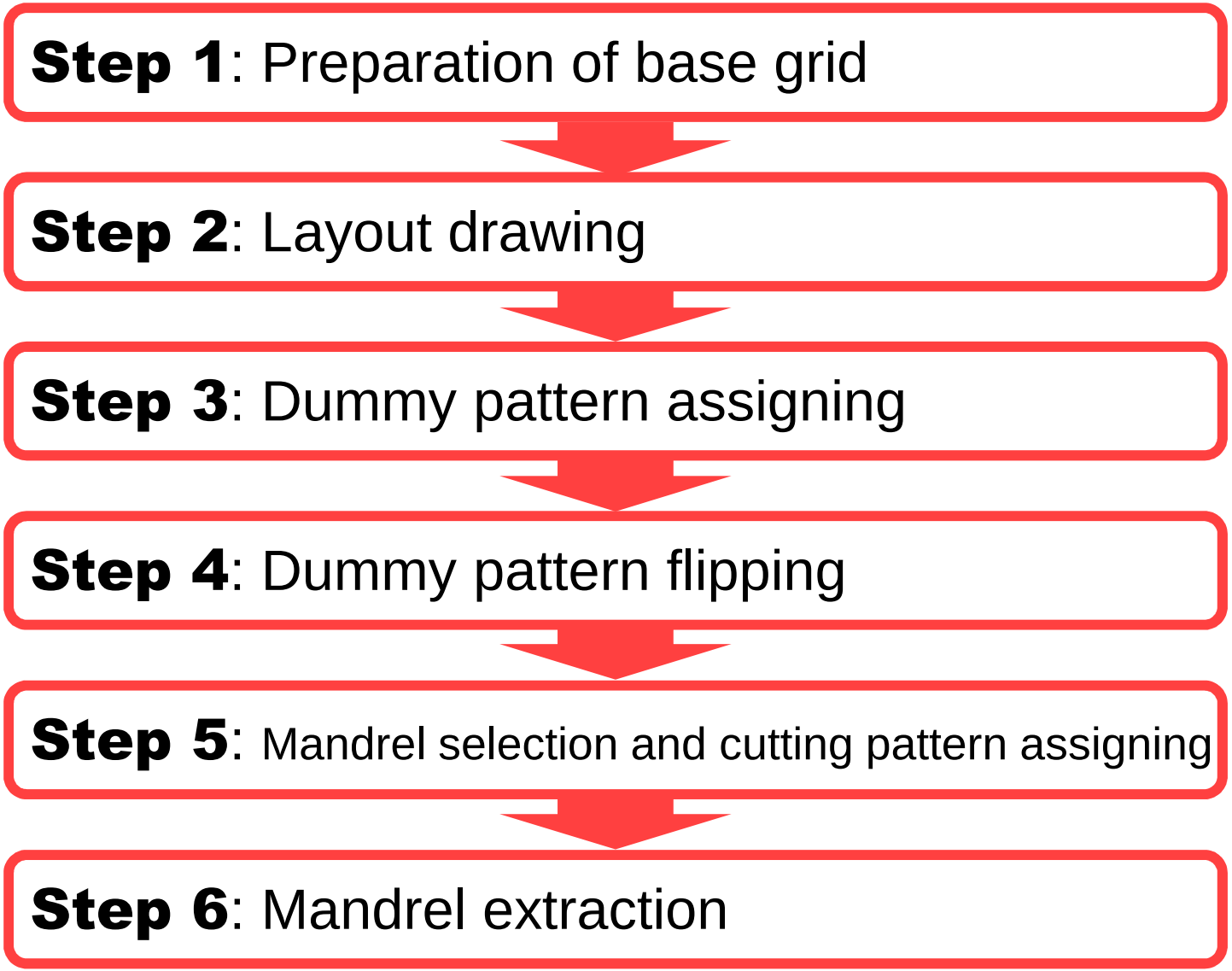


Main Contribution

- Propose a new grid structure like chessboard for routing and simple routing rule for SADP.
- A routed pattern by the proposed method is automatically decomposed into two colors.
- All patterns routed by the proposed method are protected by sidewall spacers.
- Patterns are not formed by trimming process.
- A new concept "**Cutting Pattern**" is adopted in the proposed method

SADP-aware Grid Routing

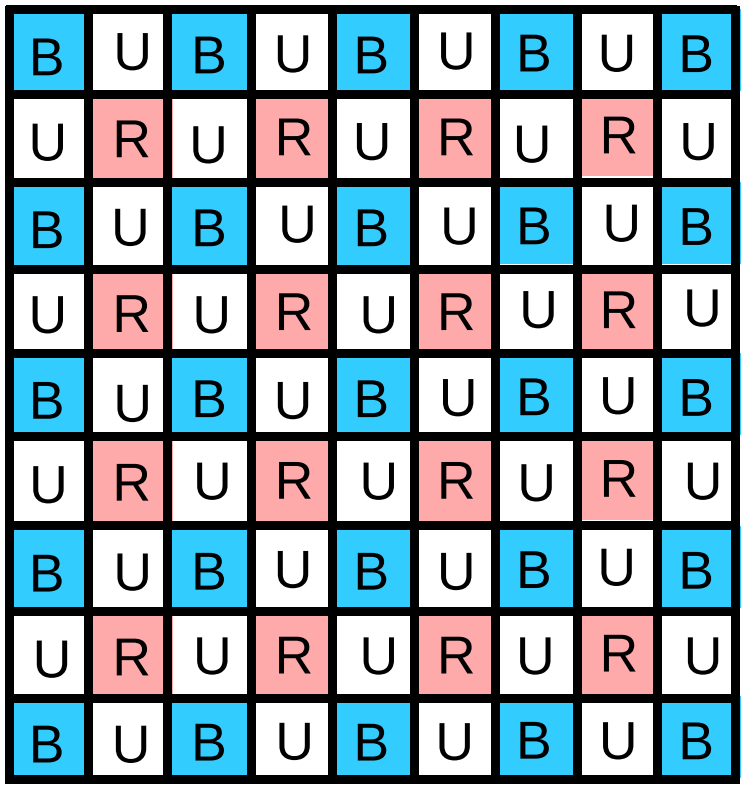
SADP-aware Grid Routing



SADP Grid Routing: Step 1

Base grid

Prepare grid structure like chessboard.



