Writing 32nm-hp Contacts with Curvilinear Assist Features

Aki Fujimura*[a], David Kim[b], Ingo Bork[a], Christophe Pierrat[c]
[a]D2S, Inc., 4040 Moorpark Ave, Suite 250, San Jose, CA, 95117, USA;
[b]Luminescent Technologies, Inc., 2471 East Bayshore Road, Suite 600, Palo Alto, CA 94303, USA
[c]IC Images Technologies, Inc., 2061 Rockhurst Court, Santa Clara CA 95051, USA

ABSTRACT

In writing contacts at 32nm half-pitch with 193nm immersion lithography, circular main features and curvilinear sub-resolution assist features will be desirable on masks. Using conventional methods, the best depth of focus, exposure latitude, and critical dimension uniformity on wafer could only be achieved with unrealizable mask write times. Previous papers have described a gradual improvement over the past two years to avoid this trade-off. For example, Manhattanization of the shapes generated by inverse lithography techniques has reduced the required shot count while maintaining best process windows. Using the MB-MDP technique, total shot count required to print such Manhattanized assist features is further reduced significantly. This paper is the first to present test writing results of 32nm-hp patterns using a conventional variable shaped beam mask writer with the new MB-MDP technique. Using this new technique, best process window and improved critical dimension uniformity are achieved while demonstrating reduced shot count. SEM images of resist patterns written by a production mask writer will be shown.

Keywords: Photo mask, shaped-beam, shot count, mask writer

1. INTRODUCTION

In a previous paper [1], a novel approach to writing masks using MB-MDP was introduced. This technique further described in [2], is a new simulation-based approach that does not "fracture" the desired mask shapes. In conventional fracturing, the union of non-overlapping VSB shot shapes produce the drawn, desired shape on the mask. The input shapes are geometrically fractured into constituent VSB shots within some grid resolution. These shots are projected on the mask using uniform dose. The dose amounts are varied later in the e-beam writing machine to compensate for mid- to long-range effect corrections such as backscatter proximity effect correction (PEC). But the input to the machines have "unassigned" dose.

In MB-MDP, the shots may overlap, each shot may be of different dose, and the shots may be of any shape including any VSB and any character projection characters. A particularly useful character was shown to be a set of circular characters. By having a discrete set of circle diameters available as characters in the second aperture, a continuous range of diameters of circles within a certain range can be drawn. The "in between" sizes are shot using dose modulation. Since circles do not tessellate any shape other than a circle, "fracturing" as a concept is incompatible. Overlapping shots is required to be able to make use of these circular shots.

Circles, however, have a big advantage over VSB shots in one important way, particularly for small geometries.

A circle has the same best edge definition and edge slope all around the circumference. There is no "corner rounding" because all corners are already rounded. Electron beams are naturally rounding, so circular shots can be made most accurately of any character shape in a shaped beam system. It should be noted that a shaped circular beam is not the same as a large Gaussian beam. A large Gaussian beam is circular, but is not shaped, and has lower edge slope.

It was also noted that the desired shapes on masks are becoming increasingly circular and curvilinear. In 193i lithography, regardless of the shape drawn on the mask, all contacts will be circular on the wafer. Since MEEF from a circle on the mask is provably the best of any possible shapes of a given area, circles as main features on mask is sensible [1]. In addition, even with dipole or source-mask optimized (SMO) illumination, best assist features are going to be curvilinear features placed around contacts and lines. "Ideal" Inverse Lithography Technology (ILT) techniques have demonstrated good wafer results using circular main features and curvilinear sub-resolution assist features (SRAFs).

*aki@design2silicon.com; www.design2silicon.com

In particular, Kim et al. [3] demonstrated that there is a trade-off in the balance of e-beam shot count in mask making vs. depth of focus (DOF) achievable on the wafer. Different trade-offs are appropriate for different types of masks, depending on the economics of the chip for which the mask is meant, and on the operational constraints of the mask shop in which the mask is written. High-volume designs will tend to be less sensitive to mask cost, and more sensitive to wafer quality. Mask shops that must prepare many different types of masks tend to need to care more about throughput, and therefore need shorter and more uniform turnaround time for each mask.

