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RAITH_GDSII MATLAB TOOLBOX USER GUIDE

VERSION 1.2

NATIONAL INSTITUTE FOR NANOTECHNOLOGY &
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1 Introduction

The Raith_GDSII toolbox provides a simple, versatile, and scriptable means of generating patterns for Raith electron-beam lithography (EBL) and focused ion beam (FIB) tools[1] using MATLAB[2].

[1] www.raith.com

[2] www.mathworks.com/products/matlab/

Although relatively simple structures may be generated directly within the Raith software via the GDSII editing tools in the *Design* panel, this interface becomes cumbersome for complicated structures comprising many elements, or for arrays of structures with subtle variations in geometry. GDSII files can be scripted using third-party libraries[3], but beam dose information and Raith curved elements (arcs, circles, and ellipses) are generally not supported[4]. Scripted generation of patterns using the ASCII-based .asc or .elm formats is possible[5], but these files must be manually loaded into a GDSII hierarchy file in the Raith software; the GDSII file is backed up after *each* .asc/.elm file is added to the library, which can yield unacceptably long load-times if there are many structures to add.

[3] E.g., pypi.python.org/pypi/python-gdsii

[4] The libgds Python library at github.com/scholi/libgds does in fact encode the dose factor, but does not truly support Raith curved elements, instead implementing them as polygons or paths.

[5] See §5.1.3 (Edit Menu) of the *Raith Software Reference Manual*, Version 5.0.

To circumvent these issues, the `Raith_GDSII` toolbox may be used to generate both the GDSII hierarchy and positionlist files directly within MATLAB, with full support for Raith curved elements. The relevant objects may be manipulated using standard MATLAB functionality, making scripting easy. Furthermore, structures may be plotted using the standard Raith dose factor colourmap—from individual low-level elements to entire positionlists—to aid in visualisation and error-checking during the pattern design process.

1.1 The `Raith_GDSII` classes

There are four classes in the `Raith_GDSII` toolbox: `Raith_element`, `Raith_structure`, `Raith_library`, and `Raith_positionlist`. The first three classes reflect the structure of the GDSII stream format and are used to generate the GDSII library containing the structures referenced in the positionlist:

`Raith_element`

Used to define unnamed, low-level GDSII pattern elements. The following element types are supported:

`polygon` A closed, filled polygon. `'polygon'` elements are fractured into trapezoids by the Raith software before writing.

`path` A path of connected line segments. `'path'` elements may be either single-pixel lines or have a non-zero width.

`dot` A single-pixel dot, or series thereof.

`arc` A segment of a circular or elliptical path (Raith curved element). `'arc'` elements may be single-pixel lines, have a non-zero width, or be filled (i.e., a circular or elliptical segment).

`circle` A circle or disk (Raith curved element). `'circle'` elements may be single-pixel lines, have a non-zero width, or be filled (i.e., a disk).

`ellipse` An ellipse or elliptical disk (Raith curved element). `'ellipse'` elements may be single-pixel lines, have a non-zero width, or be filled (i.e., an elliptical disk).

`text` A line of text rendered as simply-connected polygons[6].

`fbmspath` A path of connected line segments and/or circular arcs, exposed using the Raith "fixed beam moving stage" (FBMS) mode. `'fbmspath'` elements may be either single-pixel lines or have a non-zero width.

`fbmscircle` A circle exposed using FBMS mode. `'fbmscircle'` elements may be either single-pixel lines or have a non-zero width.

`sref` A structure reference. `'sref'` elements refer to named `Raith_structure` objects, and may optionally apply transformations (magnification, rotation, reflection across the u axis)[7].

`aref` An array reference. `'aref'` elements generate a rectangular array of named `Raith_structure` objects, and may optionally apply transformations (magnification, rotation, reflection across the u axis)[7,8].

Elements of type `'arc'`, `'circle'`, and `'ellipse'` are implemented as Raith curved elements, with a curved beam path which in general consists of concentric ellipses, rather than being fractured into trapezoids.

`Raith_structure`

Used to define named structures, comprising collections of `Raith_element` objects.

[6] Using simply-connected polygons for text shapes prevents the interiors of letters (e.g., A,B,D) from being released if there is a subsequent undercut step.

[7] The little-used *absolute magnification* and *absolute rotation* transformations in the GDSII specification are not supported by the `Raith_GDSII` toolbox.

[8] The Raith software's interpretation of `'aref'` objects differs somewhat from the GDSII specification. See §3.2.11.

Raith_library
: Used to define a GDSII library, comprising a collection of uniquely named `Raith_structure` objects, and to write a Raith-readable GDSII hierarchy (.csf) file.

Raith_positionlist
: Used to define a positionlist, comprising chip-level references to `Raith_structure` objects in a `Raith_library`, and to write a Raith-readable positionlist (.pls) file.

1.2 *Software use and bug reporting*

Use of the `Raith_GDSII` toolbox is subject to the terms of the Mozilla Public License, v. 2.0[9].

The latest version of the `Raith_GDSII` toolbox may be downloaded from the National Research Council Canada GitHub repository[10].

Please send comments, bug reports, and future update suggestions to Aaron Hryciw at ahryciw@ualberta.ca.

[9] mozilla.org/MPL/2.0/

[10] github.com/nrc-cnrc/Raith_GDSII

1.3 *Citing `Raith_GDSII`*

Please cite the `Raith_GDSII` MATLAB toolbox in any publication for which you found it useful by including the text "The Raith_GDSII MATLAB toolbox was developed at the National Institute for Nanotechnology; it is available at github.com/nrc-cnrc." in a footnote or endnote, as appropriate.

1.4 *Installation*

To install the `Raith_GDSII` toolbox, simply place the four `Raith_GDSII` class definitions (*Raith_element.m*, *Raith_structure.m*, *Raith_library.m*, and *Raith_positionlist.m*) in a folder on your MATLAB path. A full description of the these classes is contained in §§3–6. To get started, however, the following chapter outlines a typical (albeit brief) workflow.

1.5 *Changelog*

2015-03-10, Aaron Hryciw

- Fixed Raith_library plotting bug preventing `'fbmspath'` and `'fbmscircle'` elements from being displayed (*Raith_library.m*)
- Updated user guide (*Raith_GDSII MATLAB Toolbox - User Guide.pdf*)

2014-10-07, Aaron Hryciw

- **[Version 1.2]**
- Added FBMS path and circle elements (*Raith_element.m* and *Raith_library.m*)
- Added letter μ to text characters (*Raith_element.m*)
- Updated user guide (*Raith_GDSII MATLAB Toolbox - User Guide.pdf*)
- Updated README file (*README.md*)

2014-09-19, Aaron Hryciw

- Fixed positionlist plotting bug involving structures with `'aref'` elements (*Raith_library.m*)
- Updated user guide (*Raith_GDSII MATLAB Toolbox - User Guide.pdf*)
- Updated README file (*README.md*)

2014-01-17, Aaron Hryciw

- **[Version 1.1]**
- Added plain (non-Raith-compatible) GDSII export option to **`Raith_library.writegds`** (*Raith_library.m*)
- Fixed plotting for single-pixel line `'ellipse'` and `'circle'` elements and `'path'` elements with non-zero width (*Raith_element.m*)
- Updated user guide (*Raith_GDSII MATLAB Toolbox - User Guide.pdf*)

2013-11-27, Aaron Hryciw

- Fixed **`Raith_positionlist.append`** layer calculation problem for structures containing `'sref'` and `'aref'` elements (*Raith_positionlist.m*)
- Updated user guide (*Raith_GDSII MATLAB Toolbox - User Guide.pdf*)

2013-11-26, Aaron Hryciw

- Added **`Raith_positionlist.shift`** method (*Raith_positionlist.m*)

2013-10-05, Shawn Greig

- Fixed compatibility for MATLAB R2013a: **`setdiff`** behaviour changed between R2012b and R2013a (*Raith_library.m*)

2013-10-04, Aaron Hryciw

- Minor typographical corrections in User Guide (*Raith_GDSII MATLAB Toolbox - User Guide.pdf*)

2013-09-25, Aaron Hryciw

- Initial commit (*LICENSE, README.md, Raith_GDSII MATLAB Toolbox - User Guide.pdf, Raith_element.m, Raith_library.m, Raith_structure.m, Raith_positionlist.m*)

2
Quick-start guide

As a simple example, let us construct a pattern of a cantilever for use with a positive-tone resist (e.g,. ZEP, PMMA). First, define a polygon element for a 10-μm-long, 1-μm-wide cantilever with 3 μm spacing between the cantilever and the edge of the window:

```
% obj=Raith_element('polygon',layer,uv,DF)
% uv is a 2xn matrix of polygon vertices [u_values;v_values]
E=Raith_element('polygon',0,[0 13 13 0 0 10 10 0 0; ...
                             0  0  7 7 4  4  3 3 0],1.3);
axis equal;
E.plot;
```

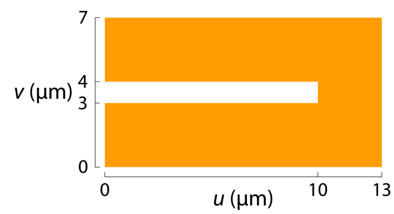


Figure 2.1: Cantilever `'polygon'` element

Next, create a text element to label the cantilever length. Since both of these elements will belong to the same `Raith_structure` object, we can make `E` an array of `Raith_element` objects:

```
% obj=Raith_element('text',layer,uv_0,h,angle,uv_align, ...
%   textlabel,DF)
E(2)=Raith_element('text',0,[14 3.5],3,0,[0 1],'10',1.5);
clf;
axis equal;
E(2).plot;
```

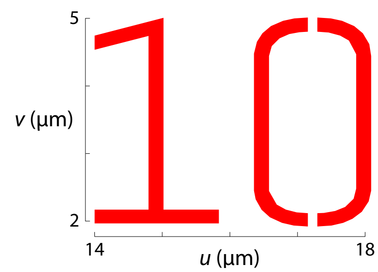


Figure 2.2: `'text'` element to label cantilever length

We now bundle these elements into a named structure:

```
% obj=Raith_structure(name,elements)
S=Raith_structure('10-um-cantilever',E);
clf;
axis equal;
S.plot;
```

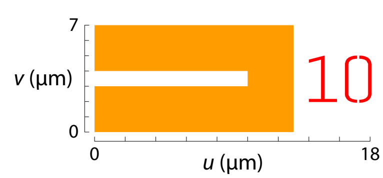


Figure 2.3: `Raith_structure` object `'10-um-cantilever'`

This structure can now be used in a `Raith_library` object, used to create the GDSII hierarchy (.csf file) which will be loaded into the Raith software:

```
% obj=Raith_library(name,structures)
L=Raith_library('cantilevers',S);
L.writegds;
```

```
Checking for missing structures...OK.
Writing C:\Users\Public\Documents\cantilevers.csf...
     Header information
     Structure 1:  10-um-cantilever
GDSII library cantilevers.csf successfully written.
```

Next, we create a positionlist using a `Raith_positionlist` object. We specify a 100 μm $\times$100 μm writefield and a 10 mm$\times$10 mm chip, and assume that the path of *cantilevers.csf* will be *F:\Raith* on the Raith computer:

```
% obj=Raith_positionlist(library,csf_path,WF,chipUV)
P=Raith_positionlist(L,'F:\Raith\cantilevers.csf',[100 100], ...
    [10 10]);
% Append a structure to the positionlist using
% P.append(structname,uv_c,DF,WA,[layers]).  WA defines the
% working area, WA=[u_min v_min u_max v_max], in um. Argument
% layers is optional, and defaults to exposing all layers
% present in structure.
P.append('10-um-cantilever',[5 5],1,[-50 -50 50 50]);
clf;
P.plot;  % Plot structures and chip boundaries
P.plotWF;  % Plot writefield as green, dotted line
P.writepls; % Write cantilevers.pls to current directory
```

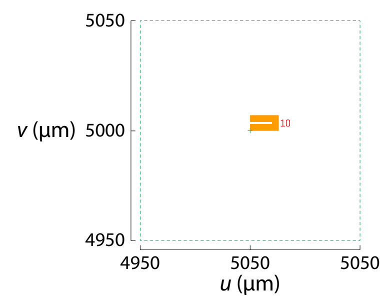


Figure 2.4: Plotting the positionlist. The writefield boundary is marked by a green dotted line, with the centre marked with a +. Axis limits were chosen to show the structure at chip centre.

