Process Centering OPC using Design Intent to Improve Yield

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ABSTRACT

As the industry moves to 90nm and below, the size of our process windows are rapidly decreasing. The process window is often not considered during optical proximity correction (OPC) which must match the printed wafer to the original design target for a single process point. This process point is usually at 'best exposure' and 'best defocus'. The results can be verified under different defocus conditions but it is generally assumed that the printed pattern will yield well for a range of defocus and exposure conditions. At 90nm or smaller this assumption is breaking down as the final yield of products is greatly reduced due to low pattern quality under even relatively small process variations.

Instead of optimizing the OPC results using a single model a multi-model approach is proposed where the pattern is optimized using two or more process points. The final printed image is optimized to both minimize the overall CD variations across a process as well as centering this variation with respect to the original target edges in CD critical areas. To maximize the benefits of this technique we also provide more freedom to OPC by making use of design intent to vary the print requirement in different areas of the design. In this paper we describe the process centering methodology and its use of design intent. To evaluate the benefits of this technique a metric is also proposed and used to quantify experimental results. Results are compared with those of a traditional OPC flow.

Keywords: DFM, OPC, yield, design intent, Mask

1. INTRODUCTION

OPC is now applied to most manufacturing layers from the diffusion, to even some of the higher level metals. As a technology OPC is in constant evolution to keep up with next generation process requirements. To achieve high yield at 90nm, assist features are used in conjunction with aggressive OPC. Phase shift mask (PSM) is also used for some of the most critical layers such as Poly. This is usually achieved at the expense of increased in mask cost[1]. At 65nm and especially 45nm, OPC must again evolve if yield targets are to be achieved.

In most OPC flows patterns are optimized under 'best focus' conditions[2]. An accurate match is made under this ideal condition. It is assumed that if this goal is achieved then the overall yield will be acceptable since the pattern is expected to match to a reasonable degree with-in the target process window. This assumption is failing as we move down to more aggressive process nodes. The patterns degrade very rapidly which is forcing most fabs to reduce their target process window to fit the pattern performance.

This paper proposes a flow where OPC is provided with models for two or more process points. The OPC tool can then optimize the pattern for best overall matching across these process points. This may provide a pattern that does not match as well under ideal conditions but still delivers the best overall pattern performance which should result in the best overall yield performance.

In order to study this OPC strategy a new evaluation model is first developed to estimates the yield. This new model evaluates the quality of the pattern across many process points to capture some of the conditions that may be encountered during manufacturing. This model has some similarity to previous work on standard cell quality grading[3].

This evaluation model is then applied to a representative 90nm IP design using both a traditional OPC script and our enhanced OPC script. The results are then compared and shown in detail. Some future enhancements that would help provide the highest possible yield are also proposed and discussed.

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Design and Process Integration for Microelectronic Manufacturing III,
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(SPIE, Bellingham, WA, 2005) · 0277-786X/05/$15 · doi: 10.1117/12.600180

2. STANDARD OPC RESULTS

2.1. Test Block

All data presented in this paper was obtained using a standard IP block designed using a commercial 90nm process with 100nm target gate lengths. This paper mostly presents Poly data but similar results where obtained on the metal 1 layer of the same block. To control measurement data size we selected a representative sub-section of the block in question and processed it using Synopsys' DFM tools. Figure 1 shows a section of the experimental block.

