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著者(和文)	AWAD Ahmed, 高橋 篤司, 田中聡, 児玉親亮
Authors(English)	Ahmed Awad, Atsushi Takahashi, Satoshi Tanaka, Chikaaki Kodama
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A Process Variability Band Area Reduction Algorithm For Optical Lithography

Ahmed Awad*, Atsushi Takahashi*, Satoshi Tanaka†, and Chikaaki Kodama†
*Department of Communications and Computer Engineering, Tokyo Institute of Technology, Tokyo, Japan
†Toshiba Corporation, Kanagawa, Japan

1 *Introduction*

As advanced technology nodes are getting smaller and smaller, lithographic process is susceptible to dose and focus variations that would badly impact the lithographic yield. Process variation can be modeled as the area of XOR between two printed mask images obtained by two extreme conditions. This metric is called Process Variability band (PV-band) which can be reduced by proper placement of Sub Resolution Assisting Features (SRAFs) during Optical Proximity Correction (OPC)[1]. This paper proposes a PV-band reduction algorithm using SRAFs and polygons shifting.

2 *Preliminaries*

In this paper, min dose and defocus kernels are used to generate inner intensity map $I_i(M)$, while max dose and in-focus kernels are used to obtain outer map $I_o(M)$. Both $I_i(M)$ and $I_o(M)$ are used to calculate PV-band area as shown in eq(1) where $I_x(M,p)$ denotes the intensity in pixel p using mask M under x conditions ($x = \{i, o\}$). Pixel p belongs to region R in which both mask M and target T are defined, and I_{th} represents the intensity threshold.

$$PVBandArea(M) = \sum_{p \in R} pv(M,p)$$
$$pv(M,p) = \begin{cases} 1; & I_o(M,p) \geq I_{\text{th}} \text{ AND } I_i(M,p) < I_{\text{th}} \\ 0; & \text{Otherwise} \end{cases} \quad (1)$$

3 *Algorithm*

Our proposed PV-band reduction algorithm is shown below. The input is an OPCed mask M obtained by some OPC algorithm. This OPCed mask is modified by inserting SRAFs and by shifting polygons that reduce $\delta I(M,t)$ for tap points $t \in A$ where A is set of tap points defined on the polygon edges of T, and $\delta I(M,t)$ is the difference between I_{th} and $I_i(M,t)$. Regression experiments are used to find a candidate distance between SRAF and the corresponding tap point, wherein, the light passing through SRAFs positively interferers with the light passing through the polygons to enlarge the inner image. Then, for each candidate distance, the SRAF sizing function to determine the best SRAF size to reduce δI value is obtained by another regression experiment.

PV-band Reduction Algorithm

```
T, M ← INPUT(T,M)
A ← getTapPoints(T)
epe ←calculateEPE(M, T)
pvband ← calculatePVBand(M)
iteration ← 0
while pvband is decreasing and epe is same and iteration < maxIterationNum do
    for each tap point t_i ∈ A do
        if δI(M, t_i) > 0 and SRAFs[S_i] not printed then
            p ← getSRAFPositions(t_i)
            if I(M, p) < (I_th − limit) then
                SRAF[S_i] ← SRAFs[S_i]+findSRAFWidth(δI(M, t_i))
            else
                SRAF[S_i] ← SRAFs[S_i]+0
            end if
        end if
    end for
    epe ←simulateUnderNominalConditionsAndCalculateEPE(M, T)
    I_i(M) ←simulateUnderMinDoseAndDefocus(M)
    I_o(M) ←simulateUnderMaxDoseAndInfocus(M)
    pvband ←calculatePvBandArea(I_i(M), I_o(M))
    iteration ← iteration + 1
end while
M ← applyShiftingAndCheckEPE(M,T)
```

First, an SRAF is inserted in a candidate position if it does not intersect with mask polygons. Then, its size is determined based on the intensity (under nominal and extreme conditions) evaluated by lithography simulation. In the next iteration, the intensity of the updated mask is evaluated by lithography simulation and if the intensity of an SRAF position exceeds I_{th}, this SRAF is restored to its previous unprinted configuration, otherwise, SRAF size is updated based on the new evaluated intensity.

Table 1:PV-band Area for Public Benchmarks

Benchmark	PV-band(before)	PV-band(afrer)	%	Iteration#
M1-test1	79801	74087	7.2	6
M1-test2	61900	61900	0	2
M1-test3	126447	125225	8.2	6
M1-test4	31353	31353	0	2
M1-test5	63485	61163	3.7	12
M1-test6	65190	64322	1.3	8
M1-test7	47123	46622	1.1	10
M1-test8	23679	22643	4.8	6
M1-test9	67909	65403	3.7	8
M1-test10	18410	17884	2.9	6

This process is repeated as long as PV-band is being reduced and the max number of iterations is not exceeded. Once this process stops, polygons are shifted slightly to approach SRAF candidate positions to functionate them as SRAFs if no EPE violation occurs. In Fig. 1, where X indicates SRAF position, the lower polygon can be shifted up slightly. If PV-band increases at the final iteration, previous iteration configuration is used in shiting step.

4 *Experimental Results*

All experiments were executed on lithosim from ICCAD contest 2013 [3] with allowable EPE value of 15 pixels. With changing the distance between SRAF center and a tap point pixel by pixel, the curve shown in Fig. 2 was obtained. In this curve, the centers of the decaying intervals of δI, such as $d = 139$ and $d = 276$ are SRAF candidate positions. With changing SRAF size pixel by pixel, we found that δI decays quadratically with width increase without exceeding 60 pixels width. Therefore, SRAF width is chosen to minimize this quadratic relation with $\delta I(M,t)$. Finally, polygons shifting is allowed as long as no EPE violations are caused (<15 pixels shifting). Table 1 shows the PV-band area before and after PV-band optimization module, the reducing percentage, and the number of iterations needed for optimization for public ICCAD contest benchmarks. OPC algorithm defined in [2] was used to generate the OPCed mask.

5 *Conclusion*

In this paper, we proposed a new algorithm to reduce PV-band for an OPCed mask without causing any violations in EPE. Experimental results show that PV-band was reduced with small number of iterations.

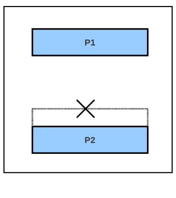

Fig. 1: Polygons Shifting

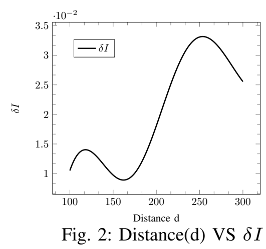

Fig. 2: Distance(d) VS δI

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[3] http://cad_contest.cs.nctu.edu.tw/CAD-contest-at-ICCAD2013/problem_c/