To use these files in an EBL or FIB session, place *cantilevers.csf* in *F:\Raith* on the Raith computer, open *cantilevers.csf* via ***Design* panel→File→Open...** in the Raith software, and open *cantilevers.pls* via **File→Open positionlist**. After the usual preliminary steps (origin and angle correction, aperture alignment, stigmation, focusing, beam current measurement, etc.), the positionlist may be scanned as normal.

The above example illustrates the main functionality of the `Raith_GDSII` toolbox. In practice, however, structure definitions could be parametrised to facilitate script-based generation of many devices with similar, though distinct, geometries. For example, we could create a function (*cantilever.m*) which takes the cantilever length, cantilever width, window width (in μm) as arguments and returns a `Raith_structure` object:

```
function S=cantilever(L_c,w_c,w_w)
%
% function S=cantilever(L_c,w_c,w_w)
%
```

```
% Create a cantilever pattern in layer 0 with unit DF.
% A label indicating cantilever length is included,
% with DF = 1.5.
%
% Arguments:
%
% L_c — Cantilever length (um)
% w_c — Cantilever width (um)
% w_w — Window width (um)
%
% Return value:
%
% S — Raith_structure object containing labelled
%      cantilever
%

%  Define vertices of cantilever polygon
u1=L_c+w_w;
u2=L_c;

v1=2*w_w+w_c;
v2=w_w+w_c;
v3=w_w;

u=[0 u1 u1 0 0 u2 u2 0 0];
v=[0 0 v1 v1 v2 v2 v3 v3 0];

E=Raith_element('polygon',0,[u;v],1);

% Define text label for cantilever length
% Text height is hard—coded at 3 um
% Label placed to left of cantilever
E(2)=Raith_element('text',0,[—2 v1/2],3,0,[2 ...
    1],num2str(L_c),1.5);

name=[num2str(L_c) '—um—cantilever'];

S=Raith_structure(name,E);

end
```

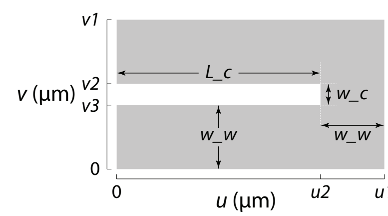


Figure 2.5: Polygon defined in function *cantilever.m*

Using this function, it is simple to generate an array of labelled cantilevers with varying lengths while keeping the window widths constant:

```
L_c=4:2:30;  % Cantilever lengths, from 4 by 2 to 30 um
w_c=1;  % Cantilever width (um)
w_w=3;  % Window width (um)

% Loop to construct all cantilever structures
for k=1:length(L_c)
    S(k)=cantilever(L_c(k),w_c,w_w);
end

L2=Raith_library('cantilevers',S);

P2=Raith_positionlist(L2,'F:\Raith\cantilevers.csf', ...
[100 100],[5 5]); % Positionlist object for a 5 x 5 mm chip
```

```
Dv=0.010;  % Vertical centre-to-centre distance (mm)

for k=1:length(L_c)
    P2.append(S(k).name,[2.5 2.5+k*Dv],1,[-50 -50 50 50]);
end

P2.plot;  % Plot structures and chip boundaries
```

As a final example of a useful `Raith_GDSII` toolbox feature, note that `Raith_positionlist` objects have a **`centre`** method which shifts an entire positionlist to centre it on the chip. This method also takes an optional argument to create a "matrix copy" array (to use Raith software terminology) of the positionlist, with the entire matrix centred on the chip; this is useful, for example, to create multiple copies of the pattern on the chip for subsequent cleaving of the specimen into sub-chips.

Given the above positionlist `P2`, we can create a 3×3 array of this pattern on the 5×5 mm chip via:

```
% "Matrix copy" current positionlist into a 3 x 3 array
% centred on the 5 x 5 mm chip.
P2.centre([3 3]);

P2.plot;  % Plot updated positionlist
```

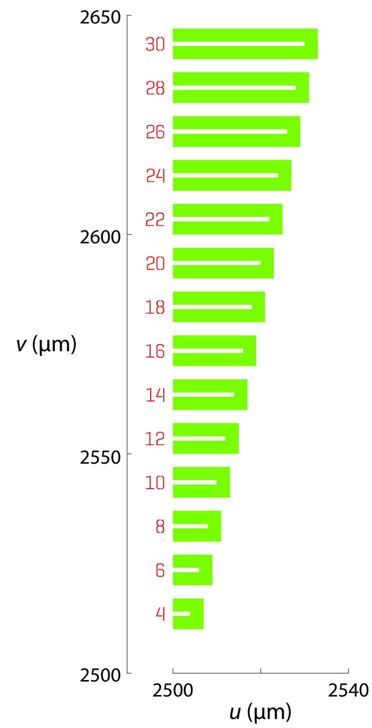


Figure 2.6: Positionlist plot of a cantilever array constructed using *cantilever.m*

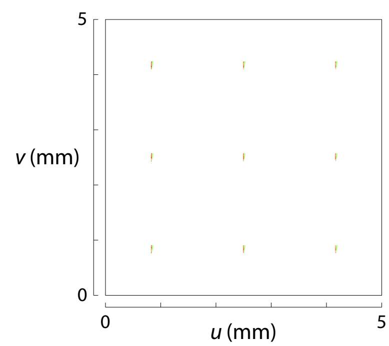


Figure 2.7: Positionlist plot of the pattern in Figure 2.6 "matrix copied" into a 3×3 array using the `Raith_positionlist.centre` method

THE PURPOSE OF THIS SECTION has been to demonstrate the major features of the `Raith_GDSII` toolbox, illustrating how to create, preview, and edit patterns for Raith electron- and ion-beam lithography tools—all within MATLAB. By enabling users to generate all files necessary for a beamwriting session within the widely available (and programmable) MATLAB environment, the `Raith_GDSII` toolbox helps to shorten and simplify design cycle iterations, especially for complicated patterns. The remainder of this document is devoted to a thorough explanation of the `Raith_GDSII` toolbox classes.

3
The `Raith_element` class

Class overview: `Raith_element`

Properties (public)

`type` String specifying type of element
`data` Structure with fields defining element geometry

Methods

`plot` Plot element as filled polygons
`plotedges` Plot element as unfilled polygons

Raith_element objects define low-level, unnamed patterns, collections of which are bundled together to form named structures in the GDSII library.

3.1 Properties

`type`: String specifying type of element; allowed values are `'polygon'`, `'path'`, `'dot'`, `'arc'`, `'circle'`, `'ellipse'`, `'text'`, `'fbmspath'`, `'fbmscircle'`, `'sref'`, or `'aref'`

`data`: Struct array containing additional record data for element; allowed field names and typing of values are determined by the element **`type`** (see §3.2)

3.2 Constructors

```
E=Raith_element('polygon',layer,uv,DF)
E=Raith_element('path',layer,uv,w,DF)
E=Raith_element('dot',layer,uv,DF)
E=Raith_element('arc',layer,uv_c,r,theta,angle,w,N,DF)
E=Raith_element('circle',layer,uv_c,r,w,N,DF)
E=Raith_element('ellipse',layer,uv_c,r,w,angle,N,DF)
E=Raith_element('text',layer,uv_0,h,angle,uv_align,textlabel,DF)
```

```
E=Raith_element('fbmspath',layer,uv,cvtr,w,DF)
E=Raith_element('fbmscircle',layer,uv_c,r,w,DF)
E=Raith_element('sref',name,uv_0,[mag,angle,reflect])
E=Raith_element('aref',name,uv_0,n_colrow,a_colrow,[mag,angle,reflect])
```

The above constructors may be used to create `Raith_element` objects. The first argument sets the element **`type`** property, followed by a list of arguments comprising the fields of the **`data`** property (a MATLAB structure), which vary depend on the **`type`**. Agruments shown in brackets are optional.

Alternately, an empty, argumentless `Raith_element` object may be called, with the **`type`** and **`data`** properties assigned afterward. For example:

```
E=Raith_element;
E.type='polygon';
E.data.layer=0;
E.data.uv=[0 1 1 0 0;0 0 1 1 0];
E.data.DF=1.5;
```

The above is equivalent to

```
E=Raith_element('polygon',0,[0 1 1 0 0;0 0 1 1 0],1.5);
```

By default, all properties are checked for correctness (typing, allowed values, size) before being assigned, whether the `Raith_element` object is created with a constructor or its properties are amended individually. Descriptions of the eleven `Raith_element` types are given in the following subsections.

3.2.1 Polygon element

Description

Closed, filled polygon

Constructor

```
E=Raith_element('polygon',layer,uv,DF)
```

Properties

`type`: `'polygon'` (string)

`data.layer`: GDSII layer; allowed values are 0–63

`data.uv`: $2 \times n$ matrix $[u;v]$ of polygon vertices (μm)

`data.DF`: Dose factor for polygon

Note

If the first and last vertices in **data.uv** are not the same (i.e., an open polygon), **data.uv** is amended to close the polygon and a warning is issued.

Example

```
E=Raith_element('polygon',0,[0 2 2 1 1 0 0; ...
    0 0 1 1 2 2 0],1.3);
```

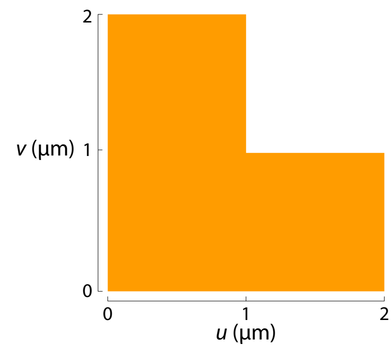


Figure 3.1: Example `'polygon'` element

3.2.2 *Path element*

Description

Path of line segments

Constructor

```
E=Raith_element('path',layer,uv,w,DF)
```

Properties

type: `'path'` (string)

data.layer: GDSII layer; allowed values are 0–63

data.uv: $2 \times n$ matrix $[u;v]$ of path vertices (μm)

data.w: Width of path (μm); a value of zero yields single-pixel line; a negative value is considered to be the same as zero by the Raith software (single-pixel line)

data.DF: Dose factor for path

Note

The interpretation of a negative value for GDSII path WIDTH records differs between the Raith software and the standard GDSII specification. In the former, a negative width is considered the same as zero width (single-pixel line); in the latter, a negative value denotes an *absolute* width, that is, a fixed width which is not affected by magnification of any parent structure (`'sref'` or `'aref'` elements).