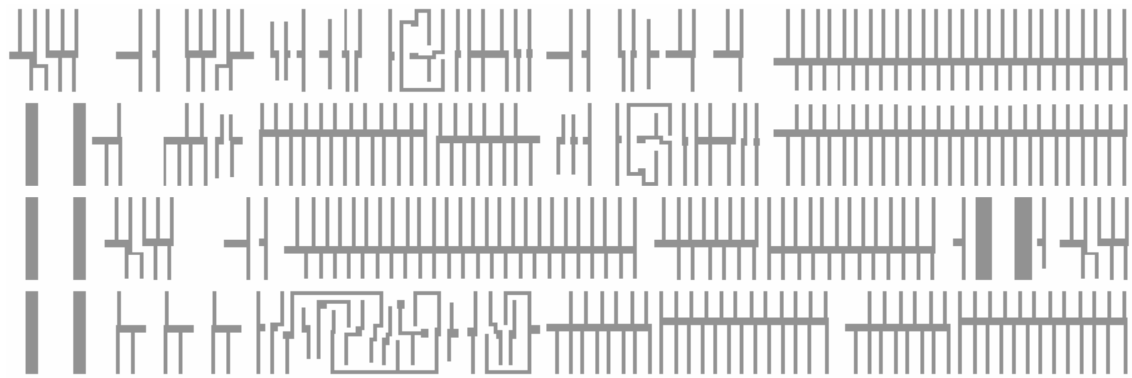


Figure 1 Poly layer of sample experimental design layout

2.2. Critical Dimension Measurements

The results of our OPC experiments are evaluated using Synopsys' SiVL tool. SiVL stands for Silicon vs. Layout. This tool uses a silicon simulation engine and calibrated process models to predict how well a pattern may print on silicon. The simulations are then compared with the original design layout. Comparisons are based on measuring target critical dimensions (CDs) of features in both the layout and the predicted silicon simulation. The measurement points are control by a set of tool parameters that allow users to specify where to make measurements. It also allows the users to specify what process conditions to use during the silicon simulations.

The normal usage of SiVL is as a verification tool. For our experiments we used SiVL to extract measurement information that we can then combine into our yield model. This has proven easy to do since SiVL puts all of its measurement data into a database based on SQL. Figure 2 shows a SiVL layout along with its silicon simulation under a single process point. The layout shown in a) also contains small horizontal and vertical bars which represent measurement locations. The simulation in b) is under ideal defocus and dosage conditions.

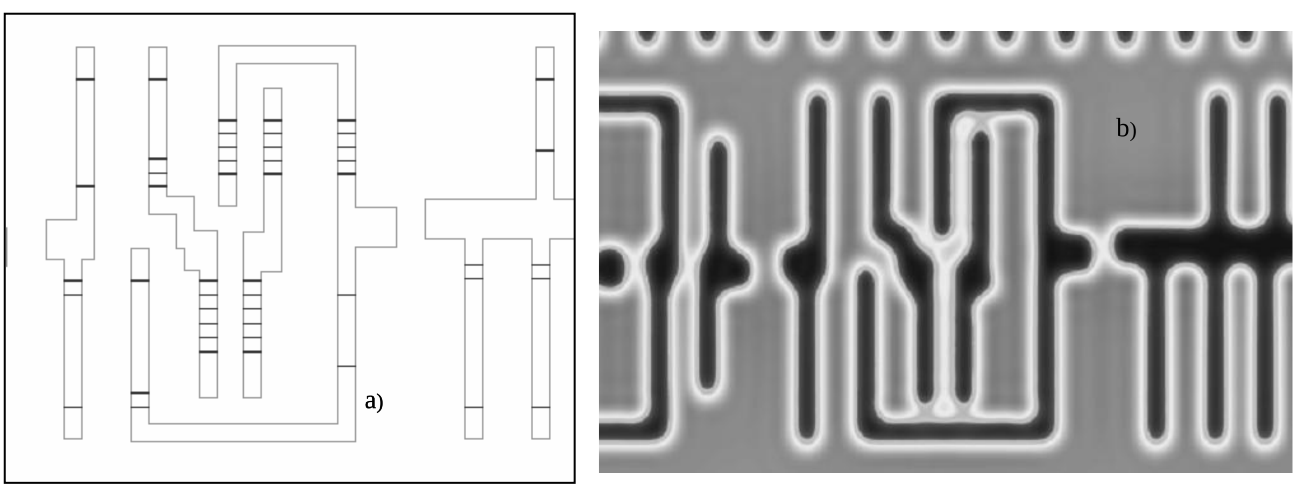
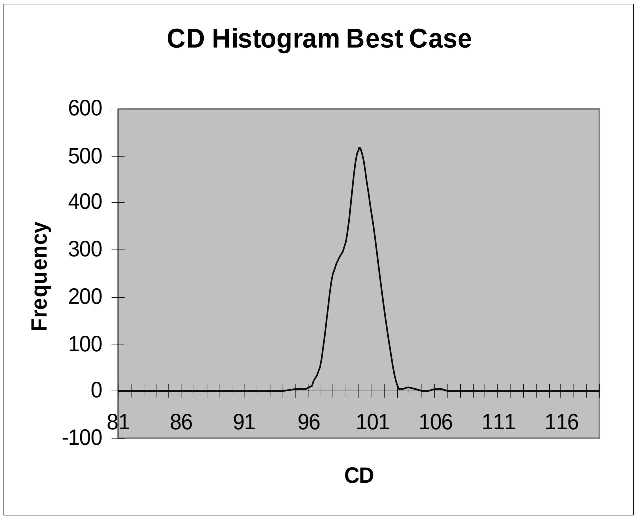


Figure 2 Pattern Sample a) Layout with measurement points b) Silicon simulation result of same area

2.3. CD Histogram Data

Most OPC today is processed using a single process model. This process model will capture the silicon image under best focus and best dosage conditions. This results in a very tight fit between the target pattern and the silicon simulation result as is shown in the histogram found in Figure 3 a). In the past this ideal fit would result in acceptable yield; but showing the same histogram under other conditions in Figure 3 b) shows just how much the pattern may degrade under worst case defocus and dosage. With CD including some gates printing below 60nm, this will cause significant yield problems.



