Pattern Conversion with CATS

Version L

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I. INTRODUCTION

CATS is used at CNF to convert GDSII files to the file formats used by lithography tools. It is a set of programs which convert from one file format to another. At each step, a number of parameters can be adjusted or operations performed on the data before writing out to the next file format. Typically a GDS file is converted to several intermediate formats and finally to a format used by a specific tool.

A. Proximity Correction

In addition to converting GDS files to tool-specific formats, CATS can be used to do proximity correction. The PROXECCO and sceleton proximity correction software by aiss, GmbH is integrated with CATS. PROXECCO calculates adjusted e beam exposure doses to compensate for electron scattering.

PROXECCO can be used after a run with the aiss sceleton Monte Carlo simulator, which calculates a point spread function (PSF) for scattered electrons. Alternatively, in any plane parallel to the upper surface of the resist, a sum of two-dimensional Gaussians can be used to model the PSF.

A typical sceleton simulation of 10,000,000 electron histories runs overnight on a Linux server for a material stack with specified layer thicknesses and compositions. The result is stored for later use with any pattern exposed using the same material stack.

Michael Rooks, a former CNF staff member now at IBM, has found that good results can be obtained without doing a sceleton run for each combination of resist and substrate[1]. Instead, he fit the long range part of a sceleton-generated PSF with a Gaussian function. Then he determined the amplitude and width of a smaller Gaussian representing forward

scatter experimentally. For chemically amplified resists, he found that a larger value of the forward scatter component's width can compensate for the diffusion of acid in the resist. CNF is now using his streamlined correction method.

B. Reporting trouble

If you encounter any problems with this document, or with CATS, please ***enter a trouble report on the CATS web page***,
http://www.cnfusers.cornell.edu/cnf5_tool.taf?_function=detail&eq_id=115

II. USING CATS WITHOUT PROXIMITY CORRECTION

The main steps for converting a pattern are described in the lettered subsections of this section.

All of the following steps take place while sitting at a PC or Mac, but much of the process takes place while logged into a server from the PC or Mac. Commands you type are in **bold non-proportional** font. Unlike VMS, commands and file names are case-sensitive on the UNIX operating system used on the CATS server. Sample file names you fill in with your own names are shown in *italics*.

A. Send pattern to CATS server

- Ask the CNF information technology staff for an account on the cats server, korat.cnf.cornell.edu, if you don't already have one.
- Use secure copy (scp) or secure file transfer protocol (sftp) to send pattern files to your directory on korat.cnf.cornell.edu. The cats server has the "unsecure" ftp server turned off. However, it is possible to use ftp to transfer files from cats to another system.
- Two free scp and sftp clients for Windows are WinSCP, at http://winscp.sourceforge.net/eng/download.php and PuTTY, at http://www.chiark.greenend.org.uk/~sgtatham/putty/download.html .
- A free scp and sftp client for Mac OS X is Fugu, at http://rsug.itd.umich.edu/software/fugu/ .
- An example of using the command line to send a file from a Unix system (Solaris, Linux, Mac OS X, Cygwin on Windows, etc.) is:

`scp` *localfilename* *myaccountname*`@`korat.cnf.cornell.edu`:` *destinationfilename*

B. Log in on cats server

On a Windows machine, use X-Windows and putty to log in on korat.cnf.cornell.edu. On a Mac, type the following in an Xterm:

`ssh -Y` *myaccountname*`@korat.cnf.cornell.edu`
(use `ssh -X` on older versions of Mac OS X).

C. Start CATS

- In a terminal window: **cd** *SubdirectoryContainingInputFile*

Set any required environment variables, such as those needed for reading AutoCAD .DXF files. See Appendix VIII C

- Type `cats`

Several windows appear: Placement is controlled by .cinc files in $TEC which is /opt/tec on korat.cnf.cornell.edu:

- CATS - graphics control window
- Your Menu - Specific to individual machine type or user
- Flying Cat Graphics: what the output file will look like
- Fracture: Name of input files, layers, options, output file name. NOTE: every parameter name in the fracture window is also a CATS command name.
- Terminal: Dialog section - with COMMAND: prompt

From the **Your Menu** window choose the proper lithography machine (JEOL, VB6, Flat) and set the proper parameters.