Example

```
E1=Raith_element('path',0,[0 0 1 1 2;1 0 0 1 1],0,1.3);
E2=Raith_element('path',0,[0 0 1 1 2;1 0 0 1 1],0.2,1.3);
```

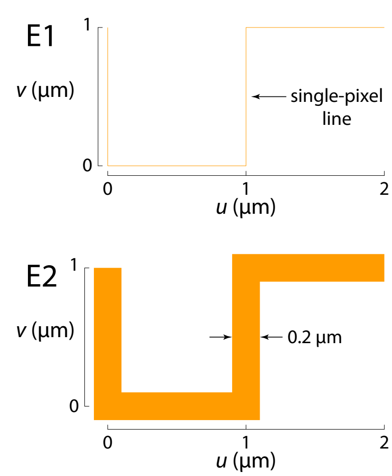


Figure 3.2: Example `'path'` elements
Element E1: `data.w = 0`
Element E2: `data.w = 0.2`

3.2.3 *Dot element*

Description

Single-pixel dot(s)

Constructor

```
E=Raith_element('dot',layer,uv,DF)
```

Properties

type: 'dot' (string)

data.layer: GDSII layer; allowed values are 0–63

data.uv: $2 \times n$ matrix [u;v] of dot positions (μm)

data.DF: Dose factor(s) for dot(s); if scalar, all dots given in **data.uv** have the same dose factor; if vector, **data.DF** must be the same length as **data.uv**, and specifies the dose factor of each dot

Example

```
E1=Raith_element('dot',0,[0 2 2 0;0 0 1 1],1.3);
E2=Raith_element('dot',0,[0 2 2 0;0 0 1 1],[0 0.5 1.0 1.5]);
```

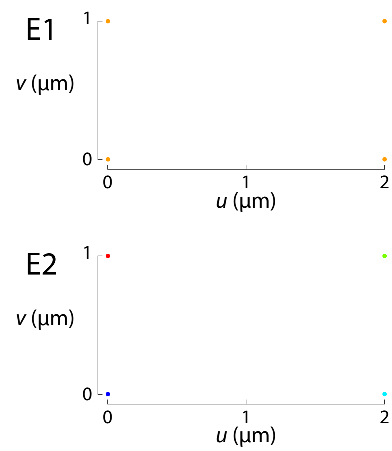


Figure 3.3: Example 'dot' elements
Element E1: scalar data.DF
Element E2: vector data.DF

3.2.4 *Arc element*

Description

Segment of circular or elliptical path (Raith curved element)

Constructor

```
E=Raith_element('arc',layer,uv_c,r,theta,angle,w,N,DF)
```

Properties

type: 'arc' (string)

data.layer: GDSII layer; allowed values are 0–63

data.uv_c: Arc centre; 1×2 vector [u_c v_c] (μm)

data.r: Radius of arc; may be scalar for a circular arc, or a 1×2 vector denoting semi-axes, [a b], for an elliptical arc (μm)

data.theta: Starting and ending angles of arc with respect to axis defined by **data.angle** argument, counter-clockwise positive; 1×2 vector [θ_1 θ_2] (degrees)

data.angle: Angle of rotation ϕ between positive u-axis and $\theta = 0$ axis (degrees)

`data.w`: Arc linewidth (μm); if empty, arc is a filled elliptical disk segment; if zero, arc is a single-pixel line; if non-zero, arc has a width; a negative value is considered to be the same as empty by the Raith software (filled elliptical disk segment)

`data.N`: Number of vertices along arc length

`data.DF`: Dose factor for arc

Note

Arc elements are interpreted by the Raith software using the following parametric equations:

$$u(\theta) = u_c + a\cos(\theta)\cos(\phi) - b\sin(\theta)\sin(\phi) \tag{3.1}$$

$$v(\theta) = v_c + a\cos(\theta)\sin(\phi) + b\sin(\theta)\cos(\phi) \tag{3.2}$$

with $\theta \in [\theta_1, \theta_2]$, spaced linearly over **`data.N`** points. As such, for elliptical arcs (i.e., $a \neq b$), θ is a *parametric* angle, and does not in general correspond to the angle from the positive u axis (assuming $\phi = 0$). To convert between the polar angle from the ellipse centre ϕ' and the parametric angle θ required by **`data.theta`**, use

$$\tan\theta = \frac{a}{b}\tan\phi' \tag{3.3}$$

Note that $\theta = \phi'$ for multiples of 90°.[1]

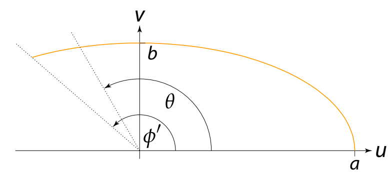


Figure 3.4: Angles used in `'arc'` elements. For a=2 and b=1, $\theta = 120°$ corresponds to $\phi' = 139.1°$.

[1] en.wikipedia.org/wiki/Ellipse

Example

```
E1=Raith_element('arc',0,[0 3],[2 1],[0 120],10,[],7,1.3);
E2=Raith_element('arc',0,[0 1.5],[2 1],[0 120],10,0,7,1.3);
E3=Raith_element('arc',0,[0 0],[2 1],[0 120],10,0.2,7,1.3);
```

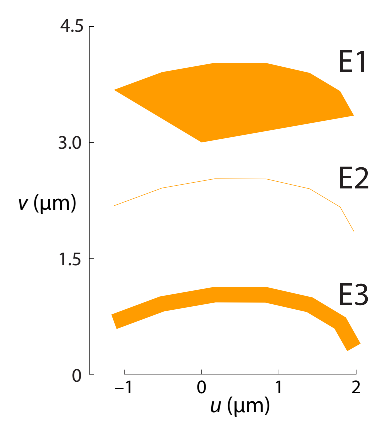


Figure 3.5: Example `'arc'` elements
Element E1: `data.w = []`
Element E2: `data.w = 0`
Element E3: `data.w = 0.2`

3.2.5 *Circle element*

Description

Circle or circular disk (Raith curved element)

Constructor

```
E=Raith_element('circle',layer,uv_c,r,w,N,DF)
```

Properties

`type`: `'circle'` (string)

`data.layer`: GDSII layer; allowed values are 0–63

`data.uv_c`: Circle centre; 1 × 2 vector $[u_c\ v_c]$ (μm)

data.r: Radius of circle (μm)

data.w: Circle linewidth (μm); if empty, circle is filled (disk); if zero, circle is a single-pixel line; if non-zero, circle has a width; a negative value is considered to be the same as empty by the Raith software (disk)

data.N: Number of vertices along circle circumference

data.DF: Dose factor for circle

Example

```
E1=Raith_element('circle',0,[0 0],1,[],60,1.3);
E2=Raith_element('circle',0,[3 0],1,0,60,1.3);
E3=Raith_element('circle',0,[6 0],1,0.2,60,1.3);
```

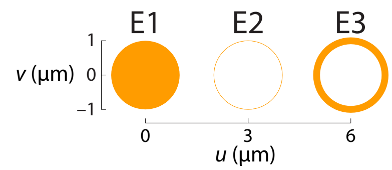


Figure 3.6: Example `'circle'` elements
Element E1: `data.w = []`
Element E2: `data.w = 0`
Element E3: `data.w = 0.2`

3.2.6 Ellipse element

Description

Ellipse or elliptical disk (Raith curved element)

Constructor

```
E=Raith_element('ellipse',layer,uv_c,r,w,angle,N,DF)
```

Properties

type: `'ellipse'` (string)

data.layer: GDSII layer; allowed values are 0–63

data.uv_c: Ellipse centre; 1 × 2 vector $[u_c\ v_c]$ (μm)

data.r: Semi-axes of ellipse; 1 × 2 vector $[a\ b]$ (μm); a corresponds to the semi-axis in the **data.angle** direction

data.w: Ellipse linewidth (μm); if empty, ellipse is filled (elliptical disk); if zero, ellipse is a single-pixel line; if non-zero, ellipse has a width; a negative value is considered to be the same as empty by the Raith software (elliptical disk)

data.angle: Angle of rotation ϕ between positive u-axis and a semi-axis (degrees)

data.N: Number of vertices along ellipse circumference

data.DF: Dose factor for ellipse

Example

```
E1=Raith_element('ellipse',0,[0 6],[2 1],[],10,60,1.3);
E2=Raith_element('ellipse',0,[0 3],[2 1],0,10,60,1.3);
E3=Raith_element('ellipse',0,[0 0],[2 1],0.2,10,60,1.3);
```

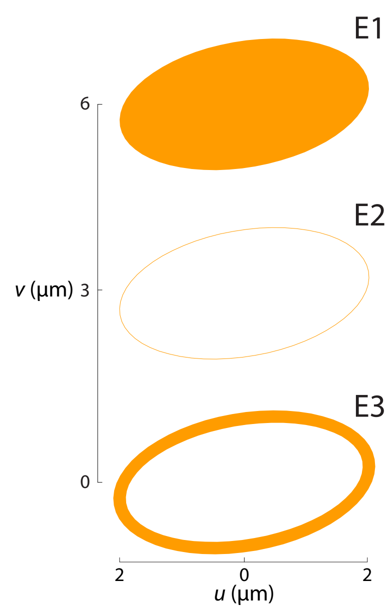


Figure 3.7: Example `'ellipse'` elements
Element E1: `data.w = []`
Element E2: `data.w = 0`
Element E3: `data.w = 0.2`

3.2.7 Text element

Description

Text rendered as simply-connected polygons

Constructor

```
E=Raith_element('text',layer,uv_0,h,angle,uv_align,textlabel,DF)
```

Properties

type: 'text' (string)

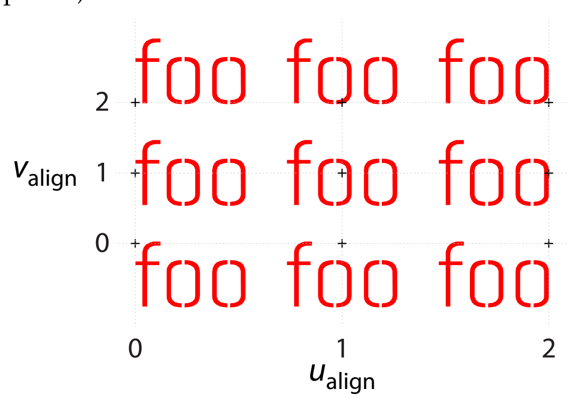
data.layer: GDSII layer; allowed values are 0–63

data.uv_0: Text anchor point $[u_0\ v_0]$ (μm)

data.h: Height of capital letters (μm)

data.angle: Angle of rotation of text with respect to positive u-axis (degrees)

data.uv_align: Alignment of text with respect to anchor point; 1×2 vector $[u_{\text{align}}\ v_{\text{align}}]$; allowed values are 0 (left/top), 1 (centre), and 2 (right/bottom), as follows (the + symbols denote the text anchor points):



data.textlabel: Text to be written (string). The allowed characters, shown as rendered, are:

` 1 2 3 4 5 6 7 8 9
0 - = q w e r t y u
i o p [ ] \ a s d f
g h j k l ; ' z x c
v b n m , . / ~ ! @
$ % ^ & * ( ) _ +
Q W E R T Y U I O P
{ } | A S D F G H J
K L : " Z X C V B N
M < > ? µ

in addition to the space character ( ). When rendered, text is kerned using a look-up table (text is not fixed width).