The PMJ2010 paper [4] focused on the Ideal ILT shapes being shot with the circular apertures. This paper extends that work to apply MB-MDP to Manhattanized ILT shapes without circular apertures. This work represents a trade-off of shot count and wafer quality that is more appropriate for System on Chip (SOC) masks that do not enjoy ultra-high volumes.

2. REVIEW OF EARLIER RESULTS

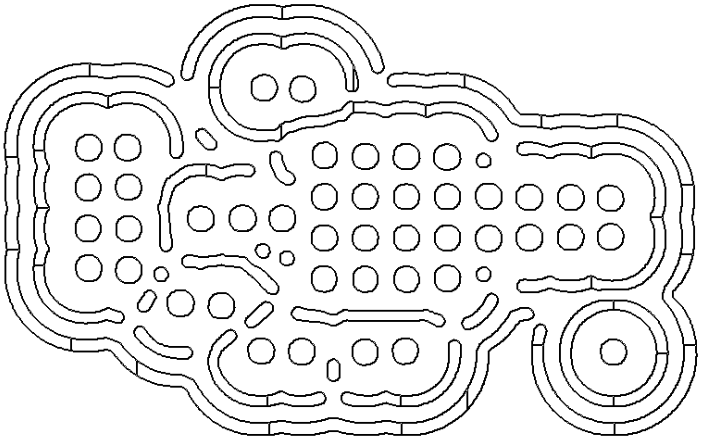

Figure 1. Ideal ILT mask of a random logic contact layout using Inverse Synthesizer™. Printing the ideal ILT mask with conventional fracturing is not practical due to the high shot count required.

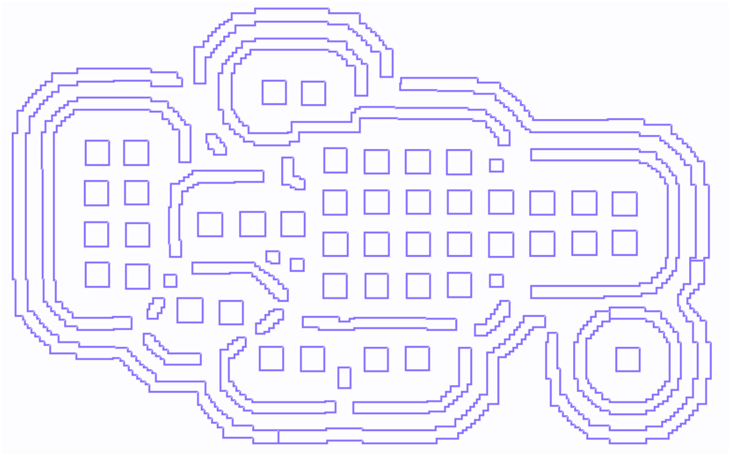

Figure 2. Optimized Manhattan version of an ILT mask for the same contact layout shown in Figure 1. The Manhattan version requires approx. 620 conventional shots.

Figure 1 shows the Ideal ILT solution for the “44 contact case” prepared by Luminescent Technologies, Inc., from the data provided by Samsung Electronics, shown in PMJ2010 [3]. Note the curvilinear nature of the SRAFs along with the circular main features. Conventionally fracturing this data would take many thousands of shots because geometrically tessellating a curvilinear shape into rectangles (or 45-degree triangles) is purely a function of the resolution grid used. Since this is not feasible, the Ideal ILT approach is not compatible with conventional fracturing.

Figure 2 shows the Optimized Manhattan version of the ILT mask from Luminescent for the same data. 620 shots are needed to write this shape using conventional fracturing. Note that the main features are shot as single rectangles. But the SRAFs are nearly octagonal with the curved corner lines being stair-stepped to produce the Manhattan shape.