D. READFILE - creates a CATS .clib file:

If your input file is a GDS file, you can skip this step and start with the next section, INPUT.

`readfile` *filename.filetype* (enter) - input filetype can be .GDS, .DXF, or one of the machine specific file types such as .FRE. Output file type is .clib (CATSlibrary), which can be read with the `input` command.

Accept the default library name or type in a new one (enter)

`ctrl-c` (to end readfile)

The default filename will be the library name of the pattern file, libname_db.clib

E. INPUT – reads in an allowed format into CATS converter

`input` *filename*.*filetype* (enter) - filetype can be .gds, .CLIB, or other allowed format

F. Set structures to work on

After inputting a file you can list the contents or cells within the GDS file with the command `cont` . Then choose which structure (cell) to display with the command `structure` *cellname*, or type `root` to get the top level structure. For GDS files created with L-Edit it is usually necessary to type `root`.

G. Select LAYERS and set EXTENT

IMPORTANT: reading in all layers and using `extent all` is the best way to make sure all layers are aligned with each other. After using all layers to set the extent, use the LAYER command *again* to select the layers you want to write out.

On COMMAND: line enter the following:

- `extent all` – will determine extents from the largest boundary - this is usually what you want to do rather than using extent, but using `limits` is useful if you want to remove part of a pattern from conversion.
- `datalayers` - to determine what layers data are on - e.g., 1,3-4,63
- `layer` *list_of_all_layers* - to read in all layers for setting limits - e.g., `layer 1,3-4,63`

IMPORTANT : This sets the pattern size/origin location on the tool you will use. It can be less then the field size; however, for small patterns it will default to the full field and place the pattern at the lower left corner.

For small patterns you should choose a symmetric set of LIMITS with approximately 300 μm total extent. This will minimize any distortions caused by beam deflection away from the central axis of the e beam column. If E_x is the pattern extent in x and E_y is the pattern extent in y, and F is the field size in μm,

Then the new limits, or lower left and upper right corners, should be

$$(L_{x1}, L_{y1}) = (-F/2 + E_x/2, -F/2 + E_y/2) \quad (1)$$

$$(L_{x2}, L_{y2}) = (F/2 + E_x/2, F/2 + E_y/2) \quad (2)$$

To center an existing pattern, for example a VB6 .fre file, use readfile to convert the .fre to .cflt, then input the .cflt file.

Example: If $E_x = 13.97$ μm, $E_y = 14.59$ μm, the limit command is

`limit -143.04,-142.705 156.96,157.295`

- `layer` *list_ of_ some_ layers* - to specify which layer(s) to operate on and convert to lithography system file format - e.g., `layer 3-4`
- From the CATS menu window, press the **DRAW** button, or type `draw` at the command line - you can now perform all resizing, overlap removal, etc.
- Use the **OPTIONS** menu to control data display
- Change any of the options for your filetype by typing on the Command: line e.g.,

`overlaps yes` (enter)

- To find out what the various parameters do type e.g.:

`help overlaps` (enter)

- (optional) `extent` - will choose extents from the largest layer selected by the `layer` command. You may choose whatever extents you like using `limits` Xmin,Ymin Xmax,Ymax.

H. Measure Pattern Area

Type `area` to see the area of the pattern in square microns. This is useful for estimating e beam write time.

I. CFA - Conditional Feature Assignment

Conditional Feature Assignment (CFA) is used to give different e beam doses to different sized shapes. It must be set up before using the DO command to fracture the pattern. If you will be using CFA, see Appendix V .

J. Output

Type `output` *filename* to specify a convenient output file name for the following steps.