Use Unicode character U+00B5 to enter the letter μ in **data.textlabel**.

data.DF: Dose factor for text

Note

A simply-connected font used in `Raith_element` `'text'` elements to avoid the problem of symbol segments being released during a sacrificial layer etch. As an example, considering etching the letter *A* through the device layer of a silicon-on-insulator chip. In the default Raith font, the triangular centre of the letter *A* is not connected to the surrounding plane. If the underlying buried oxide layer was subsequetly etched away isotropically for sufficiently long (e.g., in buffered-oxide etch), the central triangle would be released, potentially landing on a critical feature of the chip. A letter *A* rendered as a `Raith_element` `'text'` element does not encounter this problem due to its simply-connected nature. The `Raith_element` `'text'` element font is based on the Geogrotesque[2] and Geogrotesque Stencil[3] fonts.

Figure 3.8: Comparison between letter *A* rendered using the Raith default font (left) and `Raith_element` font (right)

[2] www.emtype.net/geogrotesque_01.php

[3] www.emtype.net/geogrotesque_Stencil_01.php

Example

```
E=Raith_element('text',0,[0 0],1,30,[1 1],'Raith_GDSII',1.3);
```

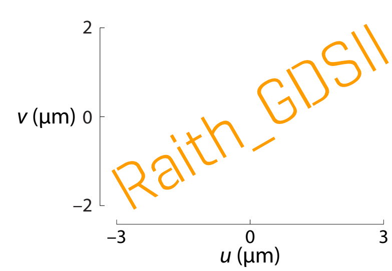


Figure 3.9: Example `'text'` element

3.2.8 *FBMS path element*

Description

Path of fixed beam moving stage line segments or arcs

Constructor

```
E=Raith_element('fbmspath',layer,uv,cvtr,w,DF)
```

Properties

`type`: `'fbmspath'` (string)

`data.layer`: GDSII layer; allowed values are 0–63

`data.uv`: $2 \times n$ matrix $[u;v]$ of path vertices (μm)

`data.cvtr`: Curvature of path segments (μm); if scalar and zero, the path comprises line segments (no curvature); if a $1 \times n$ vector, **`data.cvtr(k)`** yields a circular arc with chord endpoints of **`data.uv(:,k-1)`** and **`data.uv(:,k)`** such that the radial distance between the arc and the chord centre is **`data.cvtr(k)`**; a positive (negative) value of **`data.cvtr(k)`** corresponds to an arc to the left (right) of the chord; the value of **`data.cvtr(1)`** is ignored if **`data.cvtr`** is $1 \times n$

`data.w`: Width of path (μm); a value of zero yields single-pixel line; a negative value is considered to be the same as zero by the Raith software (single-pixel line)

`data.DF`: Dose factor for path

Example

```
E1=Raith_element('fbmspath',0,[0 0 1 1 2;1 0 0 1 1],0,0,1.3);
E2=Raith_element('fbmspath',0,[0 0 1 1 2;1 0 0 1 1], ...
     [0 0 0.2 0 -0.5],0,1.3);
```

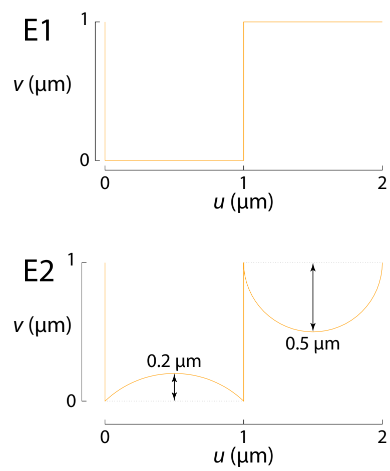


Figure 3.10: Example `'fbmspath'` elements
Element E1: `data.cvtr = 0`
Element E2: `data.cvtr = [0 0 0.2 0 -0.5]`

3.2.9 *FBMS circle element*

Description

Fixed beam moving stage circle

Constructor

```
E=Raith_element('fbmscircle',layer,uv_c,r,w,DF)
```

Properties

`type`: `'fbmscircle'` (string)

data.layer: GDSII layer; allowed values are 0–63

data.uv_c: Circle centre; 1×2 vector $[u_c\ v_c]$ (μm)

data.r: Radius of circle (μm)

data.w: Circle linewidth (μm); if zero, circle is a single-pixel line; if non-zero, circle has a width

data.DF: Dose factor for circle

Example

```
E1=Raith_element('fbmscircle',0,[0 0],1,0,1.3);
E2=Raith_element('fbmscircle',0,[3 0],1,0.2,1.3);
```

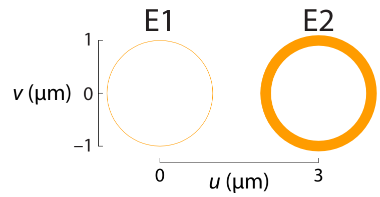


Figure 3.11: Example 'fbmscircle' elements
Element E1: data.w = 0
Element E2: data.w = 0.2

3.2.10 *Structure reference element*

Description

Reference to a named structure, with optional transformations

Constructor

```
E=Raith_element('sref',name,uv_0,[mag,angle,reflect])
```

Properties

type: 'sref' (string)

data.name: Name of structure being referenced (string)

data.uv_0: Structure origin; 1×2 vector $[u_0\ v_0]$ (μm)

data.mag: Magnification factor [optional]; default is no magnification (**data.mag** = 1)

data.angle: Angle of rotation, counter-clockwise positive (degrees) [optional]; default is no rotation (**data.angle** = 0)

data.reflect: Boolean flag (0 or 1) for reflecting about u-axis before other transformations [optional]; default is no reflection (**data.reflect** = 0)

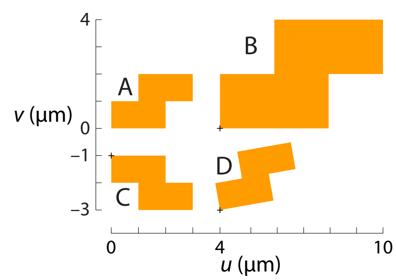


Figure 3.12: 'sref' element transformations. **data.uv_0** values for the transformed structures are marked with + signs.
A: Structure being referenced
B: data.mag = 2
B: data.reflect = 1
D: data.angle = 10

Note

Transformations are applied in the following order: 1. scaling, mirroring; 2. rotation; 3. insertion. When 'sref' elements are plotted using the **Raith_element.plot** method, the origin is marked with a + sign, labelled with **data.name**: since the structure being referenced is not part of the Raith_element 'sref' object itself, the full hierarchy cannot be plotted. To view the full hierarchy, the structure must be plotted using the **Raith_library.plot** method.

Example

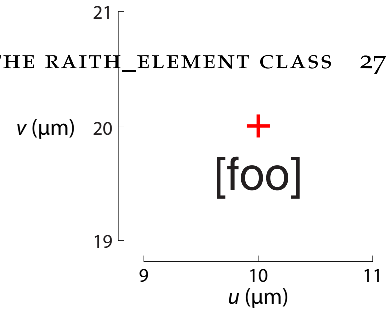


Figure 3.13: Example 'sref' element, as plotted using the **Raith_element.plot** method

```
E=Raith_element('sref','foo',[10 20],2,30);
```

3.2.11 *Array reference element*

Description

Rectangular array of named structures, with optional transformations

Constructor

```
E=Raith_element('aref',name,uv_0,n_colrow,a_colrow,[mag,angle,reflect])
```

Properties

- **type**: 'aref' (string)
- **data.name**: Name of structure being referenced (string)
- **data.uv_0**: Structure origin; 1 × 2 vector $[u_0\ v_0]$ (μm)
- **data.n_colrow**: Number of columns and rows in array; 1 × 2 vector $[n_{\text{columns}}\ n_{\text{rows}}]$
- **data.a_colrow**: Spacing of columns and rows; 1 × 2 vector $[a_{\text{columns}}\ a_{\text{rows}}]$ (μm)
- **data.mag**: Magnification factor [optional]; default is no magnification (**data.mag** = 1)
- **data.angle**: Angle of rotation, counter-clockwise positive (degrees) [optional]; default is no rotation (**data.angle** = 0)
- **data.reflect**: Boolean flag (0 or 1) for reflecting about u-axis before other transformations [optional]; default is no reflection (**data.reflect** = 0)

Note

Transformations are applied in the following order: 1. scaling, mirroring; 2. rotation; 3. insertion. When 'aref' elements are plotted using the **Raith_element.plot** method, the origins of the instances are marked with + signs, labelled with **data.name**: since the structure being referenced is not part of the Raith_element 'aref' object itself, the full hierarchy cannot be plotted. To view the full hierarchy, the structure must be plotted using the **Raith_library.plot** method.

Example

```
E=Raith_element('aref','foo',[10 20],[4 3],[3 2],[],30);
```

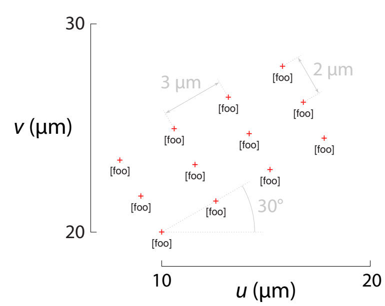


Figure 3.14: Example 'aref' element, as plotted using the **Raith_element.plot** method

It is important to note that the Raith software interprets GDSII AREF elements differently than the GDSII specification suggests. In particular, the Raith software applies rotation operations *both* to the structures being referenced and the lattice vectors defining the rectangular array. In contrast, the GDSII specification applies the rotation only to the structures; the lattice of origins for the referenced structures are fully specified using the number of rows and columns in addition to three anchor points which are calculated *after* all transformations have been applied. This variation in interpretation can result in identical AREF elements appearing differently when viewed using the Raith software versus other GDSII editors, such as KLayout; Figures 3.15 and 3.16 illustrate this behaviour.

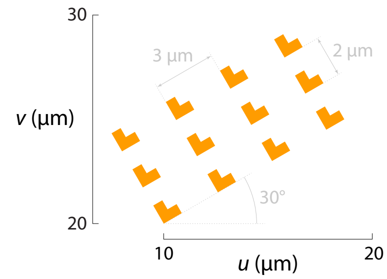


Figure 3.15: Raith interpretation of the AREF element in Figure 3.14, for an L-shaped structure named `'foo'`

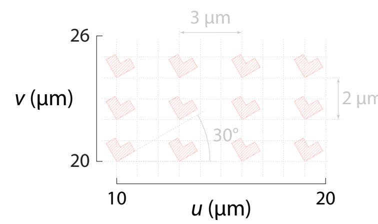


Figure 3.16: KLayout interpretation of the AREF element in Figure 3.14, for an L-shaped structure named `'foo'`

3.3 *Methods*

3.3.1 ***Raith_element.plot*** *method*

Description

Plot `Raith_element` object with Raith dose factor colouring. Elements are displayed as filled polygons, where applicable (`'polygon'`; `'path'` with non-zero **`data.w`**; `'arc'`, `'circle'`, and `'ellipse'` with empty **`data.w`**; `'text'`).

Syntax

```
plot
plot(M)
plot(M,scDF)
```

Arguments

`M` Augmented transformation matrix to be applied to element [optional]; see §§5.4.1–5.4.4

`scDF` Overall multiplicative scaling factor for dose factor specified in **`data.DF`** [optional]

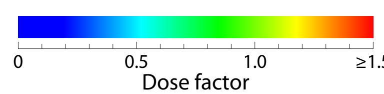


Figure 3.17: Raith dose factor colourmap

Note

Normally, **`Raith_element.plot`** is called without arguments, to display the `Raith_element` object as it would appear in the Raith software. The optional arguments `M` and `scDF` are used internally, when **`Raith_element.plot`** is called by **`Raith_structure.plot`**, **`Raith_library.plot`**, or **`Raith_positionlist.plot`**.