All OPC algorithms including ILT incorporate mask effects when modeling the shape to wafer transformation. So even though the CAD shapes draw a jagged, stair-stepped line, these algorithms anticipate the corner rounding of the jagged edges during the mask making process. Due to the limit on computational time, however, the mask models during OPC must be simplified. For example, OPC algorithms may recognize the benefit of a 60nm (mask dimensions) blob on a mask, but would not recognize that such a blob cannot be manufactured with reasonable edge slope and dose margin using only conventional fracturing. This effect is demonstrated in Figure 3.

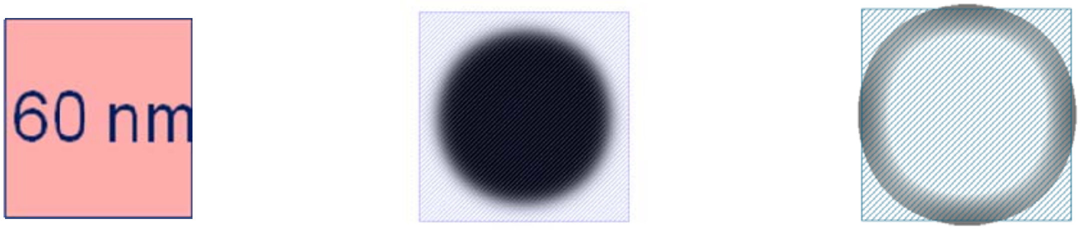

Figure 3. A 60nm x 60nm square VSB shot (left), its simulated mask shape using a 30nm short-range blur (center) and the corresponding edge slope showing larger than 1.7% dose change per 1nm slope in black and lower than 1.4% dose change per 1nm slope in white (right).

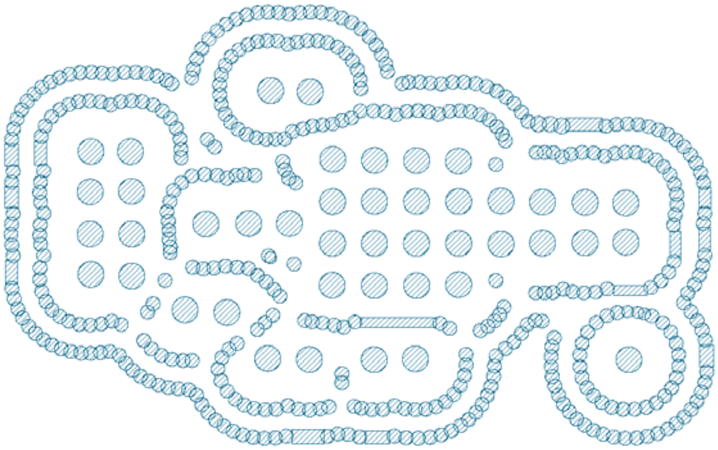

Figure 4. MB-MDP results using overlapping circular e-beam shots for a 22nm random logic contact layout achieves a 22% reduction in shot count compared to the conventionally fractured Manhattanized mask shown in Figure 2.

Figure 4 shows the previously published 484 shot solution using MB-MDP. The significance of this result was not so much the 22% reduction in shot count, but that this shot count reduction can be achieved while printing the Ideal ILT masks with circular main features and curvilinear SRAF features. Because shapes from Ideal ILT cannot be drawn within practical write times using conventional methods, the significance of the work was that Ideal ILT is practical if the masks are written with MB-MDP, particularly with circular apertures. This result can be important for higher volume designs where even slight improvements in wafer yield can be significant.

3. PRINTING MANHATTAN ASSIST FEATURES

For lower volume designs and for mask shops with throughput concerns, it is paramount to decrease the shot count further. Thankfully, recent developments in ILT have yielded Manhattanized ILT masks with wafer quality results optimized to be nearly as effective as Ideal ILT as shown in Figure 2.

The main features are rectangular and SRAFs are Manhattanized with jagged lines forming curved corners surrounding the main features. A number of smaller SRAF blobs are also present to maximally assist the main features.