K. DO

Make sure that the proper layers are specified. Exclude the boundary layer.

Type `do` to fracture the pattern and create an internal CATS format flat file - *filename*.cflt

L. WRITEFILE

This will create a lithography machine-specific file. (VB-6 will be .fre, JEOL will be .j309300fs, which must be renamed to .v30)

Find the latest .cflt or .cref file by typing `sh ls -lt | head`

- `writefile` (enter)
- *filename*.`cflt` (enter) for VB6 OR *filename*.`cref` (enter) for JEOL
- Accept the default filename or type in a new one (enter). If you are doing proximity correction with the VB6, it will type

Warning: Flatfile with CFA values; doses will be output

- `ctrl-c` to end when writefile is prompting for another input file.

You can use CATS to READFILE and INPUT the new machine-specific file, however CATS will convert it back to a .CFLT file for viewing

Writefile can also be run as a standalone program at the unix command line prompt, after the CATS session has been terminated.

M. End CATS session

Type `quit`.

If it's a JEOL pattern file, rename it by typing `mv` *filename*.`j309300fs` *filename*.`v30`

N. Preview the pattern

For VB6 .fre files, the cview previewer can be run on the CATS server before transferring the pattern to the VB6. To run it, type `cview`

III. USING CATS WITH PROXIMITY CORRECTION

A. Before starting CATS

After logging in on the server and before starting CATS, set environment variables for proximity correction. For 100 kV exposure of non-chemically-amplified resists less than 500 nm thick, (e.g. PMMA, HSQ [Fox or XR-1541], ZEP) on solid substrates you should type the following *before* running CATS on korat.cnf.cornell.edu:

```
cp   /home/CNFCommon/a_30.pec   a_30.pec
setenv TE_CFA a_30.pec
```

For 100 kV exposure of chemically amplified resists less than 500 nm thick, (e.g. KRS, UV110, NEB) on solid substrates, use **a_60.pec** instead of a_30.pec.

B. After starting CATS

Read the file in and set extents as usual. Click on **Color by CFA** in the CATS main menu window, then in the CATS console window type

```
screen prox
```

to see the proximity correction screen at the top of the terminal window. (To get back to the default fracturing screen, type `screen frac`).

To read in the proximity correction file you specified before starting CATS, type

```
prox file a_30.pec
```

(or a_60.pec, depending on what you set before starting CATS) and also type

```
overlaps no
```

You may also wish to experiment with the following before typing `do`:

Set the quality of fracturing to extra fine:

```
prox quality extrafine
```

Set the fracturing mode to physical, which takes each input rectangle or trapezoid and slices it, if necessary. This specifies the fracturing mode to be applied by the PROXECCO program. The syntax is: `prox fracturing {plain|physical}` where {} indicates use one of the two enclosed parameters. PLAIN takes each input figure and assigns a dose to it. This fracturing may destroy some compaction, resulting in the output file being larger than the input file. PHYSICAL takes each input rectangle or trapezoid and slices it, if necessary.

The Proxecco program samples the interior of the figure, and if there is a dose difference across this area, determines that the figure needs to be sliced. After slicing, it is re-sampled for further modification, if necessary. This mode of fracturing creates an output file much larger than for plain fracturing." (quoted from CATS command reference manual). The default is PLAIN, but some structures will probably come out better with PHYSICAL, so be sure to type:

```
prox fracturing physical
```

Set the size of the smallest rectangles or trapezoids by typing

```
prox min_distance 0.010
```

This sets the minimum size to 10 nm. You will want to make it larger if you will be using excels larger than 10 nm (exposure elements with size *variable resolution unit* · *pixel size*), or if output file size is too big.