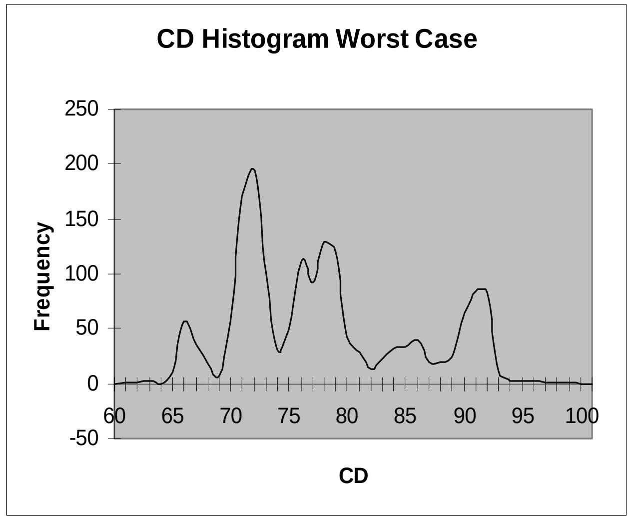


Figure 3 CD Histogram a) Best Case b) Worst Case

We are clearly heading to a time where the use of an ideal focus and dosage model during OPC is not enough. Before we propose a new OPC solution to address this problem we need a better way of representing the quality of our printed pattern across the entire process window.

3. PRINT MODEL

3.1. Process Points and the Process Window

To estimate yield using our pattern we define a printability criteria that must be met under all process conditions. This is specified as a maximum % tolerance relative to the original target CD. Any measured deviation that goes outside our tolerance criteria is considered a failure that will result in yield loss. These failures may occur under any number of process conditions. In order to model this behavior we must take measurements under a range of process conditions under which the pattern is likely to be exposed.

This paper focuses on two main variations - defocus and dosage. For each of these variables we picked three points which results in a total of 9 process points. Since the equipment will be monitored we can also expect more dies to be exposed closer to the ideal process point. This is modeled by associating probability number to each defocus and exposure conditions. These probabilities are then combined to create a set of 9 probabilities which are each associated with a process point. The complete set of process points and their probability is shown in Table 1 Process Points.

Table 1 Process Points

		Dosage Variations		
		-7% Dose	0% Dose	7% Dose
Defocus Variations	Probabilities	20 %	60 %	20 %
0nm Defocus	50 %	10%	30%	10%
100nm Defocus	30 %	6%	18%	6%
200nm Defocus	20 %	4%	12%	4%

To calculate the final print quality we find the percentage of measurements that where out of tolerances for a given process point and multiply this number by the probability of this process point. We then take the sum across all process points as the final quality metric. This can be expressed in an equation as

$$Metric = \sum_{pp=1}^{9} P(pp) * \frac{TotalNumberOfMeasurementsOutOfTolerance}{TotalNumberOfMeasurements}$$

Where pp is a specific process point
And P(pp) is the probability of the current process point.

3.2. Experimental Flow

The overall experimental tool flow is shown in Figure 4 CD Measurement Capture Flow. The design block is processed using two different OPC methodologies. The post-OPC layouts are then analyzed with 9 SiVL runs all of which generate 9 SQL databases and silicon images in GDSII format. The SQL data is then combined to generate our final print reports.