Three kinds of grids

R: **Red**

B: **Blue**

U: **Uncolored**

Occupied: Grid used by routing

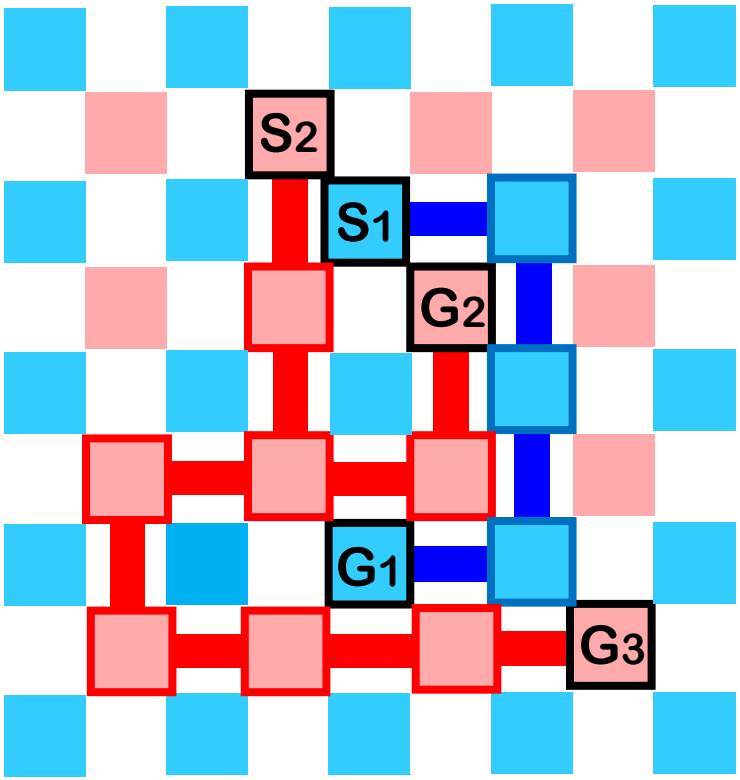
Vacant: Unused grid.

SADP Grid Routing: Step 2

Rule specification

For routing, every pin of each net is set at the same color grid R or B, but not U.

Example: Connect **S1** to **G1**, **S2** to **G2** and **G3**.



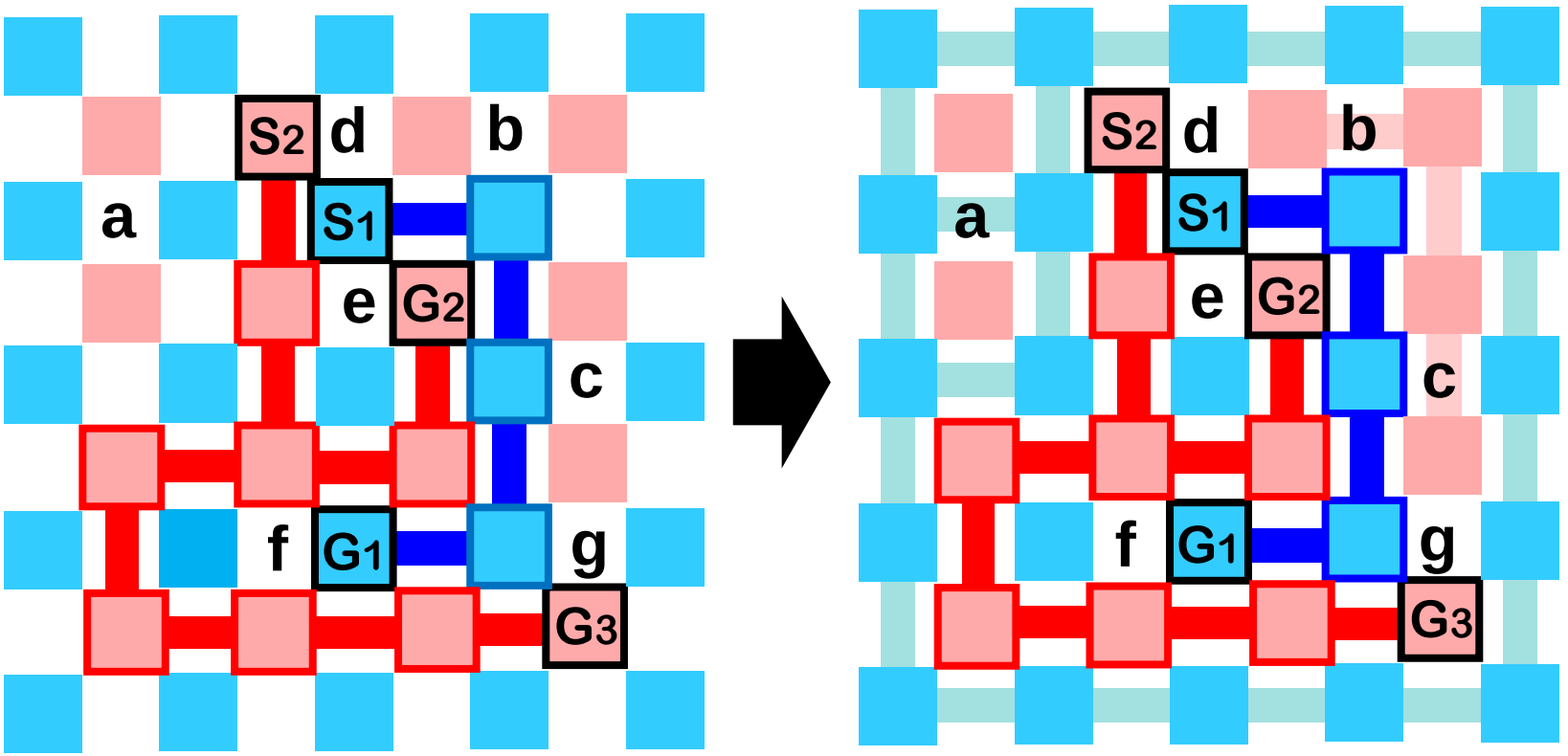
Drawing rule

- Path only goes through the grids of the same color as pins, and U which accordingly is painted with the same color too.
- Each grid is allowed to be occupied by one net only.

