CMC/SCM

Protolyne:

A Micromachining Process for Microfluidic Applications

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V1.0

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Revision History

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1. Introduction

1.1. About the Protolyne Technology

Protolyne is a glass chip prototyping technology by Micralyne Inc. The Protolyne technology enables users to develop a network of bulk-micromachined channels and features with eight reservoirs in glass substrate for microfluidic applications.

Protolyne has many applications in the biomedical field: cell manipulation, genetic analysis, medical diagnostics, protein and peptide analysis, microchemical analysis, drug delivery, and DNA analysis to name a few.

Clients receive five chips when they submit their design to Micralyne. The main features of this technology are:

- The chip consists of two pieces of Schott Borofloat glass which are fusion-bonded together; the dimensions of each glass piece is 16 X 95 X 1.1 mm.
- The top plate has eight 2-mm diameter reservoirs (holes for fluidic connections); their layout is fixed.
- The bottom plate has the client's pattern (fixed 20 µm etch depth) and the etch pads bulk-etched into it. These etch pads consist of 1.5 mm diameter circular pads to be connected to the etched channels and are also used to align the top and bottom plates.

Figure 1 shows top and cross-sectional views of Protolyne, highlighting the two pieces of glass and the locations of reservoirs.

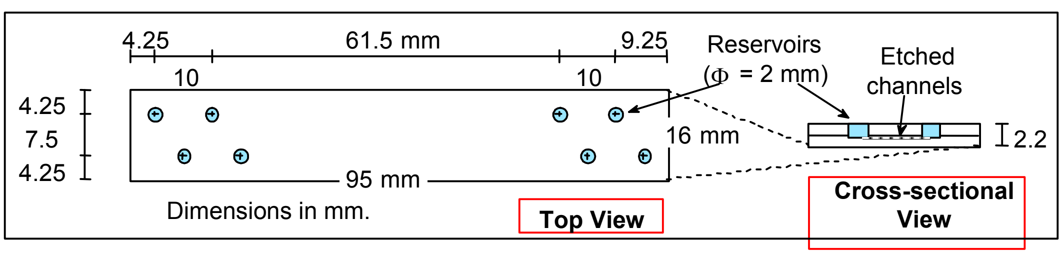


Figure 1: Top and Cross-sectional Views of Protolyne

1.2. About this Document

This document is intended to help researchers at Canadian universities access the Protolyne prototyping technology through CMC and provides new Protolyne users with information on the technology file and design rules.

The layout tools demonstrated in this document are MEMSPro from MEMSCAP and L-Edit from Tanner EDA. However, users are not restricted to these tools specifically.

The technology file described in this document uses colour in defining its layers. Therefore, this material is best viewed in softcopy or using a high-quality colour hardcopy.

1.3. User Prerequisites

This document is intended for graduate students and professors at Canadian universities that are members of CMC, and who have registered with CMC. For more information on how to register, visit CMC's Web site at:
http://www.cmc.ca/about/membership/

Additionally, users of this document should be familiar with a layout tool such as MEMSPro/L-Edit or the Cadence Virtuoso layout editor, as this document does not provide step-by-step instructions on how to navigate such a tool.

2. About the Technology File

The technology file provides a template for users when designing their Protolyne chip using MEMSPRO or L-Edit layout tools; it helps to ensure that the design will conform to manufacturing requirements. The main component of the technology file is the *layer.* These layers represent different fabrication steps of the Protolyne fabrication process, enabling designers to draw the desired features in the layout file of the microfluidic design.