A MB-MDP shot list was prepared using overlapping rectangular VSB shots as shown in Figure 5. Production JBX-3200MV machines deployed in mask shops, as well as the older generation JBX-3040MV and JBX-3050MV machines are able to write these patterns without any modifications to the machines. There are 44 main features being shot by 44 rectangular VSB shots in both the conventional fracturing case and in MB-MDP. The SRAFs in this test design are requiring 358 of the 402 shots for MB-MDP as compared to 576 of 620 shots in the conventional fracturing case. The overall shot count reduction for the pattern is 1 – (402/620) = 35%.

Figure 6 shows the result of mask simulation. Black areas are above the resist threshold while the light grey areas are below the resist threshold. The jaggedness of the non-orthogonal portions of the SRAFs are smoothed. This smoothing happens even in conventionally fractured shapes, but MB-MDP results have even more smoothing because of the overlapped shots.

The SEM picture of the resist-exposed patterns show that the shapes that print are projected well by the simulation. The patterns were exposed by JEOL, Ltd, on their JBX-3200MV machine.

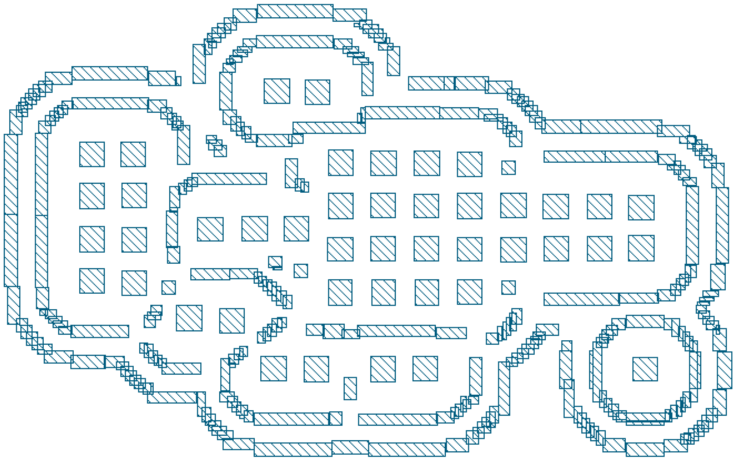

Figure 5. MB-MDP shot list using 402 rectangular VSB shots to write the Manhattanized ILT mask shown in Figure 2.