SADP Grid Routing: Step 3

Dummy pattern assigning

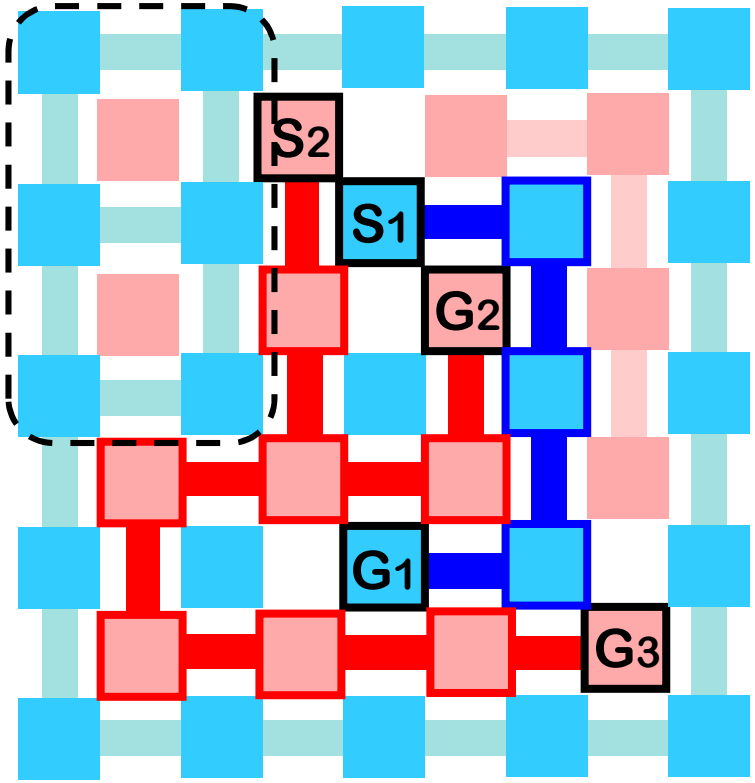
Assign dummy pattern to each vacant U if it does not connect to the path routed in Step 2.



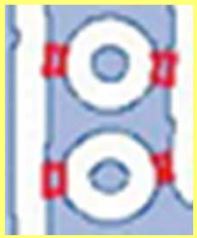
SADP Grid Routing: Step 4

Hotspots problem generated by small dummies

Dummy pattern with one grid size (like island) or small length may generate hotspots around it.

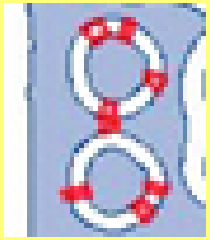


Hotspots on narrow pattern



Filling problem of conductive material
Disturbance of inspection Process

Hotspots on narrow space



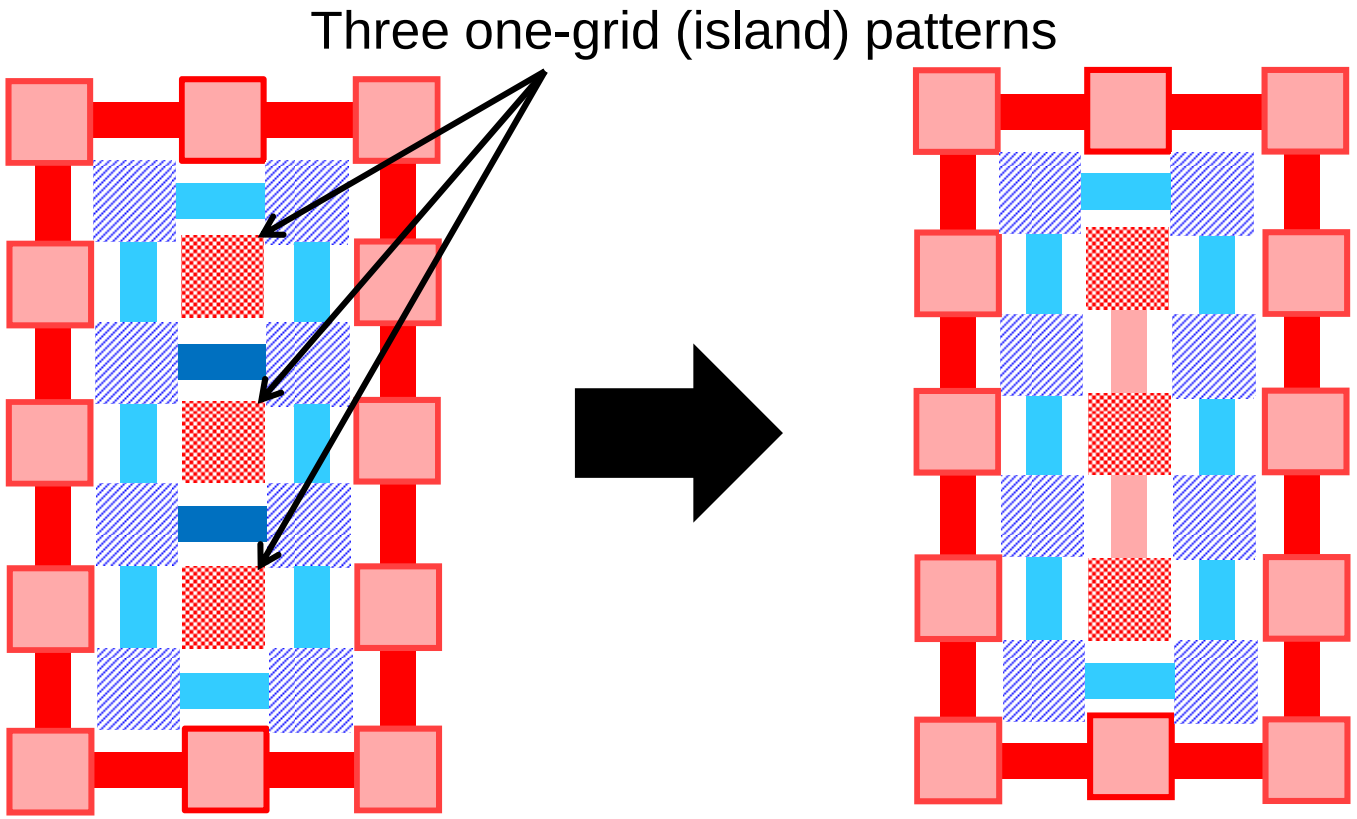
Narrow space, originally sidewall with narrow width is easy to collapse into debris.