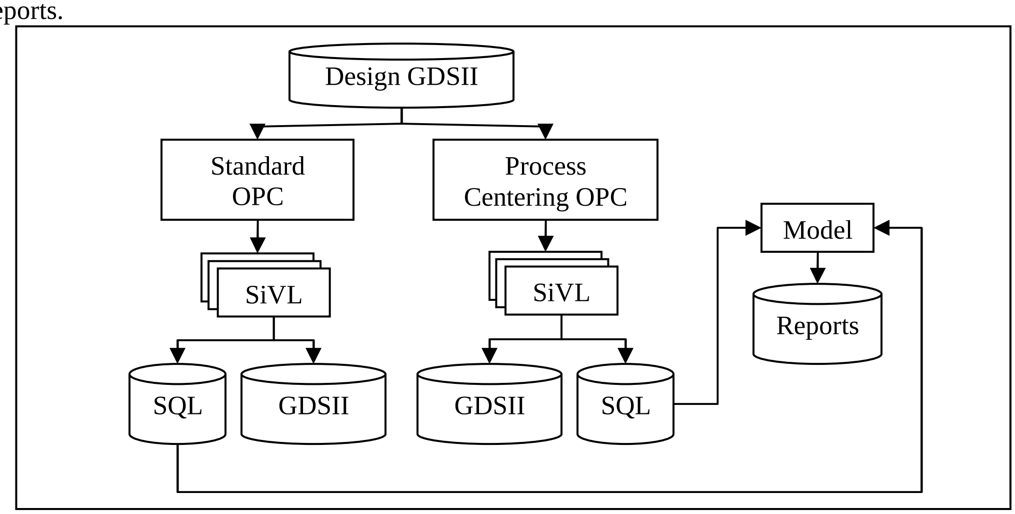


Figure 4 CD Measurement Capture Flow

4. APPLYING THE MODEL TO STANDARD OPC RESULTS

We now apply our new print model to our standard OPC results done under best focus and dosage conditions. Since the tolerance is a fundamental part of the model we choose to analyze our results across a range of tolerances starting from 5% to 20% in 1% increments. We also ran OPC under defocus conditions of 100nm. This results in the pattern printing larger under 0nm defocus conditions which may help when printing under other process points since the results will be less sensitive to pattern thinning. Figure 5 shows our final analysis of the standard OPC methodology. We quickly see that under tight tolerances the 0nm defocus model yield better results but some of this is lost as the tolerances get larger. At around 12% tolerances in the 100nm model will start producing better results since the pattern has printed slightly oversized to begin with.

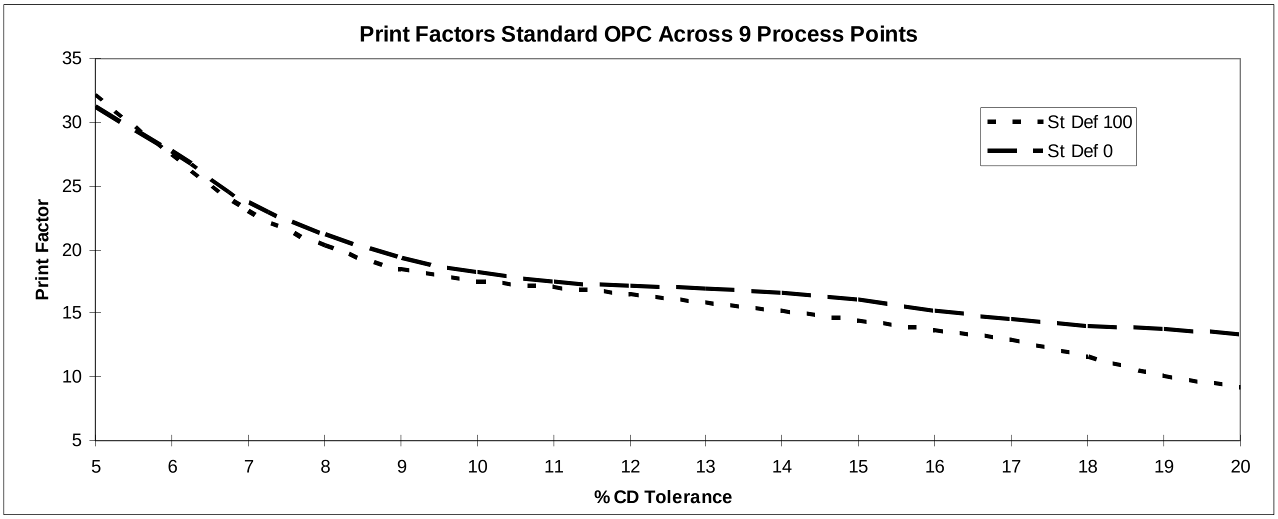


Figure 5 Print Factors Standard OPC Across 9 Process Points

5. PROCESS CENTERING

Process centering is based on using multiple process models during OPC. By using multiple models the OPC tool is able to make trade-offs between each process point so that it may sacrifice some of the best focus performance to prevent catastrophic failures under other process conditions. Among many different ways of achieving this, we selected a centering approach which is using two models. With our method, OPC centers the pattern edges between the simulation contours of the two models. Figure 6 shows the difference in behavior between the standard OPC approach and our process centering approach. In figure a) we see a great match under ideal condition with the contour overlapping the target edge but we also get a significant shift under worst case conditions relative to the original pattern edge of up to 12.6nm on both sides of the feature. This gives us a total of 24nm or 24% reduction in CD. In figure b) the ideal condition does not match the pattern edges as well as in a) but the pattern also does not deviate as much under worst case conditions with both being at about 5nm edge deviation or 10% deviation CD deviation.