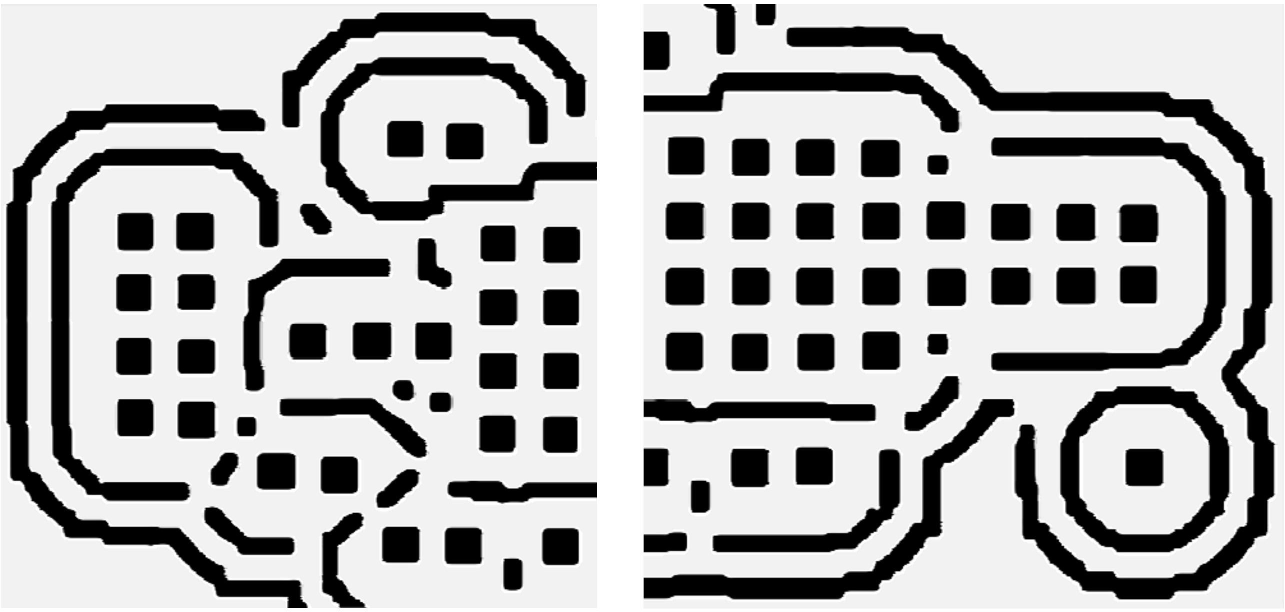

Figure 6 Mask Simulation (black) for the 44-contact test case based on the shot configuration shown in Figure 5..

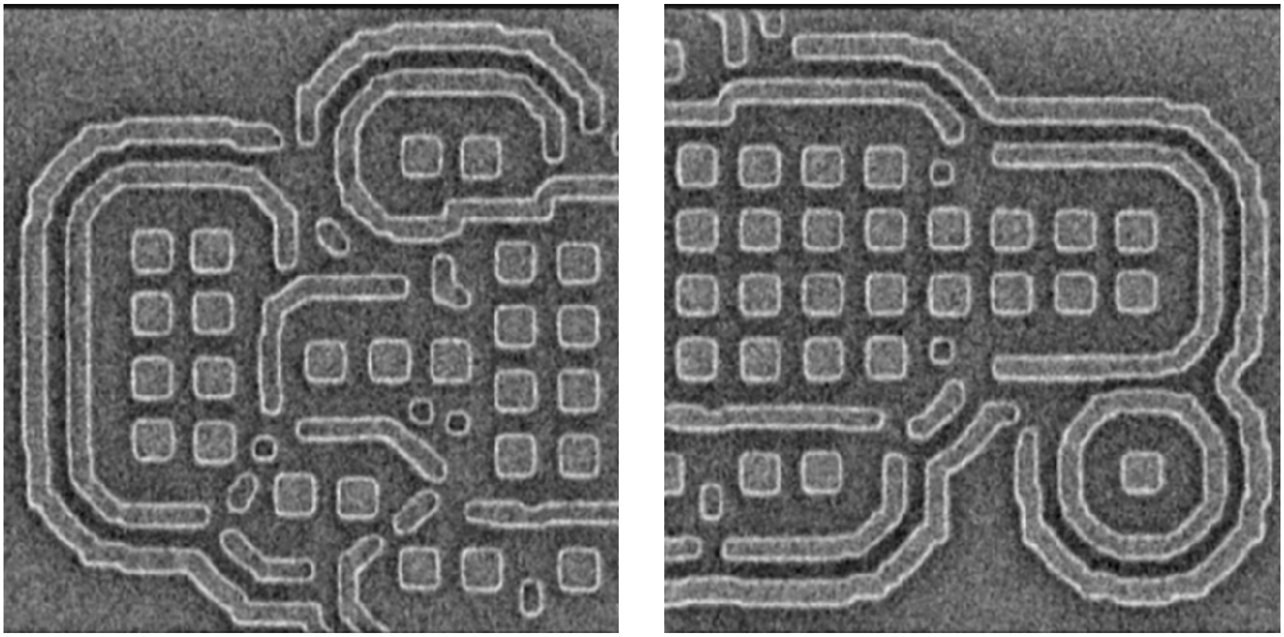

Figure 7. SEM picture of the resist-exposed image for the 44-contact test case written with MB-MDP of rectangular VSB shots only.

4. WHY MB-MDP IS EFFECTIVE IN REDUCING SHOT COUNT

A further close-up examination of the non-orthogonal SRAFs reveals why MB-MDP is effective in reducing shot count. Figure 8 shows the area being closely examined. We will focus on the outer ring.