The Protolyne technology file described in this document is available from CMC's Web site at the following link:
http://www.cmc.ca/about/program/beams.html#protolyne_fab

In this section, we will familiarize microfluidic designers with this technology file so that they can start designing their innovative Protolyne chip. The following describes the layers that will be of the most interest:

- ***Glass Substrate:*** This represents the bottom glass plate and is represented in a grey outline colour for both 2-D and 3-D models.
- ***Glass Etch****(GDS II # 46)****:*** This layer is used to represent bulk-etched microfeatures (channels, chambers, etc.) in the glass substrate. It represented is in a solid red colour.
- ***Reservoir Etch*** *(GDS II # 49)****:*** This layer is used to etch 1.5-mm diameter circular etch pads on the glass substrate to align the upper and lower glass plates. Its is represented in a solid blue colour.
- ***Cell Outline Layer****(GDS II # 50)****:*** The outer edges of the top and bottom glass pieces are represented by this layer. For 3-D model generation, this layer is used to represent the top glass plate. For 2-D layout, this layer is represented by a grey outline colour. For 3-D models, the layer is represented by a purple color.
- ***Chip Feature Outline*** *(GDS II # 58)****:*** This is not a physical layer, but a box within which all design features must fit. This layer is represented by a purple outline.
- ***Reservoir*** *(GDS II # 59):* This layer shows the outline of the 2-mm diameter holes in the top plate. It is represented by a dark blue outline color.
- ***3-D Fill:*** This layer is not used in 2-D layout and is only used when extracting the third dimension model.

Upon opening the technology file in L-Edit or MEMSPRO, users can see the layout of the Protolyne chip as shown in Figure 2.

