Defect Pattern Library Construction for the Lithography Hotspot Pattern Search based on a Two-Level 2D Pattern Matching

Shunji Saika[#], Hajime Naito[*], Bo Su[**], Ye Chen[**], Yuan Raymond Xu[**] and Chenmin Hu[**]

Semiconductor Technology Academic Research Center
17-2, Shin Yokohama 3-chome, Kohoku-ku, Yokohama, 222-0033 Japan,

[*]Marubeni Information Systems Co., Ltd.
3-12-18, Shibuya, Shibuya-ku, Tokyo 150-0002 Japam,

[**]Anchor Semiconductor, Inc.
5403 Betsy Ross Drive, Santa Clara CA 95054 USA

[#]saika.shunji@starc.or.jp

Abstract

It has been well accepted and established in the industry that lithography hotspots exist in a DRC clean design, before and even after OPC decoration. Simulation based post OPC verification has been used throughout the industry in recent years and is a critical step to find those hotspots and correct them, if necessary. However, the simulation is a time consuming and our work attempts to find an alternative, but faster way to detect those hotspots through pattern matching. We report our investigation work, conducted in STARC and using Anchor Semiconductor's advanced Pattern Matching techniques.

This paper provides a case study of DPL™ (*Defect Pattern Library*) construction for use of a new two-level 2D pattern matching function, called CEPSS™ (*Center Exact Peripheral Similar Search*), to detect lithography hotspots. CEPSS emphasizes the importance of center region of each hotspot pattern in the DPL library, using its surrounding region for the 2nd filtering. In constructing the DPL for CEPSS, reference hotspots are classified by their center region pattern, called *Core* pattern. In our case study with two different designs, it was observed that the hotspot patterns in each design are dominated by a few *Core* patterns, called major *Cores*, and that the major *Cores* are common between the two designs. We constructed a DPL from the smaller design, and applied it for CEPSS to detect hotspots in the oteher 4.5 times larger design. In both of *Necking* hotspots (width error) and *Bridging* hotspots (space error), we found some major *Cores* appeared as successful *Cores* to detect the same *Core* hotspots efficiently with 72% coverage for *Necking* and 89% coverage for *Bridging*.

Introduction

Lithography hotspots come from the fact of their not having lithography friendly layout pattern geometries, if ever they have passed DRC checking. And those hotspot patterns are expected to have high correlation to *not-so-many* specific 2D pattern topologies, which are in many cases too complicated to be described as DRCs. So, by narrowing down the candidates of hotspot locations in a current design based on the known hotspot patterns, pattern matching can be a quick and effective solution to find and avoid the yield detractors early in the design cycle.

Two-Level 2D Pattern Matching: CEPSS™

In this paper, we begin with introducing a new pattern matching, which has sequential two level matching processes: [Level 1] to deal with *Core* pattern looked at through a smaller size inner window and perform Exact-matching, and [Level 2] to deal with *Context* pattern looked at through the rectangle belt between the inner window and a larger size external window and perform a Similar-matching to have some capacity of picking up those patterns with area-correlation based similar *Context*. The Level 1 process is rather quick and expected to serve as a screening step for the more time consuming 2nd step of the Level 2 process. Anchor has realized this method as a search function, and incorporated it into the NanoScope™ environment. It is called CEPSS.

When a hotspot is found and marked through lithographic simulation, the marker's location means the center of the hotspot. Around the hotspot, as features appear farther away from the center, their impacts diminish as distances. CEPSS emphasizes the importance of center region, using its surrounding region for the 2nd filtering.

Pattern Library for CEPSS

Pattern matching needs a pattern library, and we call it DPL. So, we next show an example of implemented DPL for CEPSS, the hotspot pattern library optimized to be fed to the CEPSS.

For the results in this paper, the reference hotspots were extracted from the 2nd metal layer, where vertical wire segments are major patterns, of a 6.037mm x 1.622mm (9.79mm^2) layout design (*Design A*) at the 45nm node, each including a *Necking* (width) or *Bridging* (space) error. Although these hotspot locations had been detected through performing full and process variation aware lithographic simulations with model based OPC, the DPL construction referred to their pre-OPC layout patterns. The reference hotspots are 20 of *Necking* and 36 of *Bridging* hotspots.

