GenISys — Advancing the Standard

BEAMER

Managing PEC Data Volume to Improve Throughput

By Doc Daugherty, revision 2021-04-19.

Proximity effect correction (PEC) is an important technique in electron beam lithography that enables highly accurate writing across a range of pattern densities and device dimensions. However, applying PEC usually results an increase in shape count, as shapes often need to be fractured into smaller shapes with the correct dose assignments. This can cause increases in both further processing time and on-tool exposure time. This application note details some methods to reduce pattern data volume when using PEC, to improve exposure throughput.

BACKGROUND

PEC is a powerful method to improve e-beam lithography, especially when the exposed pattern has a large range of pattern densities and device critical dimensions (CD). PEC works by adjusting the exposure dose of shapes in pattern so that the total absorbed dose is uniform at the target pattern edge. The result of this dose adjustment is that shapes often need to be fractured in to sub-shapes with their own dose assignments. This increases the data volume or shape count, which can have two negative effects:

1. Increase in exposure time at the E-beam lithography tool. Principally, E-beam write time can be calculated by using the following equation:

$$D = \frac{it}{A}$$

   where *D* is the exposure dose, *i* is the beam current, *t* is the exposure time and *A* is the total exposed area. However, this equation only describes so-called "beam-on" time – the actual time the e-beam is writing the shape. However, there are other hardware-specific effects that also increase write time. This discussion focuses on shape overhead. Every discrete shape exposed by an e-beam tool has additional time overhead beyond beam-on time. This is due to such effects as data transfer limitations, beam blanking time and beam settling times.
2. Increase in further BEAMER data processing time. Every individual shape must be processed by BEAMER when the next module is executed (such as Fracturing or the final Export).
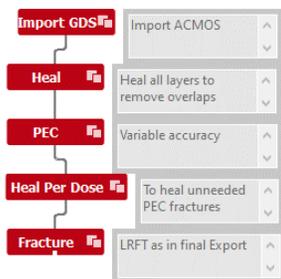
Because of these two effects, a user might want to modify the PEC module or their BEAMER flow from in order to reduce the total data volume. Some of these modifications are:

- Reducing the PEC accuracy from the default of 1%
- Healing per dose
- Adjusting PEC fracturing: through minimum figure size or isodose grid
- Reducing the total available dose classes
- …

In this application note we will focus on two of the most effective strategies: adjusting PEC accuracy and Healing per dose.

EXAMPLE SCENARIO

In this scenario, we will start with a test pattern, shown in Figure 2. This original pattern has 38,992 shapes. The PEC module parameters are shown in Table 1. All

Figure 1. The basic flow to be explored.

Figure 2. Sample pattern used for testing,

Table 1.

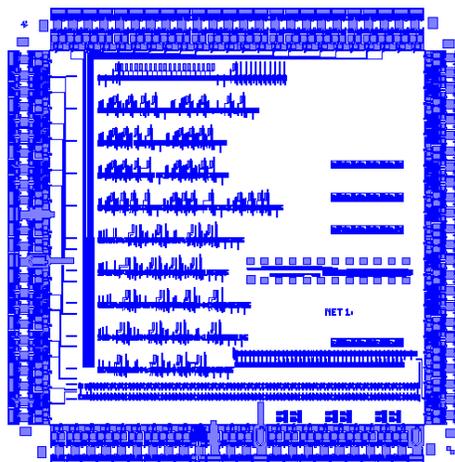| Gaussian PSF	Accuracy	LR Min. Figure Size
β = 30.00 μm η = 0.60	1.0%	0.50

other parameters are default unless noted.

The pattern is processed according to the sample flow shown in Figure 1:

1. IMPORT *Manhattan_Chip(acmos).gds*
2. HEAL in standard mode to remove shape overlaps
3. PEC with the relevant parameters in table 1
4. HEAL in PER DOSE mode
5. FRACTURE module with "LRFT" fracturing, to simulate the final tool Export step.

We will look at how adjusting the accuracy, and Healing Per Dose impacts the shape count, both before and after the final shape fracturing. This application note will have 3 main parts:

1. **PEC Module Accuracy:** What is the PEC accuracy and shape count result
2. **HEAL Per Dose**: How can we improve this result with the HEAL module
3. **FRACTURE**: What's the final shape count after PEC optimization

The pattern and sample flow are available from the GenISys applications team at support@genisys-gmbh.com.