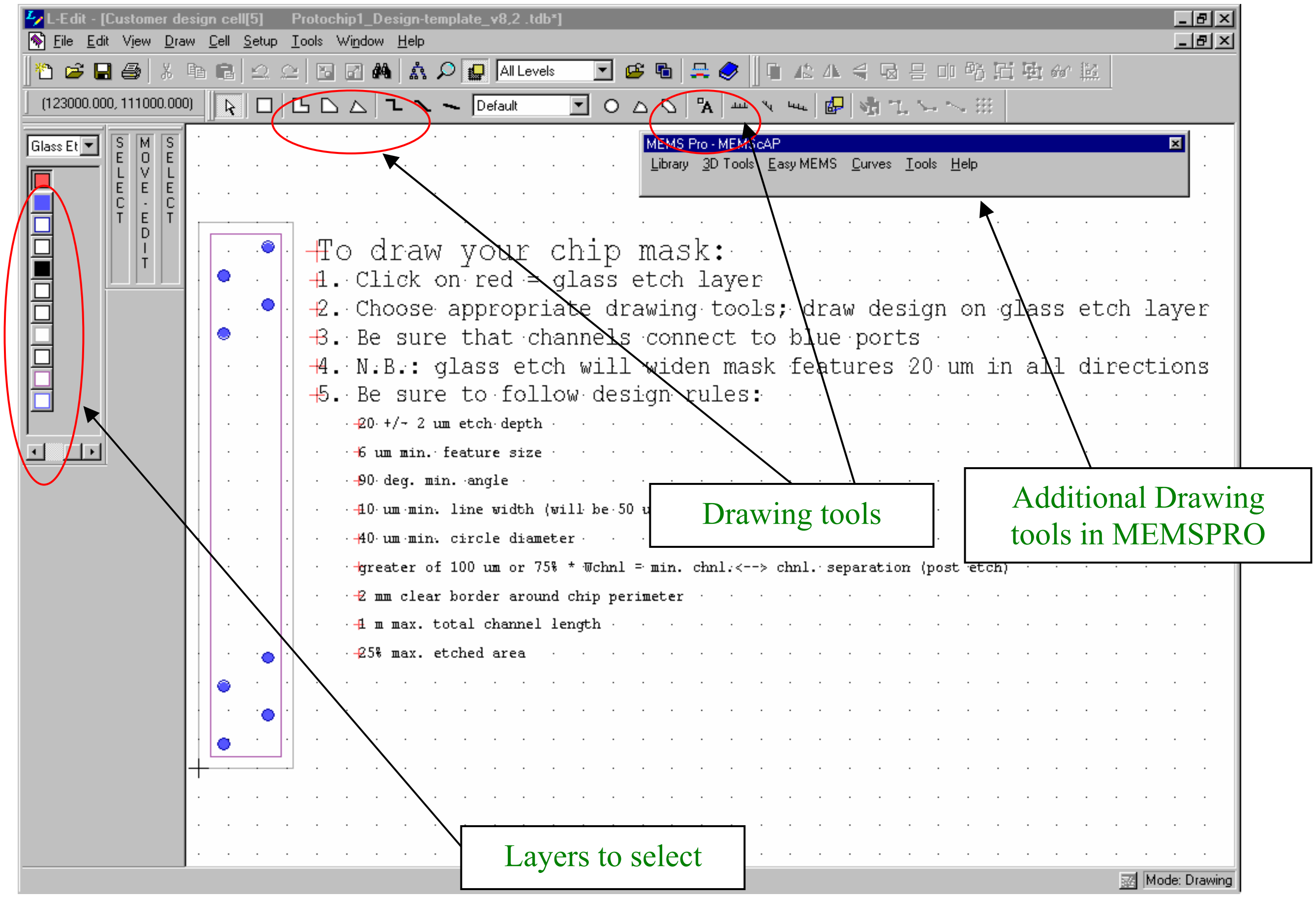


Figure 2: Protolyne Technology File

This technology file includes the layout of the chip defined by the layers *Cell Outline*, *Chip Feature Outline, Reservoir Etch and Reservoir*. While creating a 2-D layout, the designer can also position the chip horizontally as shown in Figure 3.

About the technology file:

- The location of eight reservoir holes (both on top and bottom glass plates) are fixed.
- Each reservoir hole is represented by a 1.5-mm diameter etch pad on the bottom plate and a 2-mm diameter hole on the top glass plate.
- *Reservoir Etch* and *Reservoir* layers are used to represent these two holes respectively.
- These holes are numbered in the sequence shown in Figure 4.
- The designer is required to use only *Glass Etch* layer to design microchannels.
- The *Glass Etch* layer is used to draw the network of micro channels ≥ 20 µm on the bottom glass plate.

Notice the various layers and drawing tools shown in Figures 2 & 3. In addition to design tools available in L-Edit, MEMSPro user can also use the command CURVE to draw SPLINE and ELLIPSE objects.