Constructing a DPL for CEPSS is a procedure of extracting the representatives from the references as the representative sets of *Core* and *Context* patterns, through a sequence of pattern classifications. This needs 3 steps of classifications: [Step 1] to extract primary *Core* patterns, which are all clipped through a same size square window, for temporary use followed by the final *Core* extraction, [Step 2] to extract the final *Core* patterns, which are clipped through a few variety of different rectangles, and [Step 3] to extract *Context* patterns for each of final *Cores*. Here, the Step 2 is staying semi-automatic.

Our DPL has been led to include 4 *Core*s in *Necking* DPL and 7 *Core*s in *Bridging* DPL. In *Necking* DPL, one major *Core* has an 'L' shape wire pattern and another major *Core* has a line-end pattern, others being minorities. In *Bridging* DPL, two major *Cores* have an 'L' shape space pattern and another major *Core* has an open-ended space pattern, others being minorities. The most important feature of this DPL implementation is the definition and revelation of these major *Cores*.

And for the *Context* pattern, we adopted a fixed square external window size, each edge having 4+1/3 p length, where p is the minimum routing pitch.

Experimental Results

We applied the DPL for CEPSS to detect hotspots on the same layer of a new larger design (*Design B*) which is 6.052mm x 7.352mm (44.49mm2) at the 45nm node. The *Design B* has 81 of *Necking* and 107 of *Bridging* hotspots, which are the targets of detecting through our pattern search.

Table I summarizes the *Necking* DPL and its search results, #matched locations and #detected hotspots, along with *similarity-radius* applied to group similar *Contexts* for each of *Cores*. Table II summarizes the *Bridging* case. For each *similarity-radius*, the *cepss-radius* means the corresponding tolerance to be allowed through CEPSS's Level 2 Similar-matching for judging *Context* pattern similarity.

The *Necking* 'L' shape major *Core* itself appears in *Design B* at 22,319,487 locations found through the CEPSS's Level 1 Exact-matching. As shown in Table I(a), when the DPL's *similarity-radius* is 5% (*cepss-radius* 6%), the Level 2 Similar-matching narrows them down to 58,435 locations (1/382 down), maintaining 36 hotspots detected (36/50 = 72% coverage). This shows a trend that, for this *Necking Core*, *Context* patterns of hotspots could have strong correlations among from different designs.

The *Bridging* 2 major *Cores* having an 'L' shape themselves appear in *Design B* at 489,025 locations. As shown in Table II(a1), when the DPL's *similarity-radius* is 5% (*cepss-radius* 7%), they are narrowed down to 166,808 + 39,047 = 205,855 locations (1/2.4 down), maintaining 45 + 14 = 59 hotspots detected (59/(52+14) = 89.4% coverage). This tells another trend that, for these *Bridging Cores*, *Core* patterns themselves could have relatively strong correlations to the hotspot occurrences.

Conclusions

The CEPSS supported by the optimized DPL shows encouraging performance to detect lithography hotspots. In our severe case study of small design based DPL applied to search 4.5 times larger design, for some major *Cores* the hotspot detection coverage reached near 90%. Through solving difficulties remaining with some of other *Cores*, CEPSS with optimized DPL could become a promising alternative to the simulation based lithography verification.

Acknowledgement

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References

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— Tables and Figures —

similarity-radius		0%	1%	2%	3%	4%	5%	6%	7%	8%
major *Core* N01 (L-shape)	*cepss-radius*	0%	2%	3%	4%	5%	6%	7%	8%	9%
	# Library Patterns	13	12	11	10	9	9	6	5	5
	# matched locations	670	3,672	6,461	10,481	16,337	58,435	55,993	70,453	123,092
	# detected hotspots (coverage)	6 / 50	24 / 50	26 / 50	30 / 50	34 / 50	36 / 50	33 / 50	33 / 50	36 / 50
major *Core* N02 (line-end)	*cepss-radius*	0%	2%	3%	4%	5%	6%	7%	8%	9%
	# Library Patterns	5	5	5	5	5	5	4	4	3
	# matched locations	58	43,879	48,262	76,489	104,403	132,297	495,082	789,905	820,890
	# detected hotspots (coverage)	6 / 26	11 / 26	11 / 26	12 / 26	14 / 26	14 / 26	14 / 26	15 / 26	15 / 26

Table I (a). *Necking* major *Cores*

Design B has 50 hotspots corresponding to the *Core* N01 and 26 hotspots to the *Core* N02.