PEC MODULE ACCURACY

Figure 3. *Comparing 1% and 4% PEC accuracy*
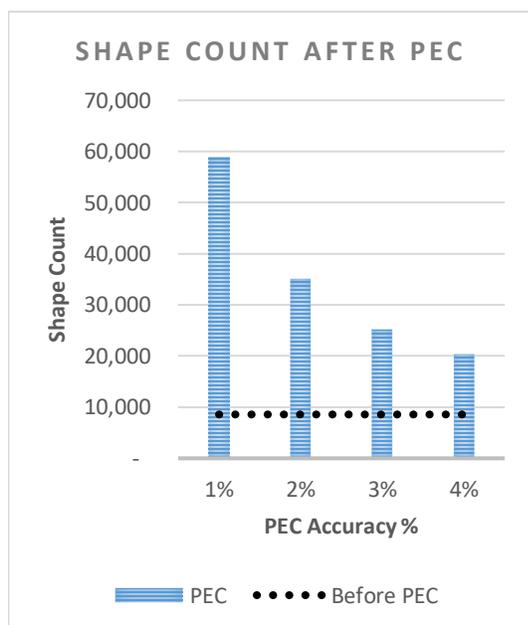
**Figure 4.** *Shape count dependency on PEC*

In the PEC module, the accuracy parameter has a major impact on the correction result. It is set to a default of 1%, as we assume that typical variations inherent in an e-beam lithography process result in a dose accuracy limit of approximately 1%. When a shape is processed by the PEC module, a shape is fractured to sub-shapes with their own dose assignments. This fracturing occurs only when the PEC module determines that the proper dose factor for that shape differs by more than the current accuracy value. In the general case, for a 1% PEC accuracy, each successive dose will be 1% larger than the previous dose. However, the set and range of dose assignments applied is ultimately pattern density and PSF dependent. As fractures are only created when it is required to maintain the specified dose accuracy, increasing the accuracy *value* results in fewer fractured shapes, which is our goal.

Figure 4 shows the total shape count after applying PEC to our example pattern. The black dashed line shows the shape count just before PEC. You can see that as the PEC accuracy value is increased from 1% to 4%, the shape counts falls substantially.

The natural question when considering a PEC accuracy value is "what value should I choose?" A higher accuracy value does means that the PEC accuracy is reduced. This can result in undesirable variations in the device critical dimensions or the fidelity of the shapes. One way to explore the effects of reducing accuracy is to examine how sensitive the feature CD is to dose change. This can be estimated by examining a line width vs. dose plot for a critical feature. Consider the example plot in Figure 5. This is simulated data for exposing a 200 nm line/space pattern at 50 kV. Our feature is correctly sized at a dose of 350 µC/cm². This process has a stable process window process and should tolerate a larger PEC accuracy. How do we know that? If we apply a trendline to the linear region of the plot, we can estimate the relative sensitivity of the CD to dose change at $\Delta 0.13 \frac{nm}{\mu C/cm^2}$. Let's assume we are evaluating using a 10% PEC accuracy. This corresponds to a max dose error of 35 µC/cm² and max CD error of 4.55 nm. If our process is tolerant to a ~5 nm error in CD, we may decide to choose this larger

PEC accuracy. While a real-world process may be less tolerant to dose change, this simulated data provides an example for how one can pick an acceptable PEC accuracy based on data. When collecting this data experimentally, one should always measure a critical feature at a representative pattern density.

Line Width vs. Dose

$y = 0.1301x + 154.13$
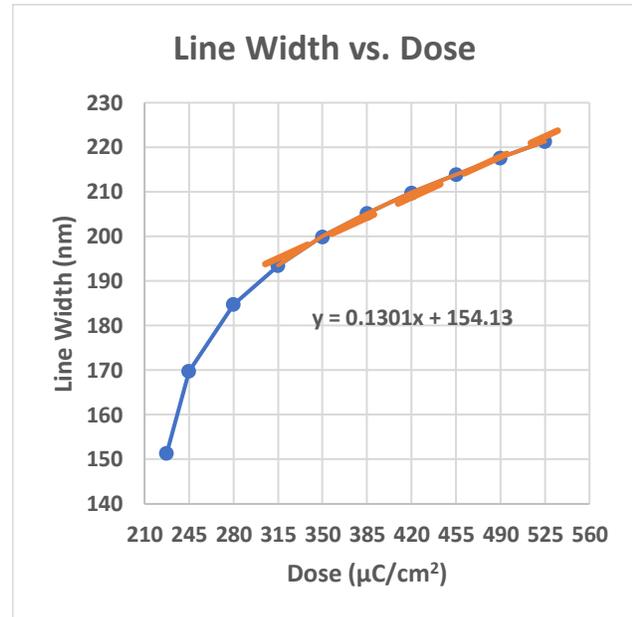
*Figure 5. Simulated data of line width vs dose plot for 200 nm line*