Dummy pattern flipping will be applied to eliminate hotspots!

SADP Grid Routing: Step 4

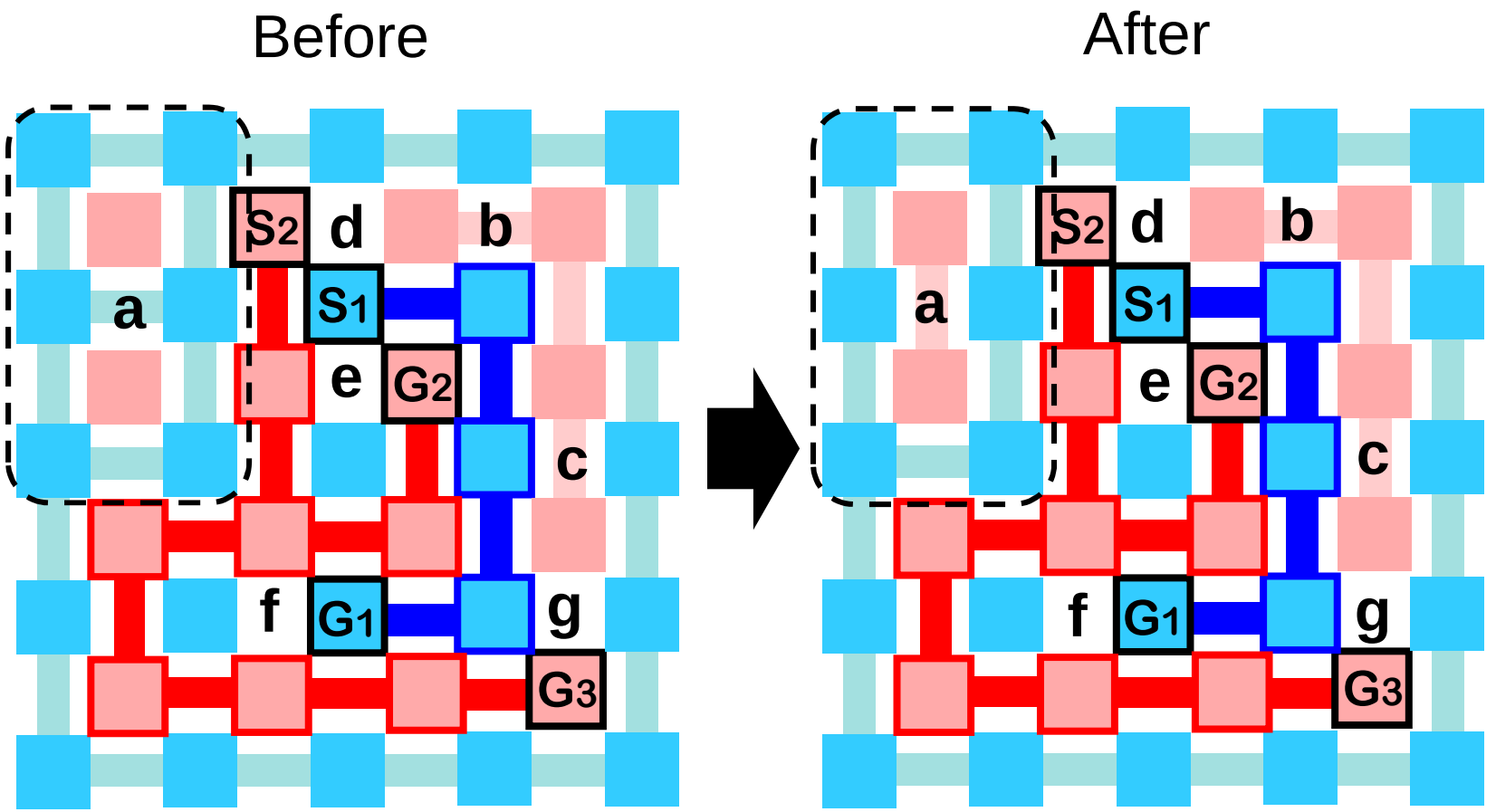
Dummy pattern flipping

Change connecting direction of dummy patterns by 90 degrees to make small length dummies disappear.