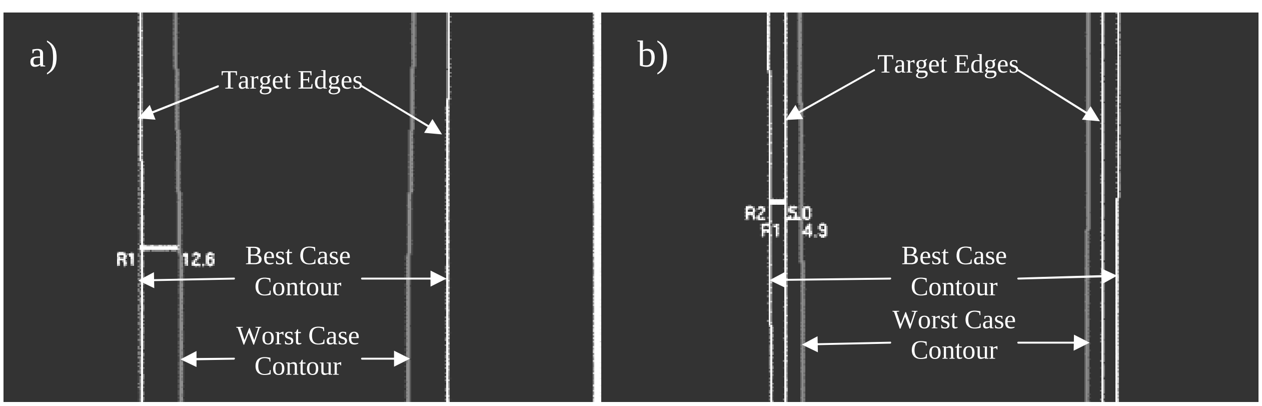


Figure 6 Standard OPC versus Process Centering a) Standard OPC (0nm defocus) b) Process Centering

5.1. Process Centering Results

The pattern was processed using a custom process centering OPC script with two models. Our first model was under 0nm defocus with -7% dosage and our second model was with 150nm defocus and +7% dosage. Our results are shown in Figure 7. The results are mixed. For tight tolerances of 10% and below we are actually loosing quality. For anything above 10% we are gaining quality.