Figure 9 shows a conventionally fractured version of this typical shape. There are 19 VSB shots required to write this shape. To contrast, the same shapes take 11 VSB shots in MB-MDP (as seen in Figure 8). Figure 10 shows the mask simulation of the conventionally fractured shapes while Figure 11 shows the MB-MDP result. The CD at the middle of the diagonal portion measured over 300nm are identical at 51.2nm in both cases. The simulated line edge roughness values are 10.7nm for conventional and 9.5nm for MB-MDP. The simulated line width roughness values are 12.3nm for conventional and 11.7nm for MB-MDP.

Overlapped portions have higher dose than the non-overlapped portions of the same shots. The overlapped portions in curvilinear or diagonal lines end up in the interior of the edge being drawn on the mask. Since these areas are overdosed, the concave corners end up being rounded further, contributing to the reduction of line edge roughness.

Overlapping shots have another important advantage. In conventional fracturing, when jogs are not aligned, i.e. the jagged shapes do not have left (or bottom) edge jog in the same Y (or X) coordinate as the right (or top) edge, extra shots are required to fill the left-over spots. Figure 12 and Figure 13 illustrate this point. In MB-MDP with overlapping shots, illustrated in Figure 14, the left-right or the top-bottom matching of the jogs are not required, saving a factor of two in shot count. As stated previously, overlapped shots produce a mask shape where the overlapped parts flare out more. These are where the valleys of the line edge waves are. But since they are in the valleys and the lithographic objective is to shoot the SRAF with roughly the same width, this reduction in the line edge roughness of the SRAFs should be welcome.

The MB-MDP approach has benefits beyond that from overlapping shots. By being simulation based, MB-MDP can see with certainty how much the mask contours are affected by the shot selection. For example, even with conventional shots with perfect left-right matching of the jogs as in Figure 12, for sufficiently small SRAFs, nearly the same shape can be created on the mask with less shots. The additional waviness in the SRAF line edges need to be evaluated for lithographic performance, but the center line of the SRAFs are preserved as well as the CD of the SRAF.