HEAL PER DOSE

The HEAL module has a processing mode called "Heal Per Dose". Sometimes, the PEC operation will result in multiple abutting shapes with the same dose assignment. This is especially true with higher accuracy processing. The Heal Per Dose option in the Heal module simply heals (merges) abutting shapes that have the same dose factor. If you look at figure 6, you can see the before and after a HEAL per dose. Note how the "1.4030" dose factor shapes are healed together without any change in actual exposed area or dose. It's generally a safe operation, but should not be used if you have intentionally pre-fractured your data. Remember that the final Fracture may create new shapes, which we will explore in the next section.
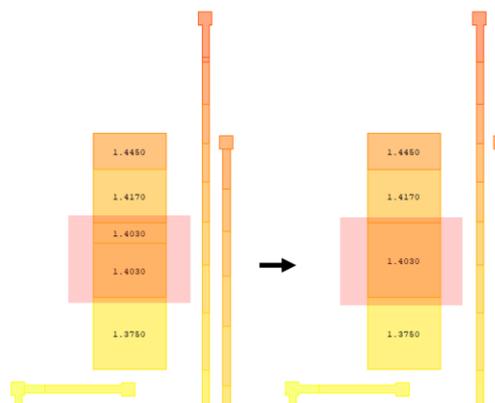
Figure 6. *Before and after a HEAL Per Dose. Note how the two adjacent shapes with dose factor 1.4030 are healed together.*

Let's return to our example scenario. On figure 7, we are comparing the shape count after PEC from the previous section, to after Heal Per Dose. You can see there is a large shape count drop in each case (although how much relative benefits depends on the accuracy as well). For this pattern, it's a very powerful strategy.
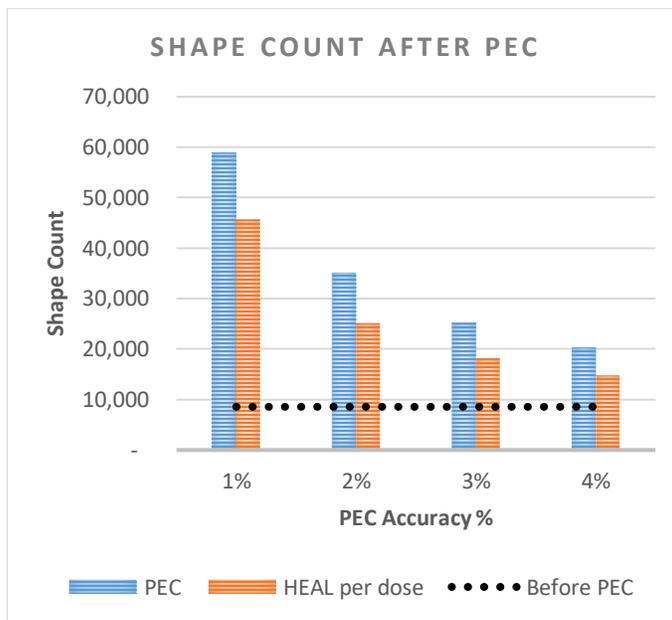

Figure 7. *Shape count after PEC from figure 4, and after Heal Per Dose.*

FRACTURE: FINAL SHAPE COUNT

The final step in any BEAMER flow will usually be exporting the pattern to a hardware specific file format. In that final step, all shapes are fractured into "primitive" shapes using BEAMER fracturing strategies such as LRFT, Conventional and Curved fracturing. This fracturing is where the final shape count is defined. Because this application note is tool independent, I will use the generic Fracture instead of a tool specific Export module, but the final shape counts would be very similar.