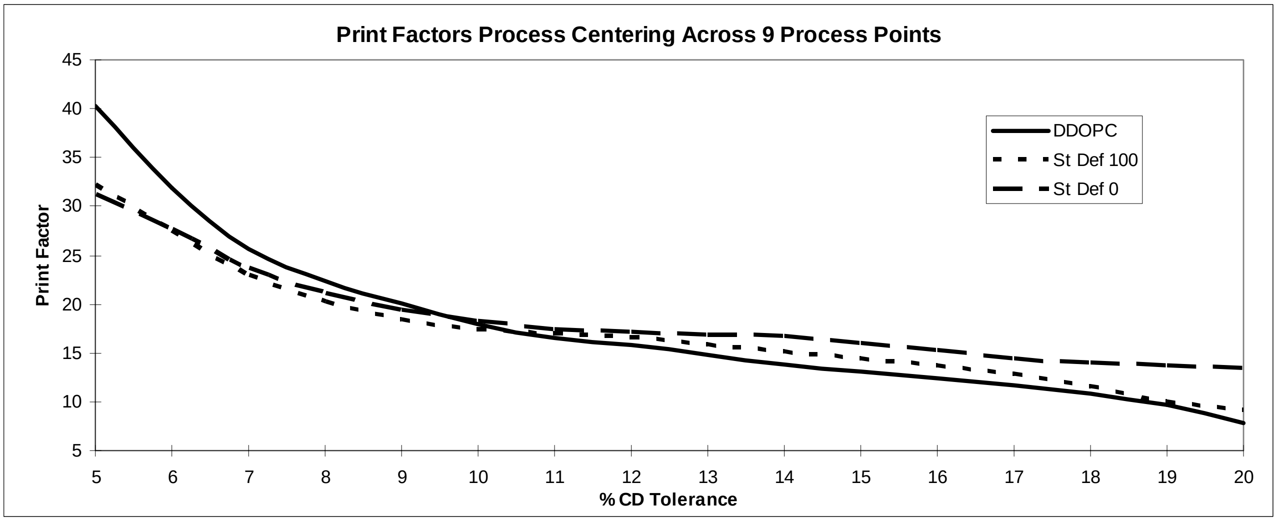


Figure 7 Print Factors Process Centering Across 9 Process Points

Our negative results for tolerances under 10% are due to having over constrained the problem. It is impossible to get both our contours with-in 5% of our target edge. The two contours are instead centered on the target edge and both extend out the tolerances and cause our negative trend. The 0nm defocus process point that no longer meets our tight tolerance requirements also carries a high probability (see Table 1). This will have a large negative impact on our print quality and will make our results worst then the standard OPC recipe since it focuses solely on the highest probability process point.

Figure 7 does not seem to provide significant benefit even above 10% but a more detailed look at the CD measurements produces a completely different conclusion. Figure 8 shows CD histograms for the metal 2, 3, and 4 layers of the sample layout. The target width of these wires is 140nm. We can see that the standard recipe under best case conditions creates a large distribution centered around the 140nm target. This is dramatically worse under worst case process conditions with some CDs dropping down to below 90nm. The results for process centering here labeled DD are printing larger then the target under ideal conditions but maintain good dimensions under worst case conditions with the worst results being around 115nm. Yield would clearly be improved if this was applied to non-critical nets where these changes would not cause parametric failures.

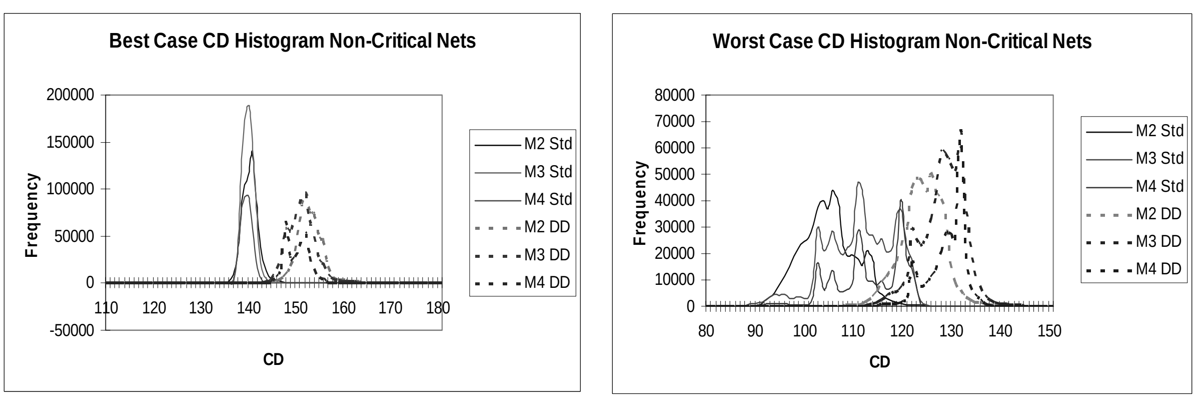


Figure 8 CD Histograms for Metals

These results bring us to two conclusions. First, for tight tolerances, a simple process centering approach will not outperform a standard recipe and must be enhanced. Second, for large tolerances we do benefit from a process centering flow but these must be applied carefully to a sub-set of the design so as not to cause parametric timing failures.

5.2. Required Enhancements

5.2.1. Process Centering OPC Enhancement

When OPC cannot find a solution that brings all models into the target tolerances it must focus on the highest probability model. The OPC pattern must be optimized to bring that model with-in the tolerances before any other model. It does not necessarily need to perfectly align with the target pattern but must be kept with-in the target tolerances. Figure 9 shows an example where in a) the two contours are perfectly centered on the target edge while in b) the 0nm defocus point seen on the outside of the feature is pushed in to meet the 5nm target while the secondary contour violates the target tolerance. This represents the best trade-off in the context of tight tolerances since the focus is on the highest probability contour.

5.2.2. Using Large Tolerances with Design Intent

Maximizing use of large tolerances is a bigger challenge. Most patterns cannot easily be allowed to use tolerances of 20%. The current OPC methodology makes use of 5% or 10% tolerances. For our example the gate regions cannot be allowed to change by up to 20% since this will easily result in a reduction in performance of anywhere form 10% to 20%. Such a change will generate timing failures and cause the parametric yield to drop drastically. This is also true for interconnect where larger wires will cause the cross coupling capacitance to increase and timing failures to occur. Making the wires thinner may also cause reliability problems due to electro migration effects.