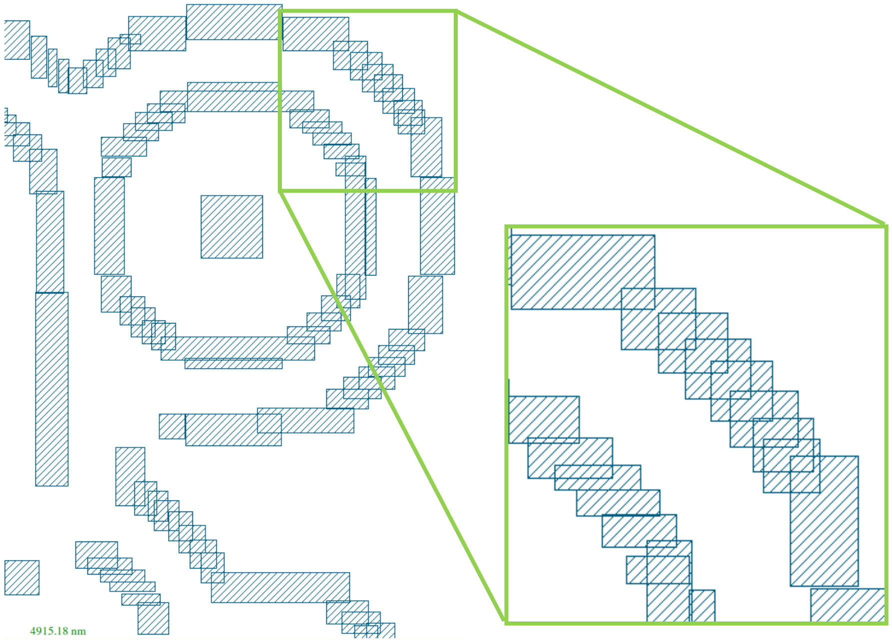

Figure 8. Close up examination of the shots and the SEM image of the SRAFs

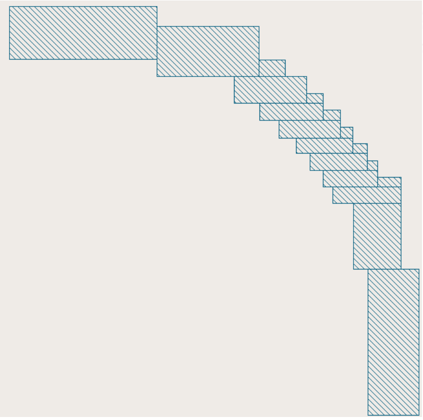

Figure 9. This segment of the outer assist feature shown in the close-up of Figure 8 can be written with 19 shots in conventional fracturing.

Figure 10. Simulated mask contour of the conventional shots shown in Fig 9

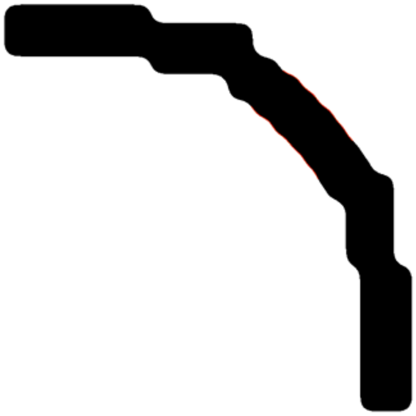

Figure 11. Simulated mask contour of the MB-MDP generated shots shown in Figure 8. Because of overlapping shots this version shows reduced line edge and line width roughness.

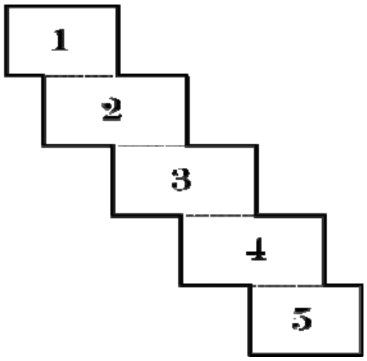

Figure 12. Jagged line with left-right matched jogs can be written with 5 shots in conventional fracturing

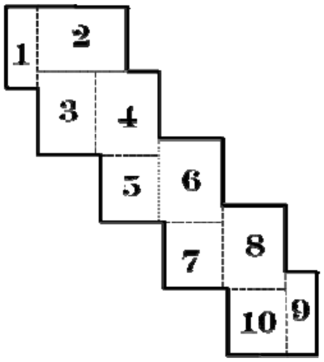

Figure 13. More typical jagged line with no left-right or top-bottom matching of the jogs producing extra shots

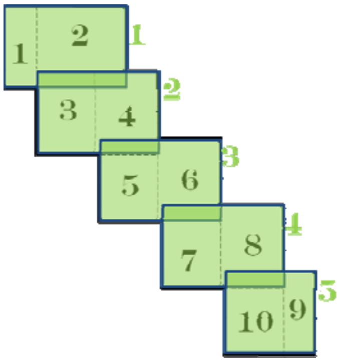

Figure 14. MB-MDP only needs 5 shots for this shape also because overlapping is allowed

5. CONCLUSIONS

Short range blur including coulomb effect, forward scattering, and resist diffusion contribute between 20nm to 35nm radius of blur. At the 22nm node, SRAFs that need to print on the mask are as small as 40nm, but more typically 50-60nm. The difference between short range blur and desired features have narrowed enough that mask simulation is a necessary step in assuring good masks and therefore wafer printing performance.

For wafer printing, complex SRAFs are required. Manhattanized ILT shapes produce very good wafer performance while minimizing the impact on mask cost and turnaround time. By taking advantage of the naturally rounding nature of e-beams, the complex SRAFs can be written in 35% less shot count than conventional methods. By being model based, MB-MDP can automatically and maximally take advantage of the short range blur to produce an equivalent mask with less cost and time.

Combined with the Alternating method, explored separately in BACUS'10 [7], the write times of these Manhattanized ILT masks can be less than half of the conventional methods by using MB-MDP with only rectangular VSB shots.

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