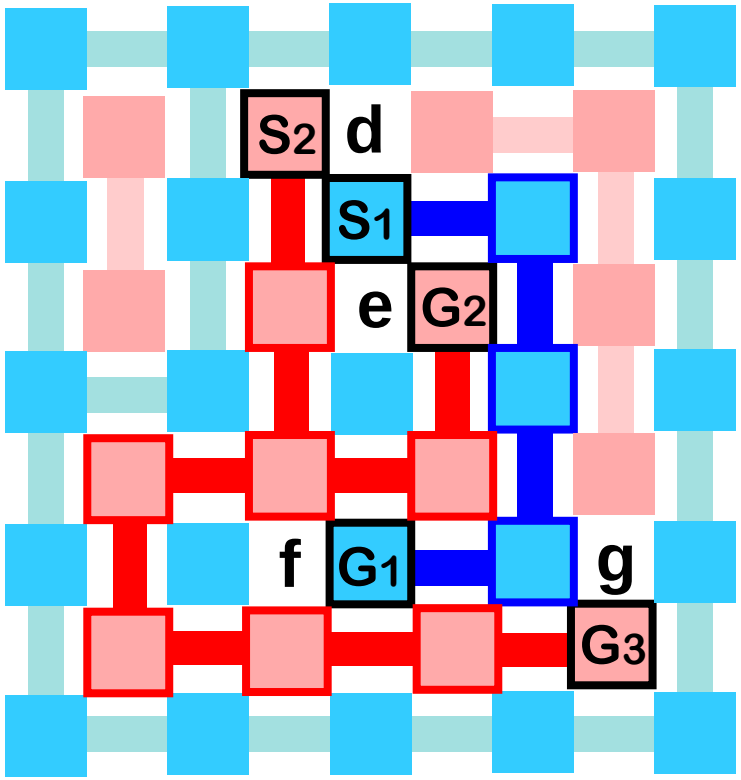
SADP Grid Routing: Step 4

Example of dummy pattern flipping



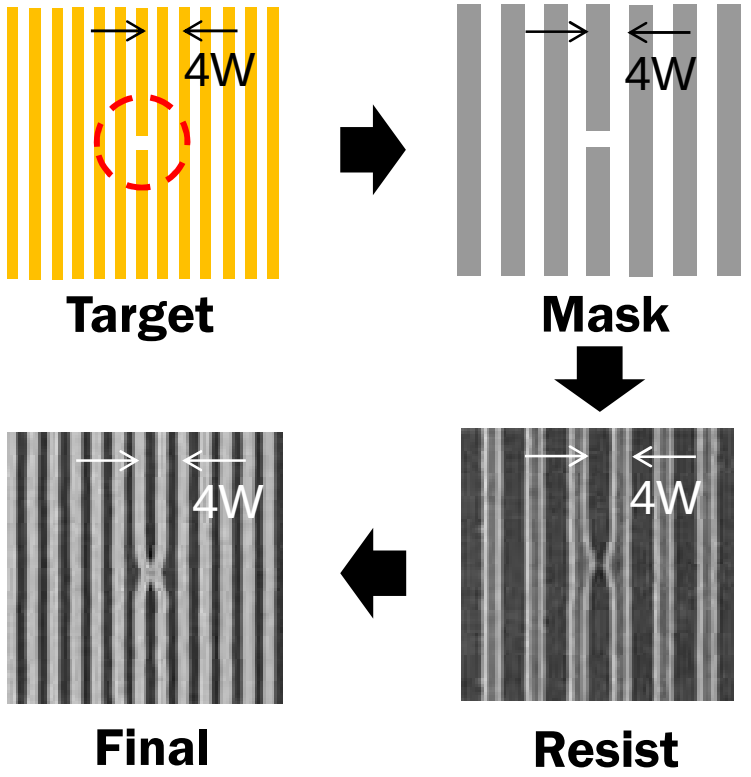
SADP Grid Routing: Step 5

Dummy patterns assigned to “d, e, f and g” must be insulated.
Assign cutting pattern.



Cutting Pattern

Dummy pattern with a narrow slit in the center.