What is truly missing for large tolerances to be applied is insight into which geometries will cause design failures and which geometries will not. It can also capture which geometries are timing sensitive and which ones are not. This information cannot be easily derived from the geometrical information normally provided to manufacturing. Instead new information must be created by the design community and supplied as part of the hand-off process.

From this new design intent information custom tolerances can be generated across all features of a pattern that defines tight tolerances in critical areas and relaxed tolerance in non-critical areas[4]. The use of design intent provides a large degree of freedom to the OPC tool so that it may better optimize for yield and in some instance mask cost. As we move forward to 65nm and 45nm, the use of design intent will likely become critical to achieving high yield given the lithographical challenges that this technology poses.

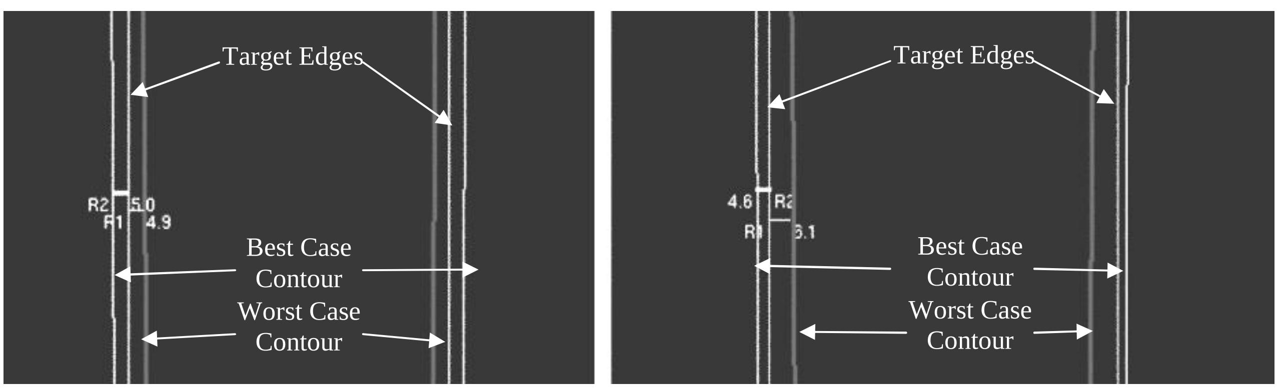


Figure 9 Process Centering Enhancement a) Original Result b) Enhanced Result

5.2.2.1. DI Generation flow

One of the ways to capture design intent (DI) is to insert it into the normal geometry based file currently used to hand of the design which today is GDSII. DI can be implemented as shapes on a new layer or data type pair that mark other geometries by overlapping them. If a DI shape overlaps a poly shape then the attribute associated with the DI shape is associated with the poly shape. This is simply an extension to the current use of diffusion layers to identify where gates are located on the poly layer. By defining a new set of layers many design attributes may be attached to existing shapes.