Figure 8 shows the final shape count after Fracture from both scenarios above: increasing PEC accuracy value and applying Heal Per Dose. The dashed black line shows the shape count after Fracture, without any PEC. We can make a few observations:

- After PEC, there will usually be a shape-count increase.
- Heal Per Dose reduced the final shape count for every trial by thousands of shapes.
- With a 1% accuracy, the shape count is over twice as large as without PEC. However, with a 3% or 4% accuracy, the values are comparable and exposure time should be very similar.
- This shows that using Heal Per Dose and an adjusted accuracy allows applying PEC with only minimal increase in shape count compared to the No-PEC case.
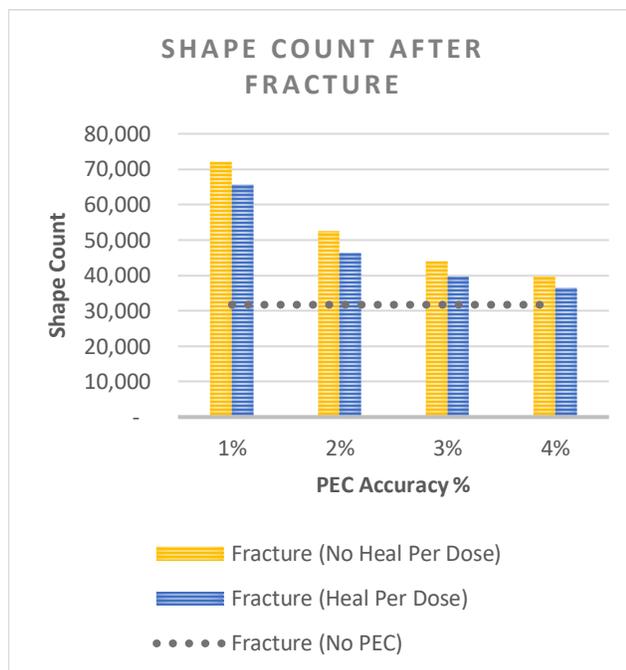
Figure 8. *Shape count after final Fracture for each example scenario.*

REVIEW

It has been shown that reducing the PEC accuracy, and Healing per Dose can have a major impact on the total shape count. This can have benefits for reducing data processing time and on-tool exposure time. It is not possible to generate a general parameter set that applies to all patterns and applications. However, for a starting point, general for a flow guidelines are given below, as shown in Figure 1:

- *Import* your pattern
- Attach a *HEAL* module
    - Heal "all layers" and in standard mode
    - Overlap removal is also acceptable.
- Attach a *PEC* module
    - Select the correct PSF
    - Adjust the accuracy value
    - Pick a reasonable accuracy value. If you want to be more thorough, determine your CD sensitivity to dose change and then choose an accuracy value that corresponds to your devices tolerance to CD error.
    - If you are not as concerned with CD accuracy as you are with throughput, choosing a less accurate PEC may be an appropriate tradeoff.
- Attach another *Heal* module
    - Heal Per Dose
    - Do not use this if you have pre-fractured your pattern.
- *Export* to your tool specific format
    - Note that your shape count will likely increase by some amount here. By how much depends on your specific tool formatter and the parameters selected.

CONCLUSION

Applying proximity effect correction is usually recommended when processing data using BEAMER. However, sometimes PEC can increase exposure time by increasing the total shape count. This application note examined how managing the PEC accuracy and using Heal Per Dose can reduce the final shape count, while still achieving highly accurate proximity effect correction.
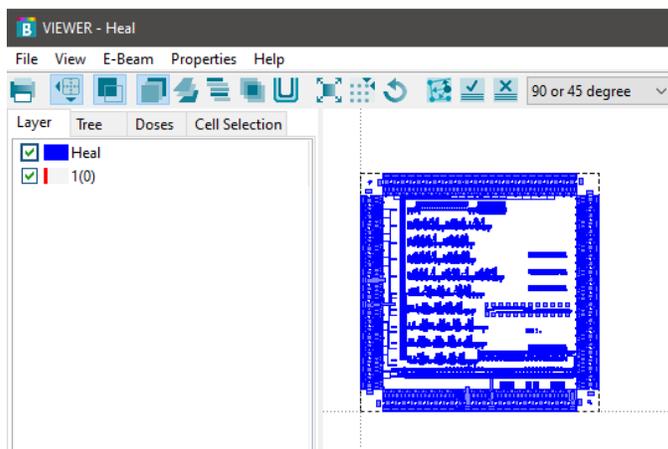
ADDENDUM

1. HOW TO VIEW TOTAL SHAPE COUNT

Select the module of interest after execution and open the VIEWER

Select the Tree tab and select the top level cell of your pattern

Check the "Geometry Count" in the Cell Information window, the "Subtree" amount is the total amount of shapes (when looking at the top cell).