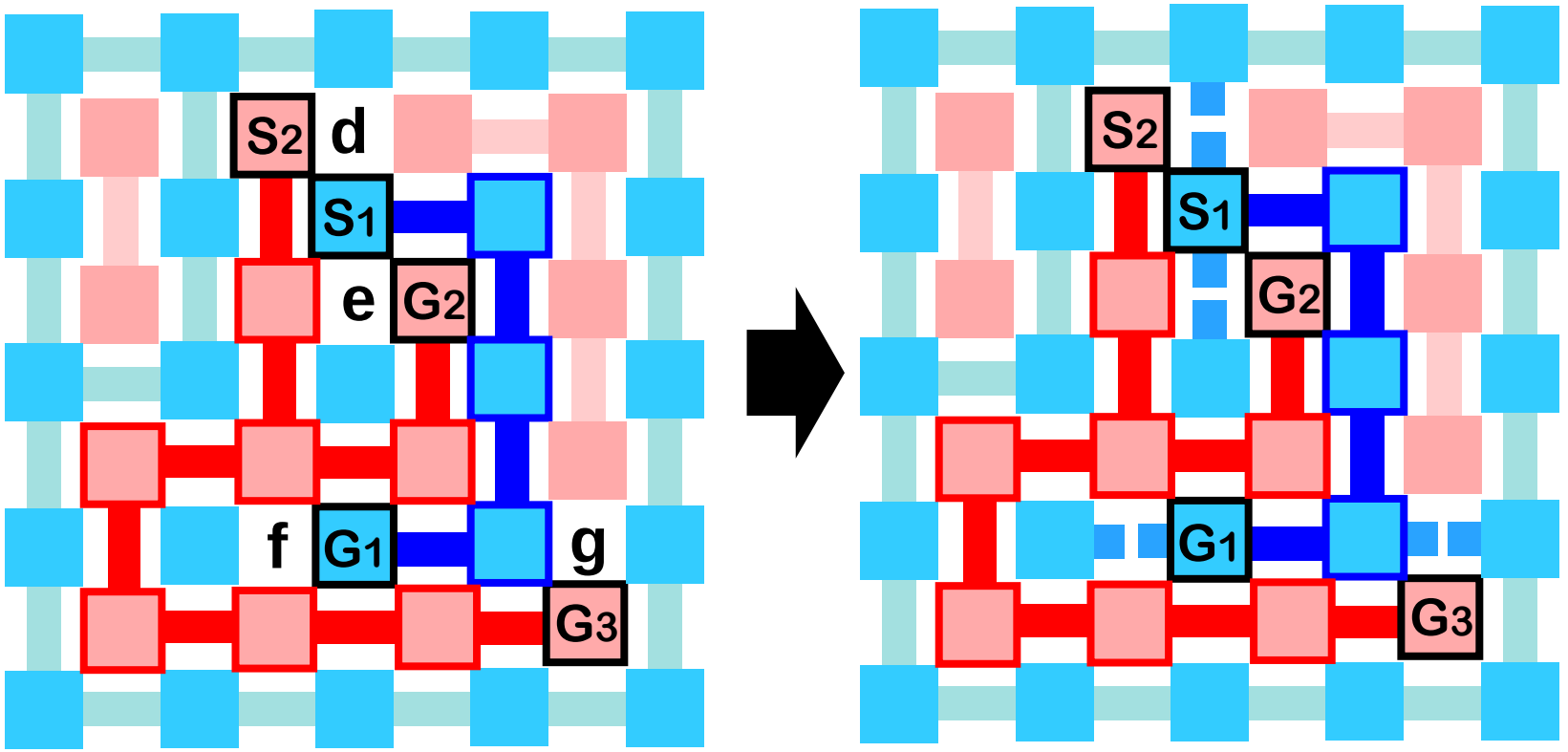


SADP Grid Routing: Step 5

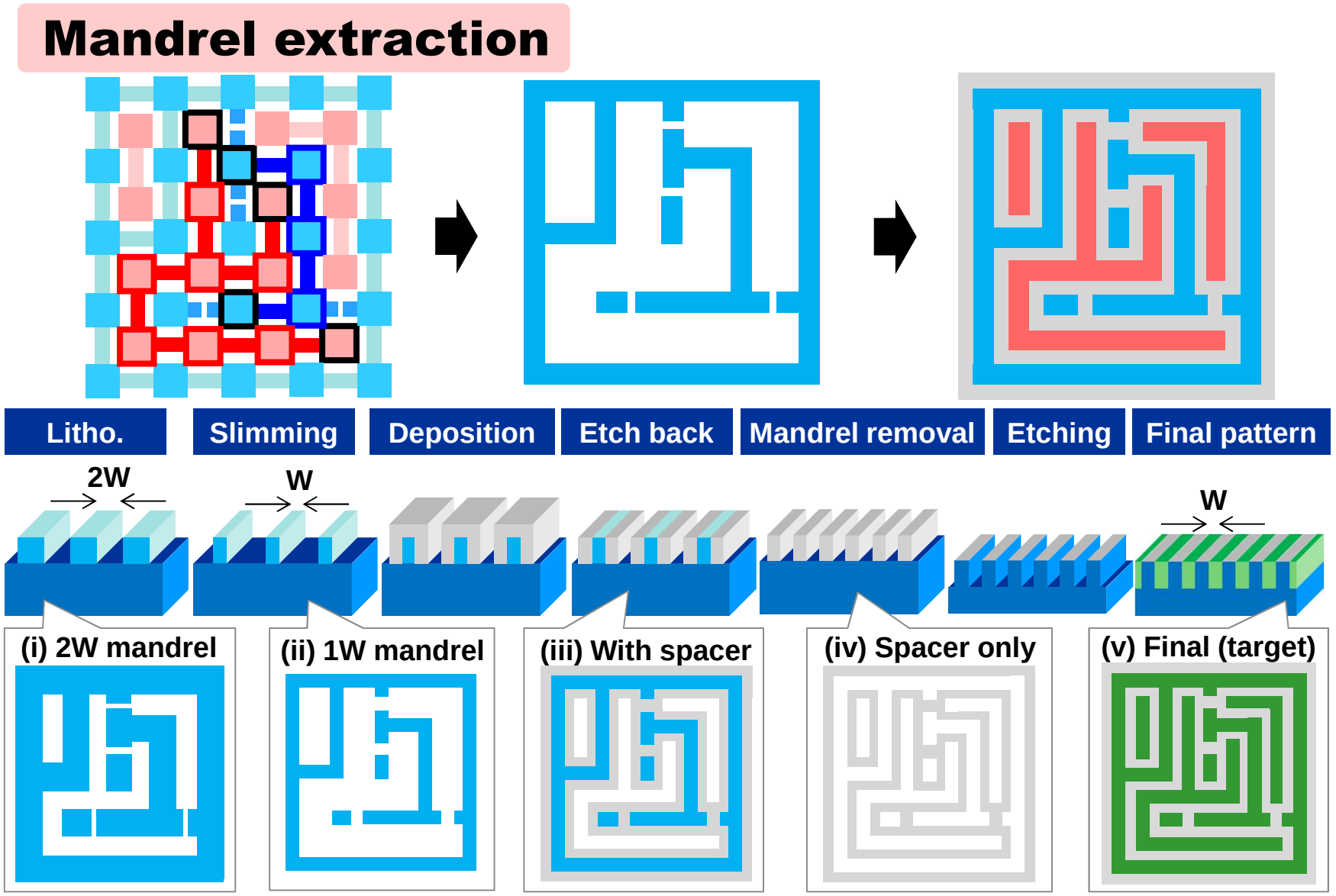
Mandrel selection and cutting pattern assigning

Choose blue or red as mandrel patterns.

Cutting pattern will be the same color as mandrel.



SADP Grid Routing: Step 6



Experiments and results

The proposed method is implemented by Ruby programming language.
Classical maze router and Path-finder (a rip-up and reroute technique) were used in Step 2.
Lithography and SADP simulation were carried out to detect Hotspots.

Platform

- Intel Xeon 2.93 GHz CPU

Lithography conditions

- Model-based OPC
- Cross pole illumination

Data

- Seven net lists made manually.
- Pattern half pitch: mandrel 60nm, target 30nm

Hotspot detecting condition

Line or space width <= 18 nm (60% of target half pitch)

Experiments and results

Net list	#nets	grids	Mandrel color	#hotspots		after flipping		reduction rate
				area	line	all area	line	all area
33-1	11	33x33	red	36	0	12	0	- 66.7%
			blue	42	3	13	2	- 69.0%
33-2	11	33x33	red	40	0	33	0	- 17.5%
			blue	31	0	17	0	- 45.1%
33-3	13	33x33	red	46	0	30	0	- 34.8%
			blue	25	0	15	0	- 40.0%
101-1	18	101x101	red	281	3	234	1	- 16.7%
			blue	169	0	120	0	- 29.0%
101-2	17	101x101	red	265	0	255	0	- 3.77%
			blue	101	0	95	0	- 5.94%
101-3	18	101x101	red	197	0	190	0	- 3.55%
			blue	171	0	160	0	- 6.43%
101-4	18	101x101	red	191	0	187	1	- 2.09%
			blue	173	1	160	0	- 7.05%

The number of hotspots is decreased.