Fracture the pattern and apply the proximity correction by typing

```
do
```

C. Dose normalization for proximity correction with the VB6

[The following is from "How to use PROXECCO Proximity Effect Correction with CATS", by Michael Rooks]

1. Normalize dose assignments

You thought you were done. Ha. You will discover that the .pec file generates a minimum dose of 0.68, and that this value appears in the header of a VB6 .fre file even if this low dose is not used. For example, you might have a pattern consisting of a 200 nm period grating with 20 nm wide lines. The lowest relative dose of 0.68 would be used only for large 20 μm sized features, but there are none of these in your pattern. And yet 0.68 appears in the .fre file header. That means Emma will NOT let you set the exposure current high enough to run the system clock at 25 MHz, and you will have an artificially slow exposure. You know that you want a mapping file that sets all the relative doses to 1.0 until you reach the lowest dose actually used in the pattern file. Fortunately that mapping file you used in the writefile step does not have to be a .pec file. In other words, at the step where you typed

`setenv TE_CFA /home/CNFCommon/a_30.pec` you could instead use a mapping file of your own devising. The TE_CFA file can be of several formats, and fortunately one of them is readable. It goes like this:

<relative dose 0>

<relative dose 1>

...

<relative dose 255>

VBMINMAX <low> <high>

Therefore you can type these doses into a file, starting with lots of 1s until you get to the CFA number for the lowest dose used in the pattern. Then get out your calculator and divide all the relative doses by the lowest. On the last line, the value of <low> will be 1.0, allowing you to run the exposure clock as fast as 25 MHz.

What? You don't like all that typing? Ok, we have a little program which will do it for you. It turns out that the log file from the pattern conversion (e.g. mypattern_02.log) contains the dose assignments, and our little program reads it and produces a new .ccfa file.

Find the lowest dose in your pattern with the CATS **OPTIONS** menu to display the CFA numbers by clicking on **Color by CFA**. The CFA values used in the file will then appear in the CATS menu box, but not necessarily in numerical order. Scroll through all the CFA numbers with the **<–Prev** and **Next–>** buttons until you have found the lowest ***non-zero*** CFA number, and ***write the number down***. **To find the number to write down:**

With CATS: use the mouse's right button to click on a shape and display the CFA number.

Then look at the dose assignment by switching to the proximity screen. Use the dose_n command to display the relevant range of CFA numbers. Suppose we want to know the relative dose used for CFA number 65...

```
screen prox
prox dose_n 66
```

(then hit Enter when it asks for a dose value)

Notice that we asked for CFA 66. ***The CFA numbers start at 0, but the LIST of doses in CATS starts at 1, so you need to add 1 to the CFA number you see on the screen when you type the prox dose command.***

Alternatively you can grep the log file from a shell window: grep 66: *mypattern_ 02*.log

Once again we had to add 1 to the CFA number to find the right dose in the log file.

Another way to see the dose assignments is to use cview. Right clicking on a shape will display the clock number in the file. But that's ***not*** the relative dose. The actual dose is determined by mapping the clock number between the max and min doses found in the header of the VB6 .fre file. The very latest version of cview for Linux will do this for you. If you have one of the older versions then [in a shell window] you can use the command

`clock2dose <min> <max> <clock>`

where <min> and <max> are the minimum and maximum doses found in the header. Use the cview menu item "pattern" then "header" to find these.

Next, `quit` CATS and crank out a CATS conditional feature assignment (.ccfa) file with a command like

`ls -lt *.log | head` (to find the newest log file)

`normalize` *mypattern_02*`.log` *my_doses*`.ccfa` *1.3564*

where 1.3564 stands for the relative dose number you wrote down.

This produces the file my_doses.ccfa (which you may view) for use like this:

`ls -lt *.ccfa | head` (to find the newest ccfa file)

`setenv TE_CFA` *my_doses*`.ccfa`

`ls -lt *.cflt | head` (to find the newest CATS flat file)

`writefile` *mypattern_02*`.cflt`

Now run `cview` to confirm that it really came out right, then you are done. Really. [end of text by Rooks]

D. Proximity Correction Commands for JEOL 9300FS

The typical commands for proximity correction for the JEOL are the same as for the VB6 through fracturing with the `do` command. Then a CATS include file, jeol_out.cinc, is used to generate a jeol_doses.txt file that can be appended to the end of a JEOL jobdeck file.