Calling **`Raith_element.plot`** does not change the current axis scaling; issue an `axis equal` command to ensure that the element is displayed in the figure correctly.

Example

```
E=Raith_element('text',0,[0 0],1,0,[0 2],'B',1.3);
E.plot;
axis equal;
```

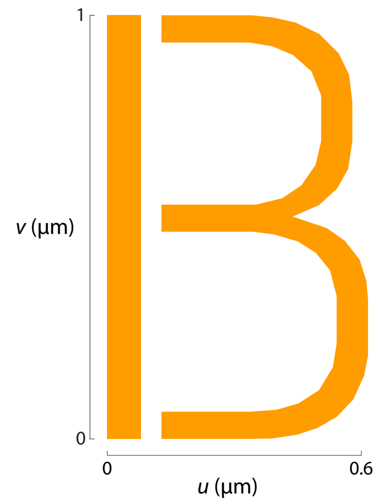


Figure 3.18: Text element plotted using the **Raith_element.plot** method

3.3.2 ***Raith_element.plotedges*** *method*

Description

Plot `Raith_element` object outlines with Raith dose factor colouring. Elements are displayed as unfilled polygons, where applicable (`'polygon'`; `'path'` with non-zero **data.w**; `'arc'`, `'circle'`, and `'ellipse'` with empty **data.w**; `'text'`).

Syntax

```
plotedges
plotedges(M)
plotedges(M,scDF)
```

Arguments

- `M` Augmented transformation matrix to be applied to element [optional]; see §§5.4.1–5.4.4
- `scDF` Overall multiplicative scaling factor for dose factor specified in **data.DF** [optional]

Note

Normally, **Raith_element.plotedges** is called without arguments. The optional arguments `M` and `scDF` are used internally, when **Raith_element.plotedges** is called by **Raith_structure.plotedges**, **Raith_library.plotedges**, or **Raith_positionlist.plotedges**.

Calling **Raith_element.plotedges** does not change the current axis scaling; issue an `axis equal` command to ensure that the element is displayed in the figure correctly.

Example

```
E=Raith_element('text',0,[0 0],1,0,[0 2],'B',1.3);
E.plotedges;
axis equal;
```

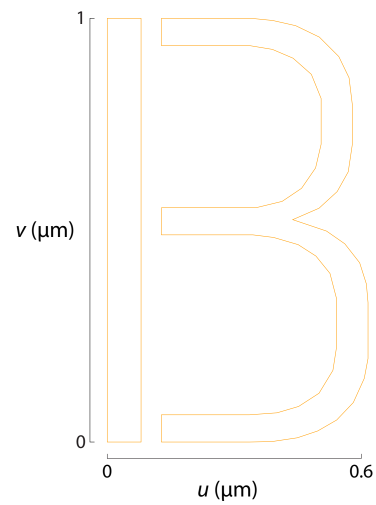


Figure 3.19: Text element plotted using the **Raith_element.plotedges** method

4
The `Raith_structure` class

Class overview: `Raith_structure`

Properties (public)

`name` String specifying name of structure

`elements` Array of `Raith_element` objects in structure

Properties (private set access)

`reflist` Cell array of referenced structure names

Methods

`plot` Plot structure as filled polygons

`plotedges` Plot structure as unfilled polygons

Raith_structure objects define named structures composed of low-level elements (`Raith_element` objects). Structures are packaged together in a GDSII hierarchy (library), and are the objects referred to in positionlist entries.

4.1 Properties

4.1.1 Public properties

`name`: String specifying name of structure. Maximum length is 127 characters. Allowed characters are A–Z, a–z, 0–9, underscore (_), period (.), dollar sign ($), question mark (?), and hyphen (-).[1]

`elements`: Array of `Raith_element` objects in structure. `Raith_element` arrays are created using standard MATLAB notation.

[1] The Raith software is somewhat more relaxed as regards structure names than the GDSII specification, which does not allow periods or hyphens and has a maximum length of 32.

4.1.2 Private set-access properties

reflist: Cell array of structure names referenced by 'sref' or 'aref' elements within the structure. **reflist** is automatically updated whenever **elements** is amended.

4.2 Constructor

```
S=Raith_structure(name,elements)
```

In a GDSII library, structures are defined by giving an arbitrary collection of elements a name; this simple conceptual framework is followed by the Raith_structure object constructor. By default, all properties are checked for correctness (typing, allowed values, size) before being assigned, whether the Raith_structure object is created with a constructor or its properties are amended individually.

Arguments

name String specifying name of structure. Maximum length is 127 characters. Allowed characters are A–Z, a–z, 0–9, underscore (_), period (.), dollar sign ($), question mark (?), and hyphen (-). Illegal characters are replaced with underscores (with a warning issued).

elements Array of Raith_element objects in structure. Raith_element arrays are created using standard MATLAB notation (see “Example” below).

Example

```
% Optical racetrack resonator
E(1)=Raith_element('arc',0,[2 0],3,[-90 90],0,0.3,200,1.3);
E(2)=Raith_element('arc',0,[-2 0],3,[90 270],0,0.3,200,1.3);
E(3)=Raith_element('path',0,[-2 2;3 3],0.3,1.3);
E(4)=Raith_element('path',0,[-2 2;-3 -3],0.3,1.3);
S=Raith_structure('racetrack',E);
```

4.3 Methods

4.3.1 **Raith_structure.plot** method

Description

Plot Raith_structure object with Raith dose factor colouring. Elements are displayed as filled polygons, where applicable ('polygon'; 'path' with non-zero **data.w**; 'arc', 'circle', and 'ellipse' with empty **data.w**; 'text'). All elements in the structure are plotted, regardless of **data.layer** value.

Syntax

```
plot
plot(M)
plot(M,scDF)
```

Arguments

`M` Augmented transformation matrix to be applied to structure [optional]; see §§5.4.1–5.4.4

`scDF` Overall multiplicative scaling factor applied to dose factors of all elements in structure [optional]

Note

Normally, **`Raith_structure.plot`** is called without arguments, to display the `Raith_structure` object as it would appear in the Raith software. The optional arguments `M` and `scDF` are used internally, when **`Raith_structure.plot`** is called by **`Raith_library.plot`** or **`Raith_positionlist.plot`**.

Calling **`Raith_structure.plot`** does not change the current axis scaling; issue an `axis equal` command to ensure that the element is displayed in the figure correctly.

Example

Given the `Raith_structure` object `S` defined in the above "Constructor" section:

```
S.plot;
axis equal;
```

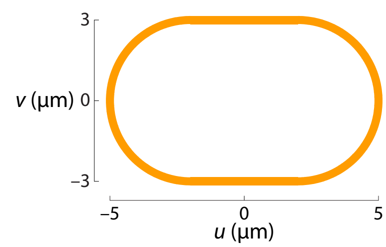


Figure 4.1: Racetrack resonator structure plotted using the **`Raith_structure.plot`** method

4.3.2 ***`Raith_structure.plotedges`*** *method*

Description

Plot `Raith_structure` object outlines with Raith dose factor colouring. Elements are displayed as unfilled polygons, where applicable (`'polygon'`; `'path'` with non-zero **`data.w`**; `'arc'`, `'circle'`, and `'ellipse'` with empty **`data.w`**; `'text'`). All elements in the structure are plotted, regardless of **`data.layer`** value.

Syntax

```
plotedges
plotedges(M)
plotedges(M,scDF)
```

Arguments

`M` Augmented transformation matrix to be applied to structure [optional]; see §§5.4.1–5.4.4

`scDF` Overall multiplicative scaling factor applied to dose factors of all elements in structure [optional]

Note

Normally, **`Raith_structure.plotedges`** is called without arguments. The optional arguments `M` and `scDF` are used internally, when **`Raith_structure.plotedges`** is called by **`Raith_library.plotedges`** or **`Raith_positionlist.plotedges`**.

Calling **`Raith_structure.plotedges`** does not change the current axis scaling; issue an `axis equal` command to ensure that the element is displayed in the figure correctly.

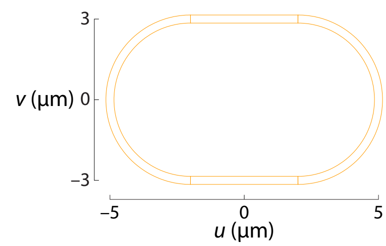


Figure 4.2: Racetrack resonator structure plotted using the **`Raith_structure.plotedges`** method

Example

Given the `Raith_structure` object `S` defined in the above "Constructor" section:

```
S.plotedges;
axis equal;
```

5
The `Raith_library` class

Class overview: `Raith_library`

Properties (public)

`name` String specifying name of GDSII library

`structures` Array of `Raith_structure` objects in library

Properties (private set access)

`structlist` Cell array of all structure names in library

Methods

`append` Append `Raith_structure` object(s) to library

`writegds` Output Raith GDSII hierarchy (.csf) file

`plot` Plot structure in library as filled polygons

`plotedges` Plot structure in library as unfilled polygons

Static Methods

`trans` Return augmented matrix for translation

`rot` Return augmented matrix for rotation

`refl` Return augmented matrix for reflection about u-axis

`scale` Return augmented matrix for uniform scaling

`writerec` Write GDSII record

`writehead` Write GDSII library header records

`writeelement` Write GDSII element record(s)

`writebeginstruct` Write GDSII records to begin a structure

`writeendstruct` Write GDSII record to end a structure

`writeendlib` Write GDSII record to end a library

Raith_library objects define GDSII hierarchies containing collections of structures (`Raith_structure` objects) which may be referred to in positionlist entries. The **`Raith_library.writegds`** method outputs a "Raith-dialect" GDSII (.csf) file which can be used by the Raith beamwriting software without any additional modification. Additionally, if all referenced structures are contained in the library, the full hierarchy of structures containing `'sref'` or `'aref'` elements may be displayed using the **`Raith_library.plot`** and **`Raith_library.plotedges`** methods.

5.1 Properties

5.1.1 Public properties

`name`: String specifying name of GDSII library, not including .csf extension.

`structures`: Array of `Raith_structure` objects in library. `Raith_structure` objects may be added to **`structures`** either using standard MATLAB notation, or via the **`Raith_library.append`** method.

5.1.2 Private set-access properties

`structlist`: Ordered cell array of all names of structures found in library. **`structlist`** is automatically updated whenever **`structures`** is amended.

5.2 Constructor

```
L=Raith_library(name,structures)
```

By default, all properties are checked for correctness (typing, allowed values, size) before being assigned, whether the `Raith_library` object is created with a constructor or its properties are amended individually.

Arguments

`name` String specifying name of GDSII library, not including .csf extension.

`structures` Array of `Raith_structure` objects in library. `Raith_structure` objects may be added to **`structures`** either using standard MATLAB notation, or via the **`Raith_library.append`** method.

Example

Given the `Raith_structure` object `S` defined in §4.2:

```
% Racetrack resonator defined in Raith_structure object S
lbl=Raith_structure('radius_label',Raith_element('text',0, ...
    [0 0],2,0,[1 0],'3 um',1.5));
L=Raith_library('resonators',[S lbl]);
```

5.3 Methods

5.3.1 **Raith_library.append** method

Description

Append `Raith_structure` object(s) to library; structure names are checked for uniqueness.