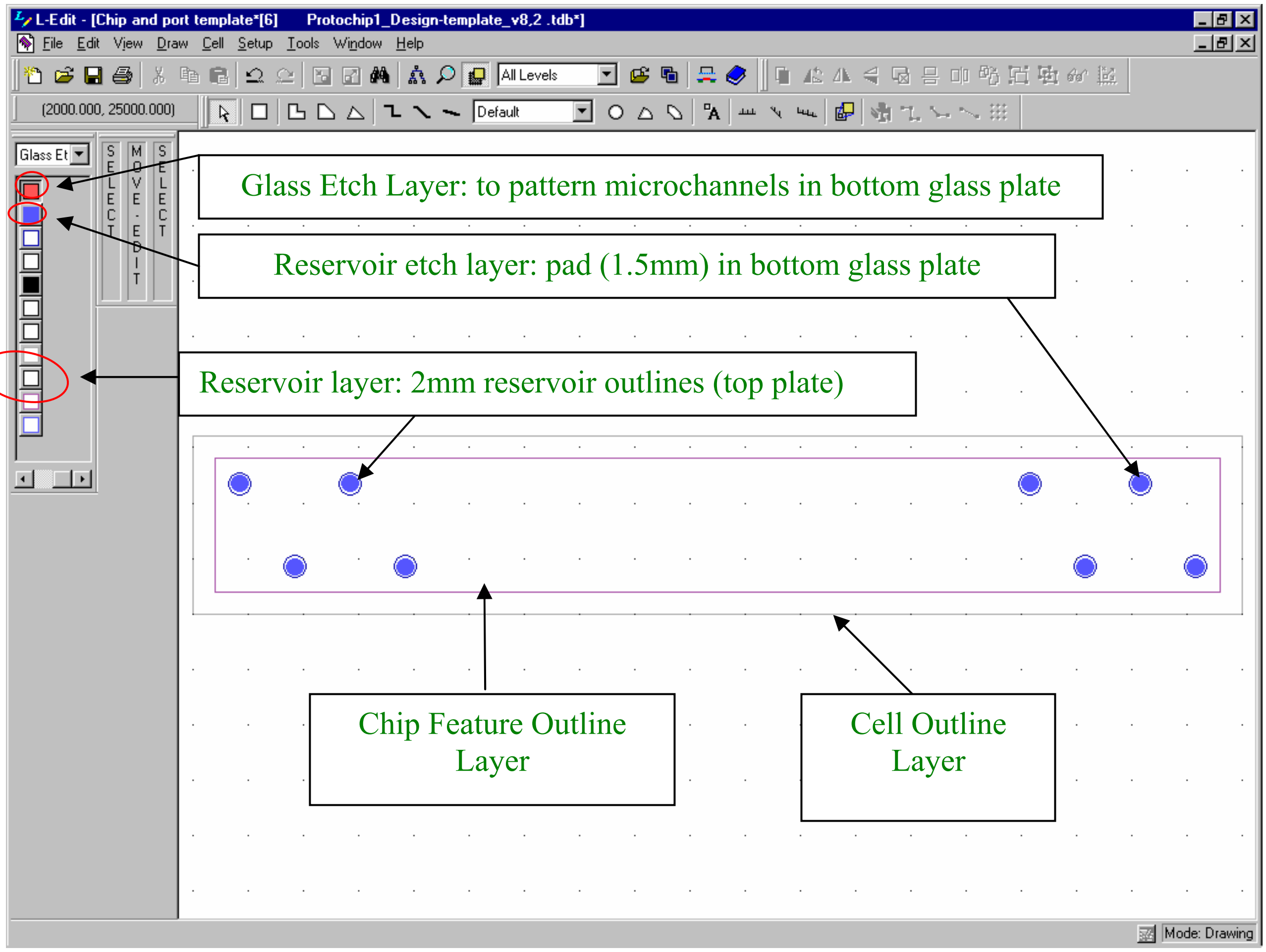


Figure 3: Horizontal Positioning of 2-D Layout

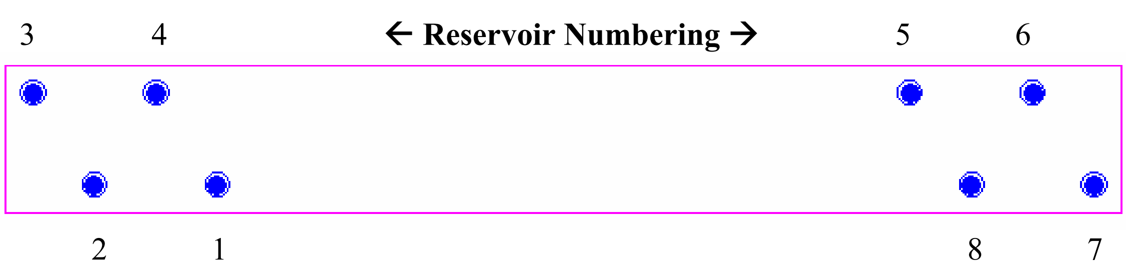


Figure 4: Location of Reservoir Holes on the Top and Bottom Plates (Reservoir Etch or Reservoir Layers)

3. Design Rules

The design example shown in Figure 5 illustrates how microchannels can be designed on a Protolyne chip. This chapter uses this example to describe different design rules which constrain designers to certain limitations when designing their network of microchannels. The rules represent various lithographic limitations of the process and ensure correct fabrication of the chip. Designer must avoid violating these design rules.