Before starting CATS,

`setenv /home/CNFCommon/a_30.pec` (or a_60.pec for chemically amplified resists) After starting CATS, reading file in, and setting extents:

- `overlap no`
- `screen prox` to see proximity correction screen
- `prox file /home/CNFCommon/a_30.pec` (or a_60.pec for chemically amplified resists)
- `prox quality extrafine`
- `prox fracturing physical`
- `prox min_distance 0.010` You may want to make it larger if output file size is too big or if you will be using excels larger than 10 nm (exposure elements with size *variable resolution unit* · *pixel size*)
- `do`
- Press **Color by CFA** button and type `draw` to see results
- `sh ls -lt *.cinc` to find the latest .cinc file, *latest*.cinc
- `include` *latest*`.cinc`
- `include /home/CNFCommon/jeol_out_255_doses.cinc` (or jeol_out_64_doses.cinc or jeol_out_128_doses.cinc depending on the number of doses in the file)
- `exit`
- `unsetenv TE_CFA` *the TE_CFA variable must* ***not*** *be set to the .pec file name when writing the JEOL pattern out, to avoid embedding relative doses in the .j309300fs file*
- `ls -lt | head` to see latest files created
- `writefile` *cref_file_name*`.cref` to convert .cref to JEOL .j309300fs format

IV. TRANSFER PATTERN FILE TO TOOL

A. VB6

`ftp vb6b.cnf.cornell.edu`

ftp> user: `vb`

ftp> password: • • • • • • • • • • [ask VB6 manager for password]

ftp> `binary`

ftp> `cd ../`*YourSubirectory* (moves up from [vb.users.manager] to [vb.users] then to YourSubdirectory)

ftp> `put` *filename*`.fre`

ftp> `quit`

B. JEOL

If the pattern file is for the JEOL, rename it by typing

`mv` *filename*`.j309300fs` *filename*`.v30`

Then transfer it to the JEOL as follows:

`ftp jeol.cnf.cornell.edu`

ftp> user: `ebtest`

ftp> password: • • • • • • • • • • [ask JEOL manager for password]

ftp> `binary`

ftp> `cd pattern/user`

ftp> `put` *filename*`.v30`

ftp> `ascii`

ftp> `put jeol_doses.txt` *unique_filename*`.txt`

ftp> `quit`

V. CONDITIONAL FEATURE ASSIGNMENT (CFA)

(do not use this if you are using proximity correction)

A. Assigning Layers or Datatypes to e-Beam Clocks

- Press the **CFA LAYERS** button to assign layers to clocks with the same number. Alternatively, copy an existing .ccfa file and edit to your liking:

`cp $TEC/cnf_cfa_layers.ccfa` *filename*`.ccfa`

- OVERLAPS must be set to "YES" [Is this still true or did it only apply to EBMF???]

- Before the DO command in CATS specify the *.CCFA file that will do the clock assignments:

`cfa` *filename*`.ccfa`

- If doing WRITEFILE from outside CATS:

`writefile` *filename*`.ccfa` *flatfilename*`.cflt`

B. Assigning Features of Different Sizes to e-Beam Clocks using "SELECT"

To assign clocks to features of different sizes or with other characteristics you can use the CFA file with the same rules as the SELECT command. See `help select`. The file below assigns features with any dimension in the range 0 – 0.05 μm to CFA 2 and so on. When you do a writefile it converts this to clock # 2 and so on. The All command selects all shapes that are left and assigns them to clock 0.

```
! cfa begin
! Rule set 0 – Note: lines with a ! are comments.
minhw 0 .05
2
! Rule set 1
minhw .05 .07
1
```