Syntax

```
append(S)
```

Arguments

`S` `Raith_structure` object (or array thereof) to be appended to library

Example

Given the `Raith_structure` objects `S` and `lbl`, defined in §4.2 and the above "Constructor" section, respectively, the three following commands all yield the same library `L`:

```
% Using Raith_library.append
L=Raith_library('resonators',S);
L.append(lbl);

% Using horizontal concatenation
L=Raith_library('resonators',[S lbl]);

% Using array indexing
L=Raith_library('resonators',S);
L.structures(end+1)=lbl;
```

5.3.2 **Raith_library.writegds** method

Description

Write Raith GDSII hierarchy of all structures to file ⟨**name**⟩*.csf*

Syntax

```
writegds
writegds(outdir)
writegds(dialect)
writegds(outdir,dialect)
```

Arguments

`outdir` String specifying directory in which to write .csf file [optional]; if called without arguments, file is written to working directory.

`dialect` String specifying dialect of GDSII to write [optional]; may be `'Raith'` (default) or `'plain'` (readable by non-Raith GDSII editors).

Note

If `'plain'` is specified for the GDSII dialect, all Raith curved elements (`'arc'`, `'circle'`, `'ellipse'`) are converted to BOUNDARY (polygon) elements if filled (**`data.w`** = []) or PATH elements if unfilled (**`data.w`** not empty). The resulting .csf file may be opened by non-Raith GDSII editors such as KLayout.

Example

Given the `Raith_library` object `L` in the above "Constructor" section:

```
L.writegds('C:\Users\Public\Documents');


Checking for missing structures...OK.
Writing C:\Users\Public\Documents\resonators.csf...
     Header information
     Structure 1/2:  racetrack
     Structure 2/2:  radius_label
GDSII library resonators.csf successfully written.
```

5.3.3 ***`Raith_library.plot`*** *method*

Description

Plot structure in library with Raith dose factor colouring. Elements are displayed as filled polygons, where applicable (`'polygon'`; `'path'` with non-zero **`data.w`**; `'arc'`, `'circle'`, and `'ellipse'` with empty **`data.w`**; `'text'`). All elements in the structure are plotted, regardless of **`data.layer`** value. The full hierarchy of structures including `'sref'` or `'aref'` elements are displayed if all structures being referenced are present in the library.

Syntax

```
plot(structname)
plot(structname,M)
plot(structname,M,scDF)
```

Arguments

`structname` String specifying name of structure to be plotted (must be in **`structlist`**)

`M` Augmented transformation matrix to be applied to structure [optional]; see §§5.4.1–5.4.4

`scDF` Overall multiplicative scaling factor applied to dose factors of all elements in structure [optional]

Note

Normally, **`Raith_library.plot`** is called without arguments, to display the structure as it would appear in the Raith software. The optional arguments `M` and `scDF` are used internally, when **`Raith_library.plot`** is called by **`Raith_positionlist.plot`**.

Calling **`Raith_library.plot`** does not change the current axis scaling; issue an `axis equal` command to ensure that the element is displayed in the figure correctly.

Example

Given the `Raith_structure` objects `S` and `lbl`, defined in §4.2 and §5.2, respectively:

```
% Racetrack resonator defined in Raith_structure object S
% Radius label defined in Raith_structure object lbl
E(1)=Raith_element('sref','racetrack',[0 0]);
E(2)=Raith_element('sref','radius_label',[0 -4]);
RR=Raith_structure('labelled_racetrack',E);

L=Raith_library('resonators',RR);
L.plot('labelled_racetrack');  % Figure 5.1

L.append(S);
clf;
L.plot('labelled_racetrack');  % Figure 5.2
axis equal;

L.append(lbl);
clf;
L.plot('labelled_racetrack');  % Figure 5.3
axis equal;
```

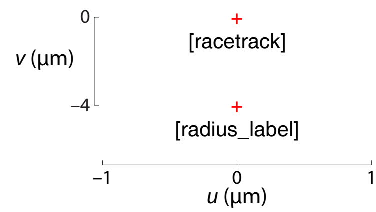


Figure 5.1: Display resulting from **`Raith_library.plot`** method when referenced structures are not in library

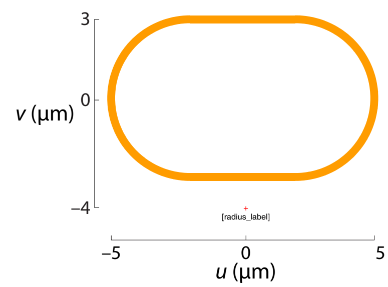


Figure 5.2: Display resulting from **`Raith_library.plot`** method when one referenced structure is not in library

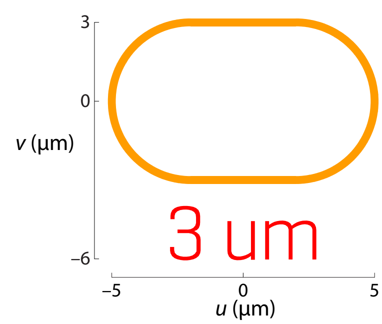


Figure 5.3: Display resulting from **`Raith_library.plot`** method when all structures are present in library

5.3.4 ***`Raith_library.plotedges`*** *method*

Description

Plot outlines of structure in library with Raith dose factor colouring. Elements are displayed as unfilled polygons, where applicable (`'polygon'`; `'path'` with non-zero **`data.w`**; `'arc'`, `'circle'`, and `'ellipse'` with empty **`data.w`**; `'text'`). All elements in the structure are plotted, regardless of **`data.layer`** value. The full hierarchy of structures including `'sref'` or `'aref'` elements are displayed if all structures being referenced are present in the library.

Syntax

```
plotedges(structname)
plotedges(structname,M)
plotedges(structname,M,scDF)
```

Arguments

`structname`	String specifying name of structure to be plotted (must be in **`structlist`**)
`M`	Augmented transformation matrix to be applied to structure [optional]; see §§5.4.1–5.4.4
`scDF`	Overall multiplicative scaling factor applied to dose factors of all elements in structure [optional]

Note

Normally, **`Raith_library.plotedges`** is called without arguments, to display the structure as it would appear in the Raith software. The optional arguments `M` and `scDF` are used internally, when **`Raith_library.plotedges`** is called by **`Raith_positionlist.plotedges`**.

Calling **`Raith_library.plotedges`** does not change the current axis scaling; issue an `axis equal` command to ensure that the element is displayed in the figure correctly.

Example

Given the `Raith_library` object `L` defined in the final example of §5.3.3:

```
L.plotedges('labelled_racetrack');
axis equal;
```

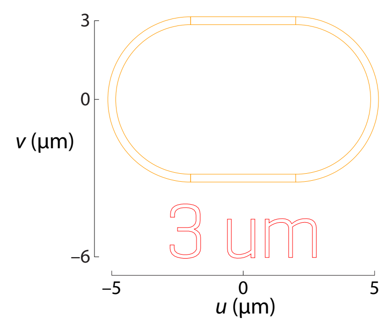


Figure 5.4: Display resulting from **`Raith_library.plotedges`** method when all structures are present in library

5.4 *Static Methods*

THE METHODS IN THIS SECTION do not require an instance of the `Raith_library` class to be called (static), and are generally used internally. Certain circumstances, however, may require the user to call them explicity (e.g., see §7.3).

5.4.1 ***`Raith_library.trans`*** *method*

Description

Return augemented matrix for translation.

Syntax

```
M=Raith_library.trans(p)
```

Arguments

`p` Translation vector; 1×2 vector $[p_u \;\; p_v]$ (μm)

Return value

`M` Augmented matrix for translation

Note

For translation by a vector $\vec{p}$, the augmented matrix is

$$\begin{bmatrix} 1 & 0 & p_u \\ 0 & 1 & p_v \\ 0 & 0 & 1 \end{bmatrix} \tag{5.1}$$

Example

```
Raith_library.trans([10 20])

ans =

     1     0    10
     0     1    20
     0     0     1
```

5.4.2 *`Raith_library.rot` method*

Description

Return augemented matrix for rotation.

Syntax

```
M=Raith_library.rot(theta)
```

Arguments

`theta` Rotation angle, counter-clockwise positive (degrees)

Return value

`M` Augmented matrix for rotation

Note

For counter-clockwise rotation through an angle θ, the augmented matrix is

$$\begin{bmatrix} \cos\theta & \sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{5.2}$$

Example

```
Raith_library.rot(30)

ans =

    0.8660   -0.5000         0
    0.5000    0.8660         0
         0         0    1.0000
```

5.4.3 *Raith_library.refl method*

Description

Return augemented matrix for reflection about u-axis n times.

Syntax

```
M=Raith_library.refl(n)
```

Arguments

`n` Number of times to reflect about u-axis

Return value

`M` Augmented matrix for reflection

Note

For reflection about the u-axis n times, the augmented matrix is

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & (-1)^n & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{5.3}$$

Example

```
Raith_library.refl(1)

ans =

     1     0     0
     0    -1     0
     0     0     1
```

5.4.4 *Raith_library.scale method*

Description

Return augemented matrix for uniform scaling

Syntax

```
M=Raith_library.scale(mag)
```

Arguments

`mag` Uniform scaling factor

Return value

`M` Augmented matrix for uniform scaling

Note

For uniform scaling by a factor m, the augmented matrix is

$$\begin{bmatrix} m & 0 & 0 \\ 0 & m & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{5.4}$$

Example

```
Raith_library.scale(3)

ans =

     3     0     0
     0     3     0
     0     0     3
```

5.4.5 *Raith_library.writerec method*

Description

Write single GDSII record to file

Syntax

```
Raith_library.writerec(FileID,rectype,datatype,parameters)
```

Arguments

`FileID` Integer file identifier obtained from MATLAB's **`fopen`** function

`rectype` GDSII record type, specified in decimal format; Table 5.1 lists the record types used in the `Raith_GDSII` toolbox.

`datatype` GDSII data type, specified in decimal format; Table 5.2 lists the data types for the GSDII specification.

`parameters` Record parameters, of type defined by `datatype`

Example

```
% Open a file for writing
FileID=fopen('test.csf','w');
% Write a BOUNDARY record, which contains no data
Raith_library.writerec(8,0,[]);
```

Record type	Hex	Dec
HEADER	0x00	0
BGNLIB	0x01	1
LIBNAME	0x02	2
UNITS	0x03	3
ENDLIB	0x04	4
BGNSTR	0x05	5
STRNAME	0x06	6
ENDSTR	0x07	7
BOUNDARY	0x08	8
PATH	0x09	9
SREF	0x0A	10
AREF	0x0B	11
LAYER	0x0D	13
DATATYPE	0x0E	14
WIDTH	0x0F	15
XY	0x10	16
SNAME	0x12	18
COLROW	0x13	19
STRANS	0x1A	26
MAG	0x1B	27
ANGLE	0x1C	28
CURVED[1]	0x56	86
FBMS[2]	0x58	88

Table 5.1: GDSII record types, with values in hexadecimal and decimal format. The latter is passed to **`Raith_library.writerec`** as the `rectype` argument.

Data type	Hex	Dec
No data present	0x00	0
Bit array (2 bytes)	0x01	1
2-byte signed integer	0x02	2
4-byte signed integer	0x03	3
4-byte float[3]	0x04	4
8-byte float	0x05	5
ASCII string	0x06	6

Table 5.2: GDSII data types, with values in hexadecimal and decimal format. The latter is passed to **`Raith_library.writerec`** as the `datatype` argument.

[3] The Raith CURVED element record type is not part of the GDSII specification. It is used by the Raith software to denote arc, ellipse, and circle elements.

[3] The Raith FBMS element record type is also not part of standard GDSII. It is used by the Raith software to denote fixed beam moving stage exposure.