The design example incorporates a simple pattern with a few fluidic features, drawn in L-Edit/MEMS Pro. For illustrative purposes, it also includes features that do not conform to Protolyne design rules. ***The design example is for demonstrative purposes only and a chip fabricated from this example may not be functional.***

The example shown in Figure 5, brings together two reagents in a Y-junction, where they mix along a meandering channel, react in a larger chamber, and finally are injected into and separated in a longer separation channel.

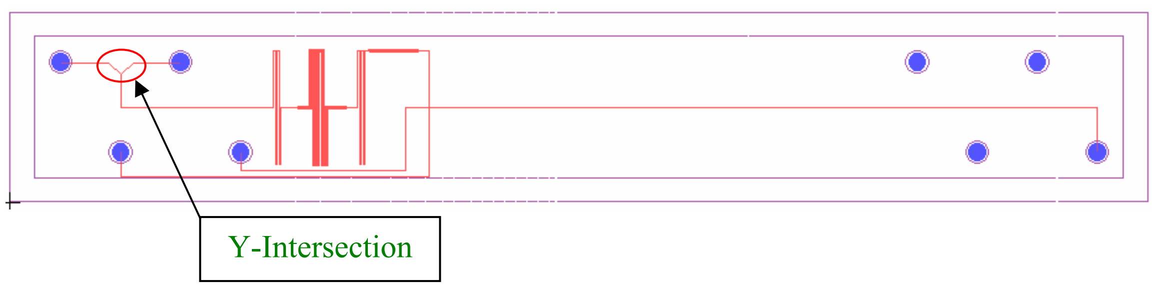


Figure 5: Example Layout for a Microfluidic Device

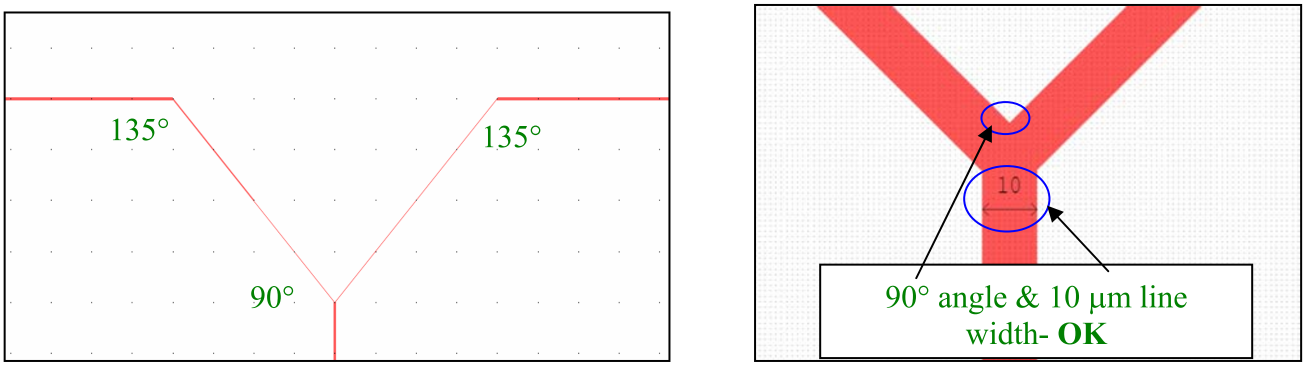
Some design rules can be checked automatically using the technology file (check your technology file using *DRC setup* command). Other rules must be implemented manually by the designer.

Rule 1: The internal acute angle between two microchannels must be ≥ 90°.

Figure 6 (a) shows an acceptable 90° Y-intersection (grid dots every 250 µm). Acute angles will be discussed in more detail later.

Rule 2: Line width must be ≥ 10 µm.

Figure 6 (b) is a closer view of the area (grid dots 1 µm). The minimum line width for *Etch Glass* layer is 10 µm, and is thus acceptable in this example.