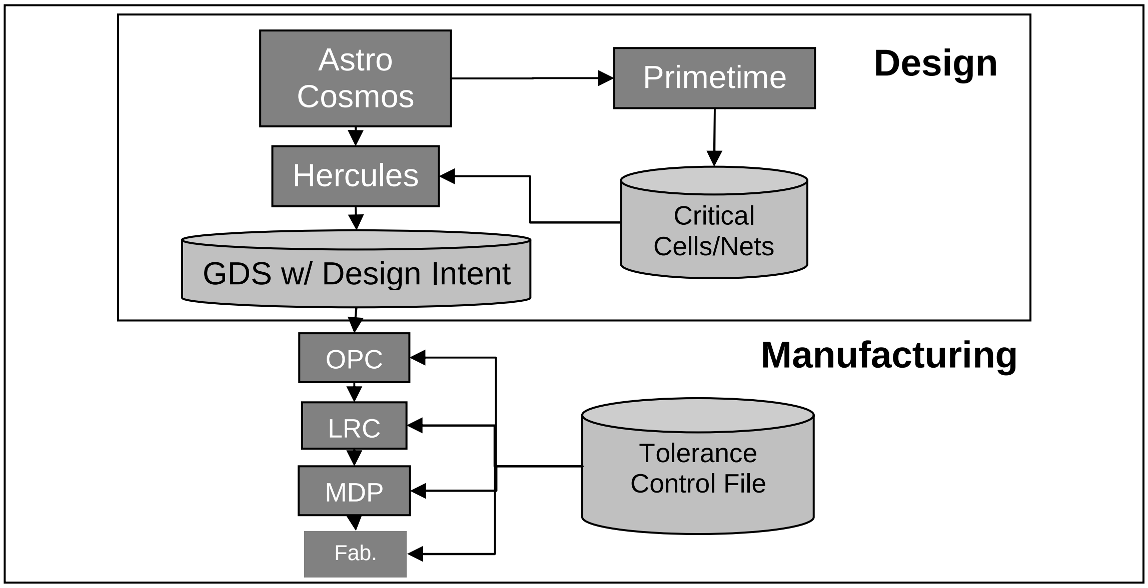


Figure 10 Design Intent Generation Flow

One possible flow that can generate design intent is shown in Figure 10. This flow uses Synopsys' PrimeTime static timing analysis tool to extract a list of critical nets. This list is supplied to the Hercules verification tool which maps them to the physical shapes that carry these nets. A control file is then provided to manufacturing DFM tools. This control file defines what tolerances to apply across the features of the design using the design intent.

This flow was applied to our entire design block in order to identify timing critical nets in the interconnect layers. The net selection criterion was reasonably aggressive and applied to all upper metal layers. The graphical results are shown in Figure 11. A total of 5907 geometries were selected out of a total of 152080. This represents 3.9% of all metal shapes leaving 95.1% of all geometries for processing with larger tolerances. Similar results were obtained when cells instance were selected for metal 1 and poly processing.

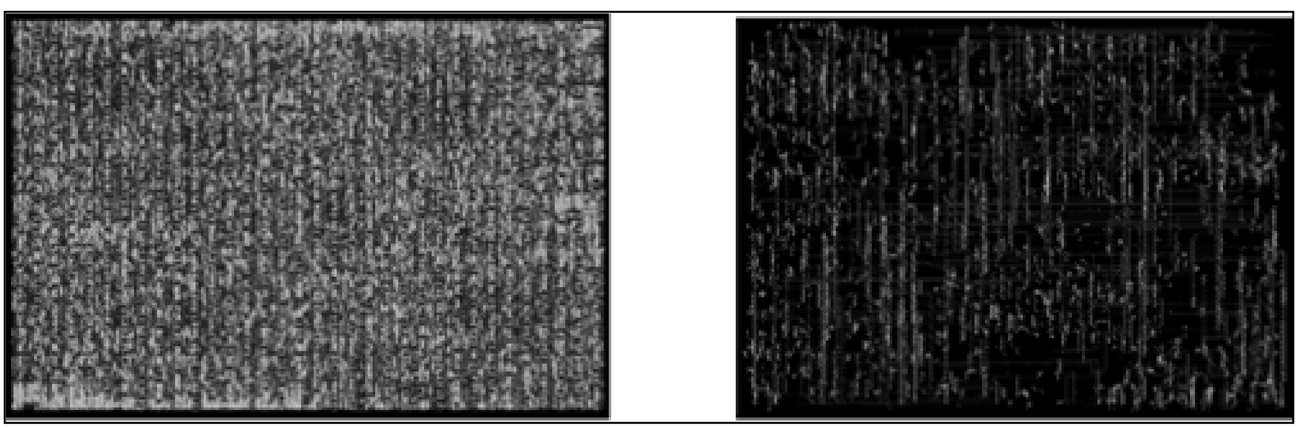


Figure 11 Design Intent Identification

Since 95.1% of shapes do not require large tolerances a combination of using design intent to mark critical nets and the improvements to the process centering OPC methodology proposed in the previous section will provide an improvement in print performance across the target process window. The design intent flow will also provide much needed flexibility not only during OPC but also in LRC, MDP, mask inspection and wafer inspection.

6. CONCLUSION

In this paper we have described the challenge OPC will face as it is applied to 90nm, 65nm and 45nm and how optimizing a pattern for best focus and dosage is not enough. We then introduced a new print model that would allow us to better evaluate the quality of an OPC strategy across the target process window. This model was then used to evaluate the results of a new OPC approach that used multiple models to capture process variation across different process points. The results showed clear benefits for tolerances of more than 10%. Leveraging this fact, the process centering strategy was adapted to reduce its sensitivity to small tolerances. A flow was also described that would allow larger tolerances where it does not impact the design intent while keeping aggressive tolerances where needed.

7. REFERENCES

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