!Default

All

0

!end cfa

VI. BOOLEAN OPERATIONS WITH DATAFILES

CATS allows you to perform functions between pairs of input files. The available functions are: OR (adding), AND, XOR and MINUS. In addition, each file can be sized or scaled prior to the function execution. To perform an OR function between layer 3 in file1.clib scaled by 0.5 and file2.cflt and output it into file3.cflt follow this sequence:

- `function or`
- `input file1.clib`
- `layer 3`
- `scale 0.5`
- `switch`
- `input file2.cflt`
- `output ./file3.cflt`
- `do`

NOTE: if file1 is pre-fractured into a cflt file prior to this operation the number of new features created can be very large.

VII. ANALYSIS COMMANDS AND OTHER USEFUL COMMANDS

EXTENT - To determine bounding box dimensions

To Measure sizes on graphics window - click with right mouse button on each edge

CONTENTS *input.file* - shows all top-level cells

TREE – will display the tree structure of all the cells in the selected structure. Sub-cells are indented.

AREA - % area of pattern to be written

ROOT – will show root structures

Some Unix c shell commands are usable from the Command: line:

- `ls *.gds`

Other Unix c shell commands can be used from the Command: line in a CATS session by typing `sh` before the command, but output will be erased when you press (enter) to get the Command: prompt back. Example:

- `sh ls -ltF`

ORIENTATION - rotate pattern by a multiple of 90°, e.g.

- `orientation 180`

SIZING - expands or shrinks shapes. Useful for shrinking shapes to compensate for enlargement of features from drawn size to larger written size in e beam lithography. Use negative values to shrink, positive values to expand. For example, to shrink all shapes by 5 nm on each side, use

- `sizing -0.005`

EVALUATE - query CATS for the current value of certain parameters

- `evaluate area_total`
- `evaluate area_total_percent`
- `evaluate te_vru`

VIII. UTILITIES

A. TEXTLIB and LIBTEXT:

Text files: (.CTXT) can be used to define shapes and layers:

The input file name must have the format: *filename*`_db.ctxt` (`_db` must be present)

TEXTLIB – Enter TEXTLIB on COMMAND: line – converts CATS text files (.CTXT) to CATS library files (.CLIB)

LIBTEXT does the reverse – handy for converting simple CAD designs to .CTXT format for easy editing and conversion back to .CLIB

B. STREAMFILE

STREAMFILE Creates a GDS2 file from .CLIB and .CFLT files.

C. ENVIRONMENT VARIABLES

Environment variables in UNIX are analogous to logical values in VMS. Assign environment variables in a terminal window ***prior to starting CATS*** to control various functions. Example:

- `setenv TE_DXF_UNIT 25400` – to convert a .dxf file, that was created in inches, to microns

D. TO PRINT THE GRAPHICS SCREEN:

- Press **Main Menu** button at the bottom of the **Your Menu** window.
- Press **Printer Menu** button
- Press **Hardcopy to LaserWriter** button. This creates a file called **print.lw** which is a black and white postscript file, and sends it to the CAD room black and white printer.

If you want to print it in color, the easiest way to do it is to grab the screen using Grab on Mac OS X (in /Applications/Utilities) or the freely downloadable ScreenGrab on Windows, from http://no-nonsense-software.com/freeware

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Proximity correction information from: "How to Use PROCECCO Proximity Effect Correction With CATS Or The Lazy Person's Quick Guide to Proximity Effect Correction", Michael Rooks, IBM T. J. Watson Research Center, Yorktown Heights NY

Previous versions of this document were written by Roberto Panepucci and David Spencer.

REFERENCES

[1] M. Rooks, N. Belic, E. Kratschmer, and R. Viswanathan, "Experimental optimization of the electron-beam proximity effect forward scattering parameter," *Journal of Vacuum Science and Technology B: Microelectronics and Nanometer Structures*, vol. 23, no. 6, pp. 2769–2774, 2005.