[3] The 4-byte float data type is listed as unused in the GDSII Stream Format Manual v6.0.

5.4.6 **`Raith_library.writehead`** *method*

Description

Write GDSII library header records

Syntax

```
Raith_library.writehead(FileID,name)
```

Arguments

`FileID` Integer file identifier obtained from MATLAB's **`fopen`** function

`rectype` GDSII library name, without .csf extension (string)

Note

This method writes the HEADER, BGNLIB, LIBNAME, and UNITS records. The current system time is used for the BGNLIB record, a ".csf" is appended to `name` for the LIBNAME record, and 1 μm and 1 nm are used for the user and database units, respectively, in the UNITS record.

Example

```
% Open a file for writing
FileID=fopen('test.csf','w');
% Write GDSII header information
Raith_library.writehead(FileID,'test');
```

5.4.7 **`Raith_library.writebeginstruct`** *method*

Description

Write GDSII records to begin a structure

Syntax

```
Raith_library.writebeginstruct(FileID,name)
```

Arguments

`FileID` Integer file identifier obtained from MATLAB's **`fopen`** function

`name` Name of structure (string)

Note

This method writes the BGNSTR and STRNAME records. The current system time is used for BGNSTR.

Example

```
% Open a file for writing
FileID=fopen('test.csf','w');
Raith_library.writebeginstruct(FileID,'waveguide');
```

5.4.8 **Raith_library.writeelement** *method*

Description

Write GDSII element records

Syntax

```
Raith_library.writeelement(FileID,element)
```

Arguments

`FileID`	Integer file identifier obtained from MATLAB's **`fopen`** function
`element`	`Raith_element` object describing element

Note

The GDSII record types written vary according to the type of element.

Example

```
% Open a file for writing
FileID=fopen('test.csf','w');
% Define an element
E=Raith_element('path',0,[0 1 1;0 0 1],0.2,1);
Raith_library.writeelement(FileID,E);
```

5.4.9 **Raith_library.writeendstruct** *method*

Description

Write GDSII record to end a structure

Syntax

```
Raith_library.writeendstruct(FileID)
```

Arguments

`FileID`	Integer file identifier obtained from MATLAB's **`fopen`** function

Note

This method writes the ENDSTR record, which has no parameters.

Example

```
% Open a file for writing
FileID=fopen('test.csf','w');
Raith_library.writeendstruct(FileID);
```

5.4.10 **`Raith_library.writeendlib`** *method*

Description

Write GDSII record to end a library

Syntax

```
Raith_library.writeendlib(FileID)
```

Arguments

`FileID` Integer file identifier obtained from MATLAB's **`fopen`** function

Note

This method writes the ENDLIB record, which has no parameters.

Example

```
% Open a file for writing
FileID=fopen('test.csf','w');
Raith_library.writeendlib(FileID);
```

6
The `Raith_positionlist` class

Class overview: `Raith_positionlist`

Properties (public)

`library` `Raith_library` object containing all structures
`csf_path` Path of GDSII library on Raith computer
`WF` Writefield dimensions
`chipUV` Size of rectangular chip (specimen)
`poslist` Structure array of positionlist entries

Methods

`append` Append `Raith_structure` object to positionlist
`plot` Plot entire positionlist as filled polygons
`plotedges` Plot entire positionlist as unfilled polygons
`plotWA` Plot working areas of all structures in positionlist
`plotWF` Plot first writefields of all structures in positionlist
`centre` Centre current positionlist entries on chip
`shift` Shift current positionlist entries on chip
`writepls` Output Raith positionlist (.pls) file

Raith_positionlist objects define positionlists: a sequential list of instructions to write a structure defined in a GDSII hierarchy at a certain position on the chip. The **`Raith_positionlist.writepls`** method outputs a Raith positionlist (.pls) file which can be used by the Raith beamwriting software without any additional modification. As an aid to chip layout, the structures, working areas, and writefields of the entire positionlist can be plotted.

6.1 Properties

`library`: `Raith_library` object containing all structures to be referenced in positionlist

csf_path: Full path of GDSII hierarchy (.csf) file, as found on the Raith computer

WF: Writefield size; 1 × 2 vector [$size_u$ $size_v$] (μm)

chipUV: Size of rectangular chip; 1 × 2 vector [$size_u$ $size_v$] (mm)

poslist: Structure array of positionlist entries, containing fields **name**, **uv_c**, **DF**, **WA**, and **layers**; see 6.3.1 for a description of these fields

6.2 *Constructor*

```
P=Raith_positionlist(library,csf_path,WF,chipUV)
```

By default, the arguments are checked for correctness (typing, allowed values, size) before being assigned, whether the `Raith_positionlist` object is created with a constructor or these four properties are amended individually.

Arguments

`library`	`Raith_library` object containing all structures to be placed in positionlist
`csf_path`	Full path of GDSII hierarchy file, as found on Raith computer
`WF`	Writefield size; 1 × 2 vector [$size_u$ $size_v$] (μm)
`chipUV`	Size of rectangular chip; 1 × 2 vector [$size_u$ $size_v$] (mm)

Example

Given the `Raith_structure` object `S` defined in §4.2:

```
% Racetrack resonator defined in Raith_structure object S
lbl=Raith_structure('radius_label',Raith_element('text',0, ...
    [0 0],2,0,[1 0],'3 um',1.5));
L=Raith_library('resonators',[S lbl]);
% Postionlist for a 5 mm x 5 mm chip, 100 um writefield
P=Raith_positionlist(L,'F:\Raith\resonators.csf', ...
    [100 100],[5 5]);
```

6.3 *Methods*

6.3.1 ***Raith_positionlist.append*** *method*

Description

Append `Raith_structure` object to positionlist.

Syntax

```
append(name,uv_c,DF,WA)
append(name,uv_c,DF,WA,layers)
```

Arguments

- `name` `Raith_structure` object name (as found in GDSII library)
- `uv_c` Centre of first writefield of structure; 1 × 2 vector [u_c v_c] (mm)
- `DF` Overall dose factor scaling for entire structure
- `WA` Working area of structure; 1 × 4 vector [$u_{\min}$ $v_{\min}$ $u_{\max}$ $v_{\max}$] (μm)
- `layers` Vector of layers to expose [optional]; defaults to all layers present in structure elements

Note

The units of the arguments reflect how they are stored in the positionlist: `uv_c` is in mm and `WA` is in μm. The working area coordinates are defined with respect to the origin of the `Raith_structure` object. As in the Raith software, the bottom-left corners of the working area and the writefield are aligned; as such, `uv¸` specifies a point half a writefield width above and to the right of the bottom-left corner of the working area. One design paradigm which simplifies the positioning of structures contained in a single writefield is to define them centred on the origin, then specify a working area—also centred on the origin—which is the same size as the writefield (see following Example). In this case, `uv_c` will correspond to the origin of the structure.

Example

Given the `Raith_library` and `Raith_positionlist` objects `L` and `P`, respectively, defined in the above "Constructor" section:

```
% Write a racetrack resonator and label near the top-left
% corner of the chip (100 um WF)
P.append('racetrack',[1 4],1,[-50 -50 50 50]);
P.append('radius_label',[1 3.996],1,[-50 -50 50 50]);
```

6.3.2 ***Raith_positionlist.plot*** *method*

Description

Plot all structures in positionlist with Raith dose factor colouring, with chip outline. Elements are displayed as filled polygons, where applicable (`'polygon'`; `'path'` with non-zero **`data.w`**;

'arc', 'circle', and 'ellipse' with empty **data.w**; 'text'). All elements in the structures are plotted, regardless of **data.layer** value. The full hierarchy of structures including 'sref' or 'aref' elements are displayed if all structures being referenced are present in the library contained in the Raith_positionlist object.

Syntax

```
plot
```

Arguments

(None)

Note

Calling **Raith_positionlist.plot** sets the axis scaling to equal; all plotted objects therefore appear with correct scaling. The axes are in units of μm.

Example

Given the Raith_positionlist object defined in §6.3.1, above:

```
P.plot;  % Structures are too small to see at this scale
axis([990 1010 3990 4010]);  % Zoom to structures
```

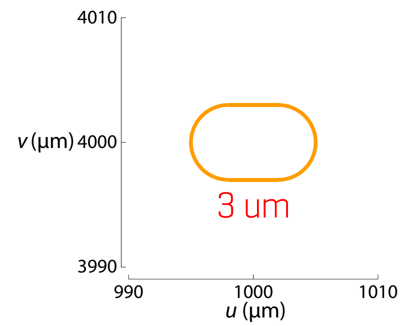


Figure 6.1: Positionlist plotted using the **Raith_positionlist.plot** method

6.3.3 *Raith_positionlist.plotedges method*

Description

Plot outlines of all structures in positionlist with Raith dose factor colouring, with chip outline. Elements are displayed as unfilled polygons, where applicable ('polygon'; 'path' with non-zero **data.w**; 'arc', 'circle', and 'ellipse' with empty **data.w**; 'text'). All elements in the structures are plotted, regardless of **data.layer** value. The full hierarchy of structures including 'sref' or 'aref' elements are displayed if all structures being referenced are present in the library contained in the Raith_positionlist object.

Syntax

```
plotedges
```

Arguments

(None)

Note

Calling **Raith_positionlist.plotedges** sets the axis scaling to equal; all plotted objects therefore appear with correct scaling. The axes are in units of μm.

Example

Given the `Raith_positionlist` object defined in §6.3.1, above:

```
P.plotedges;  % Structures are too small to see at this scale
axis([990 1010 3990 4010]);  % Zoom to structures
```

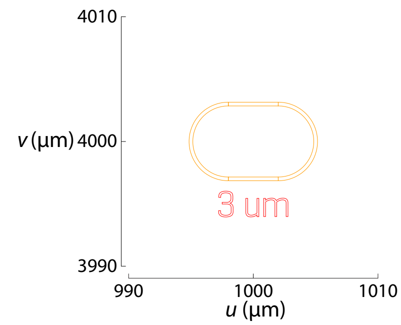


Figure 6.2: Positionlist plotted using the **Raith_positionlist.plotedges** method

6.3.4 *Raith_positionlist.plotWA method*

Description

Plot working area of all structures in positionlist in dotted blue lines, with chip outline.

Syntax

```
plotWA
```

Arguments

(None)

Note

Calling **Raith_positionlist.plotWA** sets the axis scaling to equal; all working areas therefore appear with correct scaling.

Example

To illustrate the alignment of working areas and writefields, this example specifies working areas which are smaller than the writefield. Assume the `Raith_library` and `Raith_positionlist` objects `L` and `P`, respectively, are defined as in §6.2; to preserve the relative alignment of the racetrack and the label, `uv_c` must be changed to accommodate the difference in WA:

```
P.append('racetrack',[1 4],1,[-10 -10 20 10]);
P.append('radius_label',[0.99 4.001],1,[-20 -5 10 5]);
P.plot;  % Plot structures
P.plotWA;  % Plot working areas
axis([935 985 3945 3975]);  % Zoom to structures
```

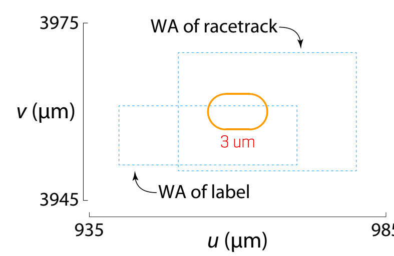


Figure 6.3: Working areas in positionilst plotted using the **Raith_positionlist.plotWA** method

6.3.5 *Raith_positionlist.plotWF method*

Description

Plot writefields of all structures in positionlist in dotted green lines; writefield centres are marked with a + sign.

