Application of Automated Design Migration to Alternating Phase Shift Mask (AltPSM) Design

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Outline

- Background
- Prior art in altPSM legalization
- Our approach
- Results
- Future challenges
AltPSM Primer

- Powerful Resolution Enhancement Technique (RET)
- Uses destructive interference of projecting light

Phase shapes need to be created for critical elements
- They need to satisfy the phase transition requirement
Layout Impacts

- Density impacts: up to 6% (180nm node)
- Resource impacts: 10-20%
  - Verification, phase shapes generation
  - AltPSM legalization and migration
  - Assembly methodologies
Conflicts in AltPSM Layouts

- Forbidden Topologies

- Spacing conflict
Resolving AltPSM Conflicts
Prior Art in Layout Legalization

**Compaction**
- Legalizes a layout topology
  \[
  \text{Minimize: } \sum x_i
  \]
  \[
  \text{Subject to: } x_i - x_j \geq d_{ij}
  \]
- Translate symbolic layout to physical layout

**Minimum Perturbation**
- Legalizes an almost correct layout
  \[
  \text{Minimize: } w_i \cdot \| x_i - x_i^{\text{old}} \| \\
  \text{Subject to: } x_i - x_j \geq d_{ij}
  \]
- Migrate existing layouts from source to target technology
Prior Art in Layout Legalization

- **Constraint based**
- **Adjacent relationship between objects does not capture altPSM requirements**

DIFF-CA Spacing violation

Spacing and width get squeezed to minimum

Non-minimum spacing and width are preserved

Compacted layout

Minimally perturbed layout
Conflict Detection & Legalization

PSM Verification (Galan et al)

- Geometric method based on counting ends
- Legalization based on design guidelines
- Exceptions are allowed in waivered layouts

Graph Bipartiztions (Kahng et al)

- Graph theoretic method using a feature graph
- Legalization formulated as a graph bipartization
- Minimum topological modification

Geometric method

Graph

Intersection containing odd number of critical segment ends

Feature graph

Shifter node

Feature node

Conflict node
Marker Shapes

- Derived shapes that denote conflicts
- Used to suggest legal solutions

Marker shapes generation

1. Classified critical features
   
2. DRC - including altPSM conflict detection
3. Derived markers with shape operations

Entire shape edge is classified as critical

Line-end conflict

Line-end conflict markers
Instructing Minimum Perturbation

- $W_{NC}$: Non-critical width
- $L_{NC}$: Non-critical length
- $W$: Width of PC shape

Edges of marker coincident with PC shape
- $m_L$, $m_R$, $m_T$, $m_B$ denote left, right, top and bottom edges of marker
- $s_L$, $s_T$, $s_B$ denote left, top and bottom edges of PC
Instructing Minimum Perturbation

X-direction rules
- Intersection(Marker, PC) ≥ \( L_{NC} \)
- Length(Marker) ≥ \( L_{NC} \)

Y-direction rules
- OverlapOf(Marker, PC) ≥ \( W \)
- Width(Marker) ≥ \( W_{NC} \)
Resolving T-junction Conflict

- In practice, use a simplified rule to expand all legs of T-junction

- Diffusion
- PC
- Gate constraint prevented expansion
Prioritization of Conflict Resolutions

- Adjust minimum perturbation objective function
- Manipulate layout variables to control changes

1. Expand marker shapes
   - Freeze non-marker variables
2. Move and/or expand marker shapes and critical features without size increase
   - Un-freeze variables of critical features
   - Add source to sink upper bound constraint
3. Allow shapes in predetermined level to move
   - Un-freeze variables of shapes
4. Allow layout to expand by percentage
   - Expand upper bound constraint
Summary

- AltPSM legalization is more an art than a science
- Used marker shapes to indicate conflicts
- Designed solutions based on experience
- Formulated sol'n as a layout optimization problem
- Prioritized solutions based on design preferences
Results

- Customized MASH to perform altPSM legalization
- Migrated layouts comparable with manual results
- Typical standard cell took between 1 and 30 secs
- A custom multiplexer with 50+ devices took < 1 min
- Same layout took 8 hrs to legalize manually!
- Established a feasibility milestone
Example of AltPSM Legalization
Example of AltPSM Legalization
Future Challenges

- Constraint generation technique that discovers altPSM requirements
- Automation to create altPSM compliant layouts
- AltPSM assembly tools and methodologies

Today's standard cells

Cells with phase shapes