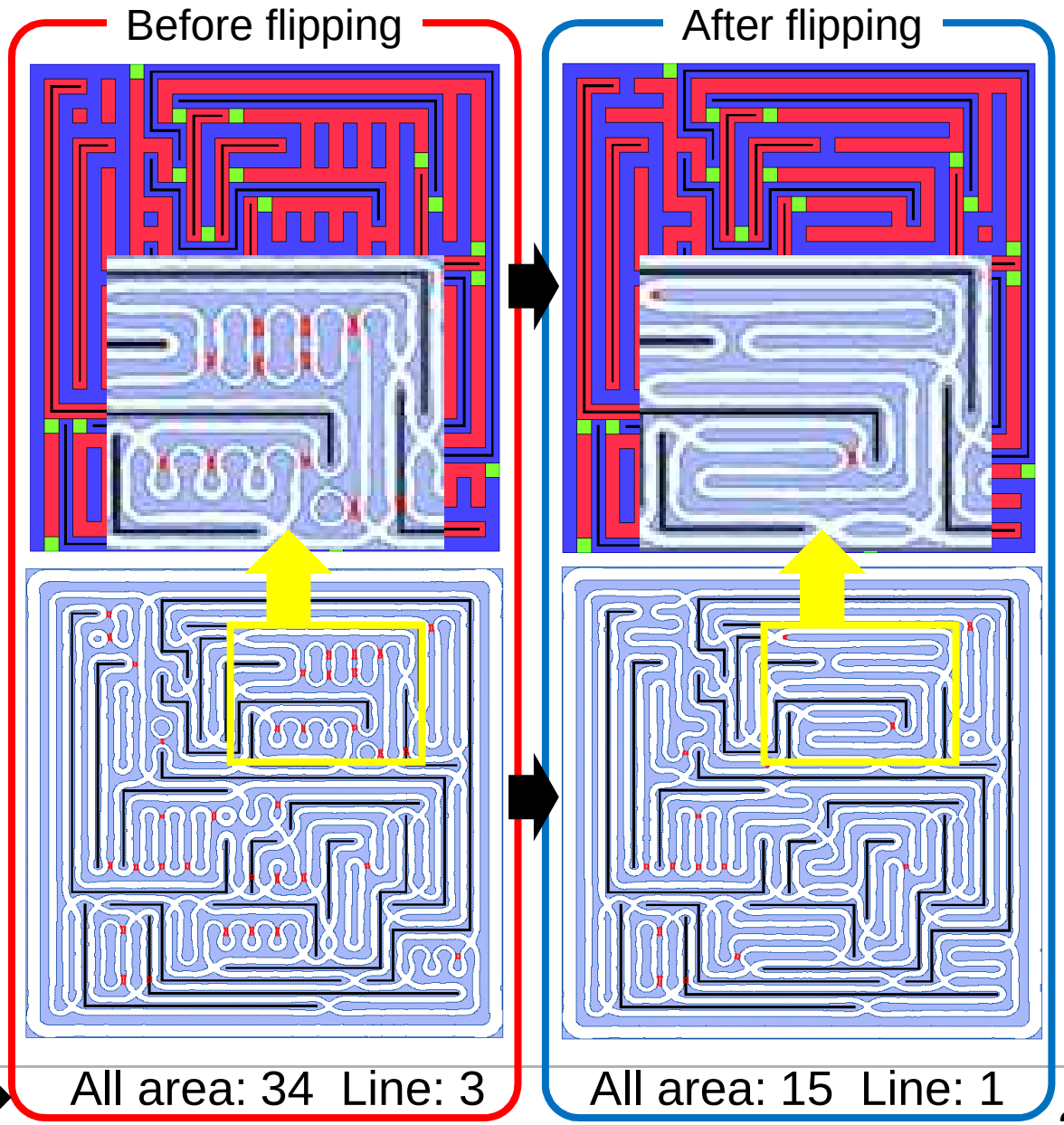
Experiments and results

Another Result

Grid: 33x33
#net: 20

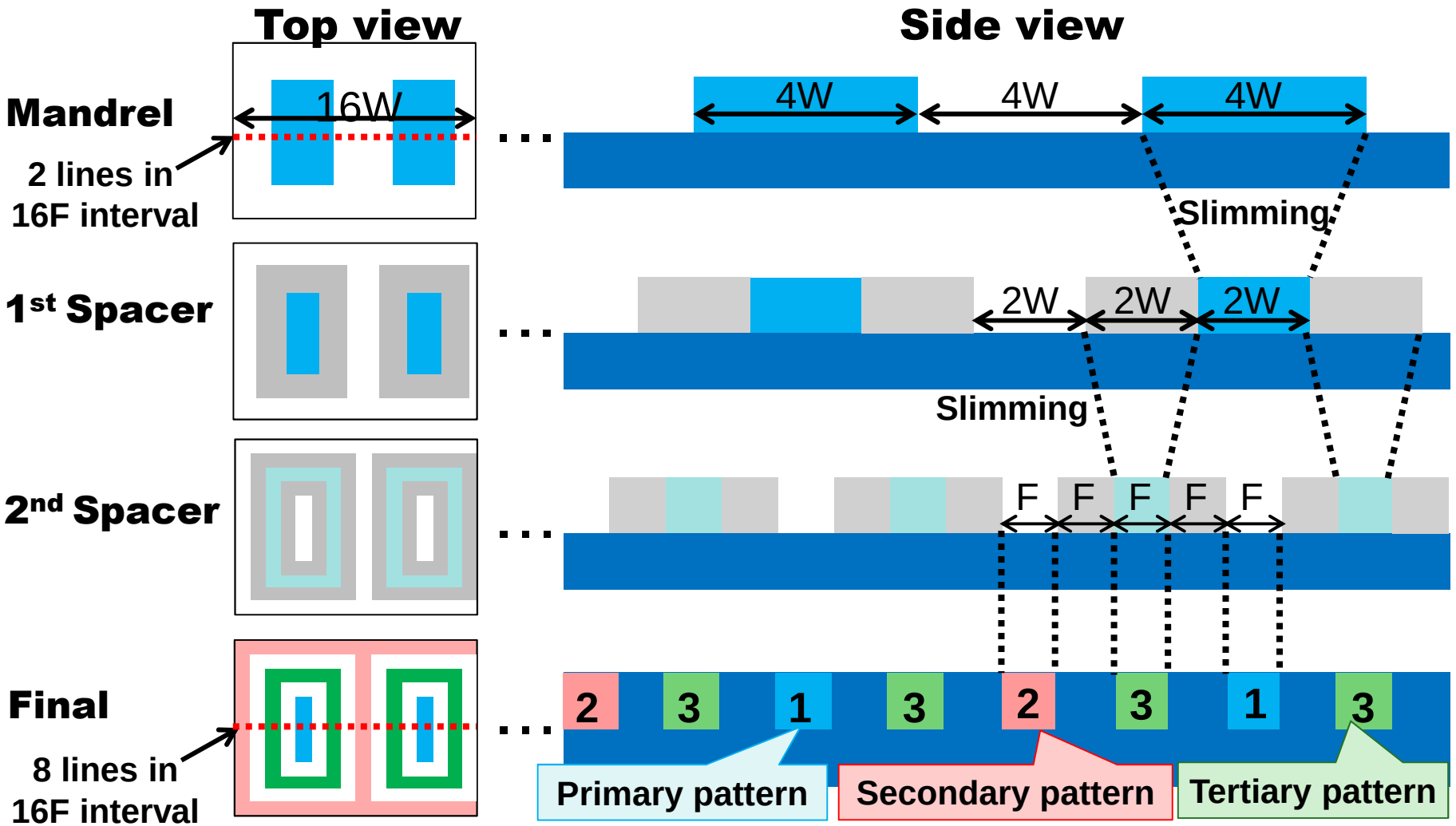
Resultant layout
Black line: Routed paths
Green grid: Cutting pattern