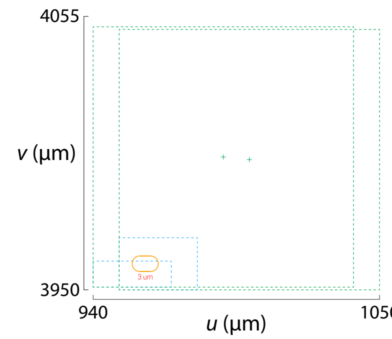


Figure 6.4: Working areas and writefields in positionilst plotted using the **Raith_positionlist.plotWA** and **Raith_positionlist.plotWF** methods

Syntax

```
plotWA
```

Arguments

(None)

Note

Calling **Raith_positionlist.plotWF** sets the axis scaling to equal; all working areas therefore appear with correct scaling.

Example

Given all objects defined as in the above "**Raith_positionlist.plotWA** method" Example:

```
P.plot;  % Plot structures
P.plotWA;  % Plot working areas
P.plotWF;  % Plot writefields
axis([940 1050 3950 4055]);  % Zoom to structures
```

6.3.6 *Raith_positionlist.centre method*

Description

Centre current positionlist entries on the chip, preserving relative spacing, with the option of matrix-copying them.

Syntax

```
centre
centre(mbyn)
```

Arguments

`mbyn` Number of rows and columns of the matrix of sub-chips [optional]; 1×2 vector $[m\ n]$

Note

If called with no argument, the current positionlist entries are shifted such that the overall pattern (as defined by the working areas) are centred both vertically and horizontally on the chip. If called with the optional `mbyn` argument, the chip is divided into an m-by-n matrix of equal-sized rectangular sub-chips, and the positionlist entries are centred as described above in each sub-chip. In either case, the **poslist** property is rewritten; there is no built-in way of undoing this operation.

Example

Given the `Raith_positionlist` object defined in §6.3.4, above:

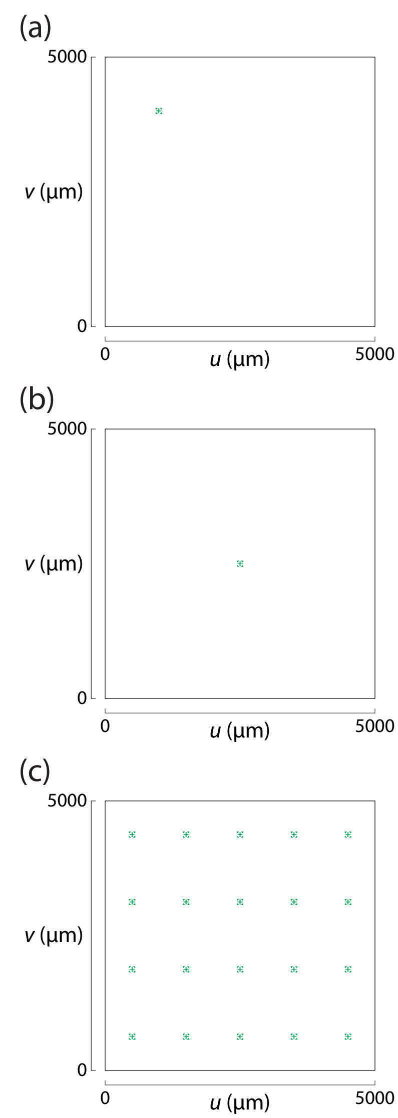


Figure 6.5: Position of writefields (a) before centring, (b) after issuing `P.centre`, and (c) after issuing `P.centre([4 5])`

```
P.plotWF;  % Before centring
P.centre;
P.plotWF;  % After centring
P.centre([4 5]);
P.plotWF;  % After matrix—copying
```

6.3.7 **Raith_positionlist.shift** *method*

Description

Shift current positionlist entries on the chip, preserving relative spacing.

Syntax

```
shift(uv_sh)
```

Arguments

`uv_sh` Relative shift of the new positionlist entries with respect to their current positions (mm); 1×2 vector $[u_{\mathrm{sh}}\ v_{\mathrm{sh}}]$

Note

The **poslist** property is rewritten when **Raith_positionlist.shift** is invoked; there is no built-in way of undoing this operation.

Example

Given the `Raith_positionlist` object defined in §6.3.4, above:

```
P.plotWF;  % Before shifting
P.shift([1 -2]);
P.plotWF;  % After shifting
```

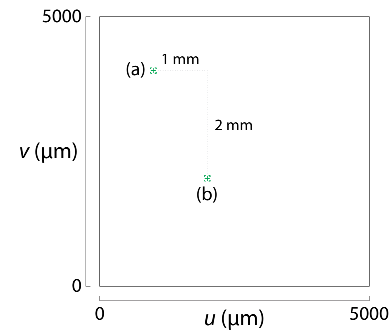


Figure 6.6: Position of writefields (a) before shifting, (b) after issuing `P.shift([1 -2])`

6.3.8 **Raith_positionlist.writepls** *method*

Description

Syntax

```
writepls
writepls(filepath)
```

Arguments

`filepath` Full path of positionlist file to be written, including .pls extension [optional]

Note

If called without argument, a ⟨**library.name**⟩*.pls* file is written to the current directory.

Example

Given the `Raith_positionlist` object defined in §6.3.4, above:

```
P.writepls;

Writing C:\Users\Public\Documents\resonators.pls...
Positionlist resonators.pls successfully written.
```

7
Extended techniques

THE NORMAL USAGE of the Raith_GDSII toolbox is explained in the foregoing sections of this document. In this section, we describe extended techniques which may be used to save time and/or memory—two concerns which can become limiting factors when generating patterns consisting of very large numbers of elements. The cost of these extended techniques includes the loss of Raith_element, Raith_structure, and Raith_library data checking and all plotting functionality, so they are best used in the final stages of the design process.

7.1 Disabling data checking

BY DEFAULT, the properties of Raith_element, Raith_structure, and Raith_library objects are checked for correctness (typing, allowed values, size) before being assigned or altered, ensuring that the resulting objects may be plotted and used to generate GDSII and positionlist files without subsequent errors. By disabling data checking, Raith_element, Raith_structure, and Raith_library objects may be created more quickly, at the risk of encountering more cryptic error messages downstream.

Data checking may be disabled by declaring a global variable checkdata and assigning it a value of logical zero (Boolean false).

Example

Creating a series of random Raith_element 'path' objects with and without data checking, resulting in a greater than $4\times$ reduction in computation time:

```
% With data checking
tic;
for k=1:1000
E=Raith_element('path',0,rand(2,1000),0,1);
end
t_Check=toc;
```

```
% Without data checking
global checkdata
checkdata=false;
tic;
for k=1:1000
E=Raith_element('path',0,rand(2,1000),0,1);
end
t_noCheck=toc;

t_Check/t_noCheck

ans =

    4.4510
```

Note

As a global variable, `checkdata` will remain accessible to any functions declaring it as global, even if a `clear` command is issued in the current workspace. To remove `checkdata` completely (i.e., restoring the default state of enabled data checking), use `clear global checkdata`.

7.2 *Defining patterns using MATLAB structures*

The time and memory overhead associated with creating `Raith_element` and `Raith_structure` objects can be further reduced—at the expense of losing all plotting functionality—by using MATLAB structures [1] with fields that match the `Raith_element` and `Raith_structure` properties, both in name and in type. "Elements" and "structures" defined in this way can be used by `Raith_library` and `Raith_positionlist` objects to generate .csf and .pls files, provided data checking is disabled (see §7.1, above). Refer to §3 and §4 for descriptions of `Raith_element` and `Raith_structure` class properties.

[1] That is, instances of the built-in `struct` class. See the MATLAB User Guide ▶ Programming Fundamentals ▶ Classes (Data Types) ▶ Structures.

Example

Creating an array of microrings with varying widths:

```
% Cell array of ring widths (um)
w=num2cell(0.1:0.05:0.5)';

% Cell array of disk centres:  15 um spacing in u, v=0
uv_c=num2cell(15*(0:length(w)-1)'*[1 0],2);

% 'circle' Raith_element objects have properties
% 'type', and 'data', the latter having fields 'layer',
% 'uv_c', 'r', 'w', 'N', and 'DF', so we create a struct
% array with these fields
data=struct('layer',0,'uv_c',uv_c,'r',5,'w',w,'N',100,'DF',1.3);
E=struct('type','circle','data',num2cell(data));

% Raith_structure objects have properties
```

```
% 'name', 'elements', and 'reflist'
S.name='rings';
S.elements=E;
S.reflist=[];

global checkdata;
checkdata=false;
L=Raith_library('ringarray',S);
L.writegds;
```

```
Skipping all data checking.
Writing C:\Users\Public\Documents\ringarray.csf...
     Header information
     Structure 1/1:  rings
GDSII library ringarray.csf successfully written.
```

Note

In the above Example, the `data` and `E` variables were created using MATLAB's **`struct`** function, which allows a structure array to be output if any of the value inputs are cell arrays; the same result could have been produced using a `for` loop.

7.3 *"On-the-fly" GDSII writing*

IN SITUATIONS WHERE the number of elements in the pattern is so large that there is insufficient memory to keep them all in the MATLAB workspace simultaneously, it is still possible to output a GDSII file by generating elements and writing them sequentially; this procedure uses the static `Raith_library` methods described in §§5.4.6–5.4.10 to write GDSII records directly[2]. The following general format must be observed:

```
Raith_library.writehead   (Header information)
    Raith_library.writebeginstruct   (Begin first structure in library)
        Raith_library.writeelement   (First element in structure)
        ⋮
        Raith_library.writeelement   (Last element in structure)
    Raith_library.writeendstruct   (End first structure)
    ⋮
    Raith_library.writebeginstruct   (Begin last structure in library)
        Raith_library.writeelement   (First element in structure)
        ⋮
        Raith_library.writeelement   (Last element in structure)
    Raith_library.writeendstruct   (End last structure)
Raith_library.writeendlib   (End library)
```

When writing GDSII files "on the fly", the user is responsible for ensuring that all structures referenced by `'sref'` and `'aref'` elements are in fact present in the library.

[2] Hard-core enthusiasts should note that it is possible to write an entire arbitrary GDSII file using only the **`Raith_library.writerec`** method; such a feat is beyond the scope of this User Guide.

Example

Creating the same array of microrings as in the above Example §7.2 "on the fly":

```
% Vector of ring widths (um)
w=0.1:0.05:0.5;

% Matrix of disk centres:  15 um spacing in u, v=0
uv_c=15*(0:length(w)-1)'*[1 0];

% Open file for writing binary data
FileID=fopen('C:\Users\Public\Documents\ringarray.csf','w');

Raith_library.writehead(FileID,'ringarray');
Raith_library.writebeginstruct(FileID,'rings');

% Loop through all elements in structure; only one
% Raith_element object is in memory at any given time.
for k=1:length(w)
E=Raith_element('circle',0,uv_c(k,:),5,w(k),100,1.3);
Raith_library.writeelement(FileID,E);
end

Raith_library.writeendstruct(FileID);
Raith_library.writeendlib(FileID);

fclose(FileID);
```

Note

In the above Example, the `data` and `E` variables were created using MATLAB's **`struct`** function, which allows a structure array to be output if any of the value inputs are cell arrays; the same result could have been produced using a `for` loop.

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