similarity-radius		0%	1%	2%	3%	4%	5%	6%
minor *Cores* **2 *Cores* included**	*cepss-radius*	0%	2%	3%	4%	5%	6%	8%
	# Library Patterns	2	2	2	2	2	2	2
	# matched locations	2	14	14	63	1,353	1,461	32,406
	# detected Hotspot (Coverage)	1 / 5	1 / 5	1 / 5	2 / 5	2 / 5	3 / 5	3 / 5

Table I (b). *Necking* minor *Cores*

Table I. *Necking* DPLs with *similarity-radius* variation and their coverage against the larger *Design B*

similarity-radius		0%	1%	2%	3%	4%	5%	6%
major *Core* B01 (L-shape)	*cepss-radius*	0%	2%	3%	4%	6%	7%	8%
	# Library Patterns	15	11	11	10	7	5	5
	# matched locations	25,275	45,378	50,847	111,629	161,057	166,808	205,999
	# detected hotspots (coverage)	10 / 52	27 / 52	32 / 52	44 / 52	44 / 52	45 / 52	47 / 52
major *Core* B02 (extended-L-shape)	*cepss-radius*	0%	2%	3%	4%	6%	7%	8%
	# Library Patterns	3	2	2	2	1	1	1
	# matched locations	13,937	21,273	21,908	35,838	36,995	39,047	42,848
	# detected hotspots (coverage)	8 / 14	9 / 14	10 / 14	11 / 14	12 / 14	14 / 14 (100%)	14 / 14 (100%)

Table II (a1). *Bridging* major *Cores* having a L-shape spacing pattern
Design B has 52 hotspots corresponding to the *Core* B01 and 14 hotspots to the *Core* B02.

similarity-radius		0%	1%	2%	3%	4%	5%	6%
major *Core* B03 (open-end)	*cepss-radius*	0%	2%	3%	4%	6%	7%	8%
	# Library Patterns	9	9	7	6	6	6	6
	# matched locations	19,148	77,745	100,859	183,997	310,833	845,769	1,314,476
	# detected hotspots (coverage)	1 / 15	6 / 15	8 / 15	8 / 15	9 / 15	10 / 15	13 / 15

Table II (a2). *Bridging* major *Cores* having an open-end spacing pattern
Design B has 15 hotspots corresponding to the *Core* B03.

similarity-radius		0%	1%	2%	3%	4%	5%	6%
minor *Cores* **4 *Cores* included**	*cepss-radius*	0%	2%	3%	4%	5%	7%	8%
	# Library Patterns	9	9	9	9	9	9	9
	# matched locations	19,148	77,745	100,859	183,997	310,833	845,769	1,314,476
	# detected hotspots (coverage)	6 / 26	8 / 26	10 / 26	10 / 26	10 / 26	11 / 26	11 / 26

Table II (b). *Bridging* minor *Cores*

Table II. *Bridging* DPLs with *similarity-radius* variation and their coverage against the larger *Design B*

similarity-radius		0%	1%	2%	3%	4%	5%	6%	7%	8%
major *Core* N01 (L-shape)	*cepss-radius*	0%	2%	3%	4%	5%	6%	7%	8%	9%
	# Library Patterns	13	12	11	10	9	9	6	5	5
	# matched locations	670	3,672	6,461	10,481	16,337	58,435	55,993	70,453	123,092
	Elapsed time [sec]	**2191**	**2068**	**1874**	not observed	**1599**	**1595**	**1095**	**1094**	**1110**

similarity-radius		0%	1%	2%	3%	4%	5%	6%
major *Core* B03 (open-end)	*cepss-radius*	0%	2%	3%	4%	6%	7%	8%
	# Library Patterns	9	9	7	6	6	6	6
	# matched locations	19,148	77,745	100,859	183,997	310,833	845,769	1,314,476
	Elapsed time [sec]	**379**	**373**	**302**	**278**	**267**	**283**	**304**

Table III. Operation times of CEPSS runs against 45nm node 44.49mm^2 2nd-metal layer of *Design B*

Operation times were observed at 12 CPU parallel processing: 2.7GHz Opteron with 128GB Memory.

CEPSS with the *Bridging* DPL uses larger *Core* patterns than the *Necking* case, so the CEPSS's Level 1 Exact-matching process feeds smaller count of locations to the following Level 2 Similar-matching process, leading to the results of great time saving.