SADP simulation results
Mandrel selection: blue
Black line: Routed paths
Red dots: Hotspots



Expansion into SAQP-aware Grid Routing (Digest)

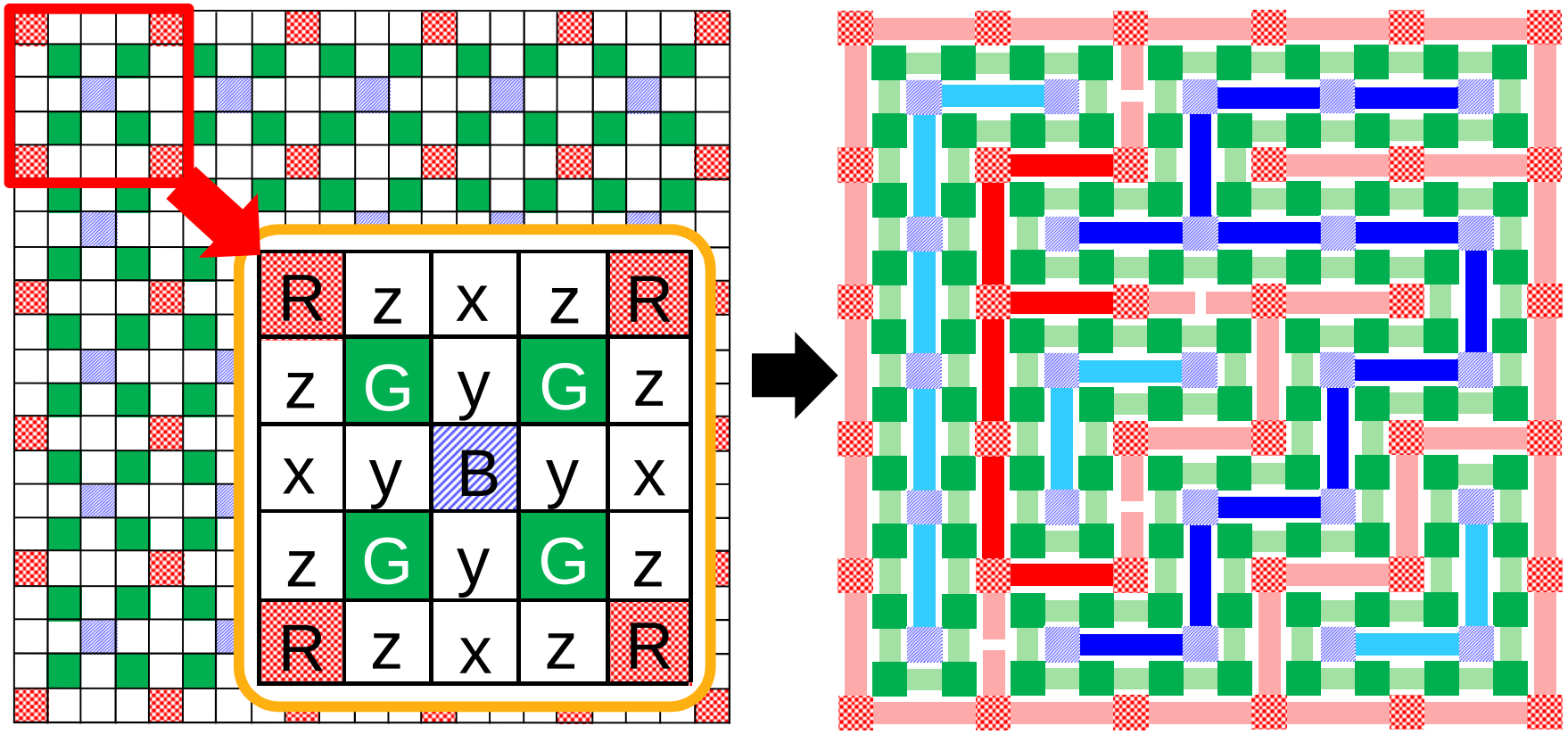
SAQP Process Overview



SADP: Two color mapping **SAQP: Three color mapping**

SAQP Routing

Drawing Example



There are six kinds of grids. Drawing rule is similar to SADP.
Design freedom of SAQP grid layout is less than SADP

Please find details in our paper.

Conclusions

- Proposed grid structures and simple routing methods for SADP and SAQP.
- Utilized cutting pattern (trimming pattern is not necessary).
- No need to consider space constraints
- Experimental results show the reduced number of hotspots by dummy pattern flipping.

Future work

- Try to be free from color constrains of pins in our SADP routing method.

SPIE Advanced Lithography 2013 (24 – 28 Feb.)
8684-10 “Detailed routing with advanced flexibility and in compliance with self-aligned double-patterning constraints”
See you at Sun Jose!!

Acknowledgments

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END