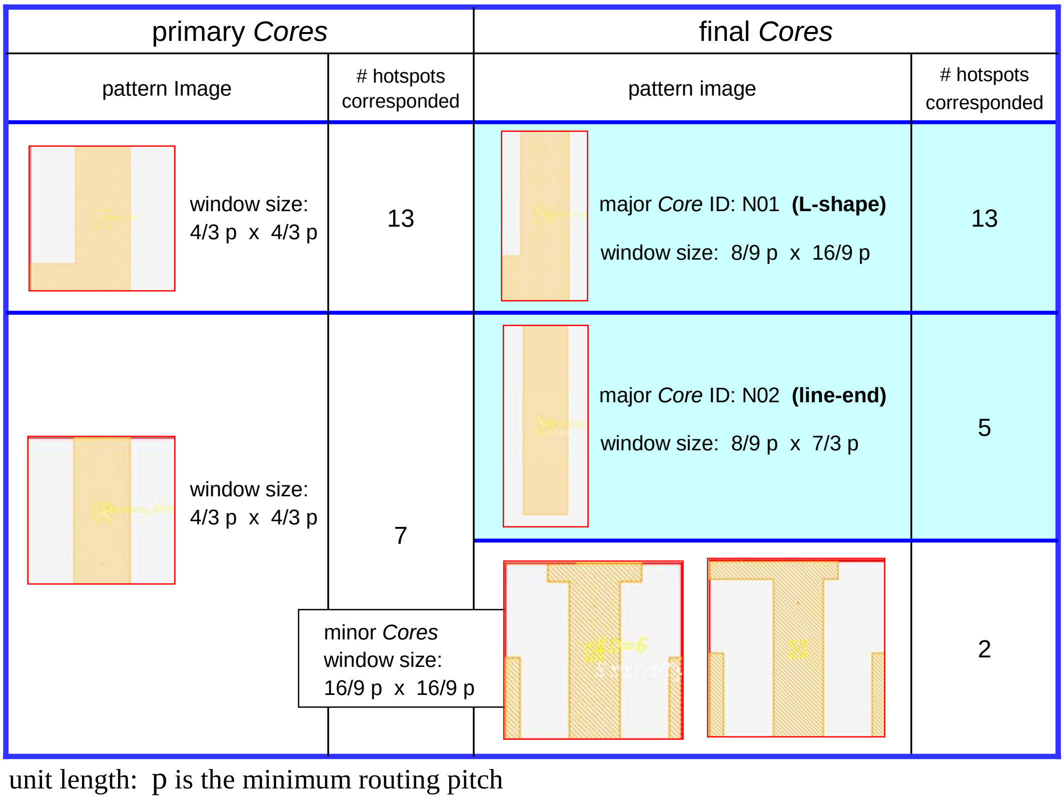
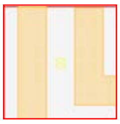
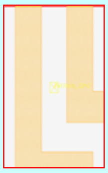
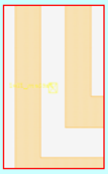
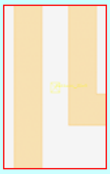
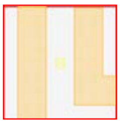
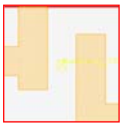
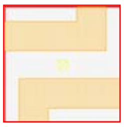
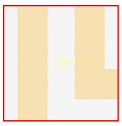
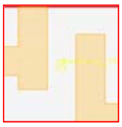
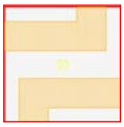
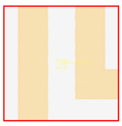


Figure 1. 20 *Necking* hotspots in *Design A* are classified by their *Cores*

primary *Cores*		final *Cores*	
pattern Image	# hotspots corresponded	pattern image	# hotspots corresponded
 window size: 2 p x 2 p	33	 major *Core* ID: B01 **(L-shape)** window size: 16/9 p x 8/3 p	15
		 major *Core* ID: B02 **(extended-L-shape)** window size: 16/9 p x 8/3 p	3
		 major *Core* ID: B03 **(open-end)** window size: 16/9 p x 8/3 p	9
		 minor *Core* window size: 2 p x 2 p	6

unit length: p is the minimum routing pitch

primary *Cores*		final *Cores*	
pattern Image	# hotspots corresponded	pattern image	# hotspots corresponded
   window size: 2 p x 2 p	3	   minor *Cores* window size: 2 p x 2 p	3

unit length: p is the minimum routing pitch

Figure 2. 36 *Bridging* hotspots in *Design A* are classified by their *Cores*