(a) (b)

Figure 6: (a) The 90° Y-Channel. (b) Enlarged View of the Y-Channel

Rule 3: A line width of the *Glass Etch* layer will produce features 40 µm greater than specified in the layout.

Another consideration to bear in mind is the pre- and post-etch appearance of the features being designed (Figure 7). In the Y-intersection shown, each Y branch is 10 µm wide. During fabrication, wet chemical isotropic etching of the glass with hydrofluoric acid will begin with an opening exactly the shape of the Y above, and will remove 20 µm glass directly below and also beyond the edges in a curved pattern. This will result in 50-µm wide by 20-µm deep microchannels.

Note that the depth of the channels is fixed. The only way to change the size of the channel is using the width, which can be modified using the *Etch Glass* Layer.

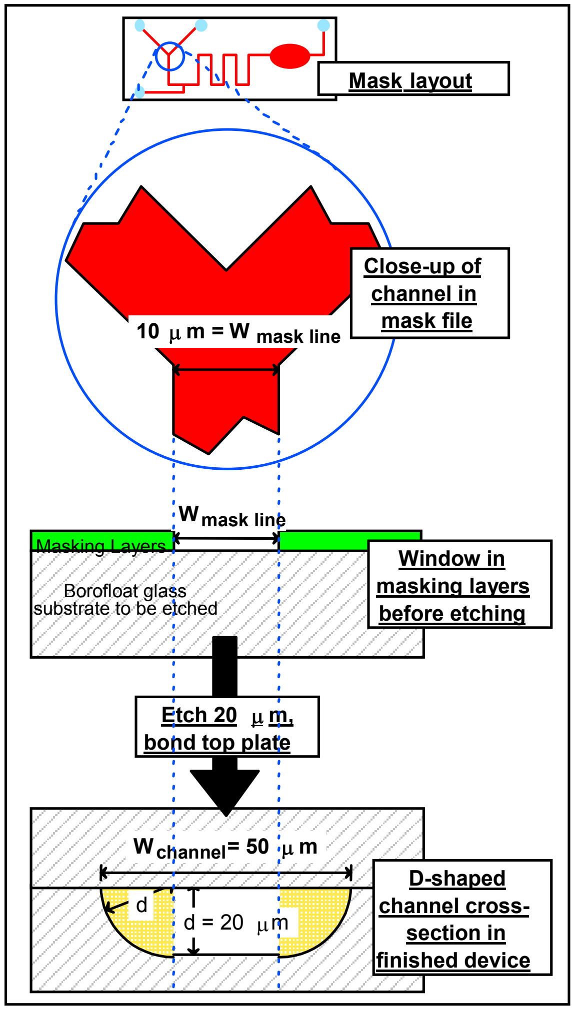


Figure 7: Pre and Post Appearance of the Feature Being Designed

Rule 4: Designs must maintain a 2-mm distance from the chip edge.

The view shown in Figure 8 illustrates several feature: the Y-intersection, three meandering sections, a wide reaction channel, and a cross intersection. Outside of the layout are two boundaries:

1. Outer boundary: the *Glass Substrate* layer, labeled *Chip footprint* in Figure 8, represents the actual outline (outer dimensions) of the Protolyne chip.
2. Inner Boundary: The inner boundary, represented by the *Chip Feature Outline* layer and labeled as *Layout* boundary in Figure 8, is the limit to which a microchannel feature may extend; microchannels outside of this boundary infringe upon the 2-mm minimum distance from the chip edge that must be maintained.

Note that the channels from the lower two (blue) reservoirs extend close to, but not beyond the layout boundary, and are thus acceptable.

Rule 5: Acute angles (45°) are only permitted outside of the feature drawn.

Figure 8 highlights the large rectangular reaction chamber (circled). With grid dots set at 25 µm, Figure 9 zooms in on the left edge the reaction chamber. The square chamber is 250 µm wide.

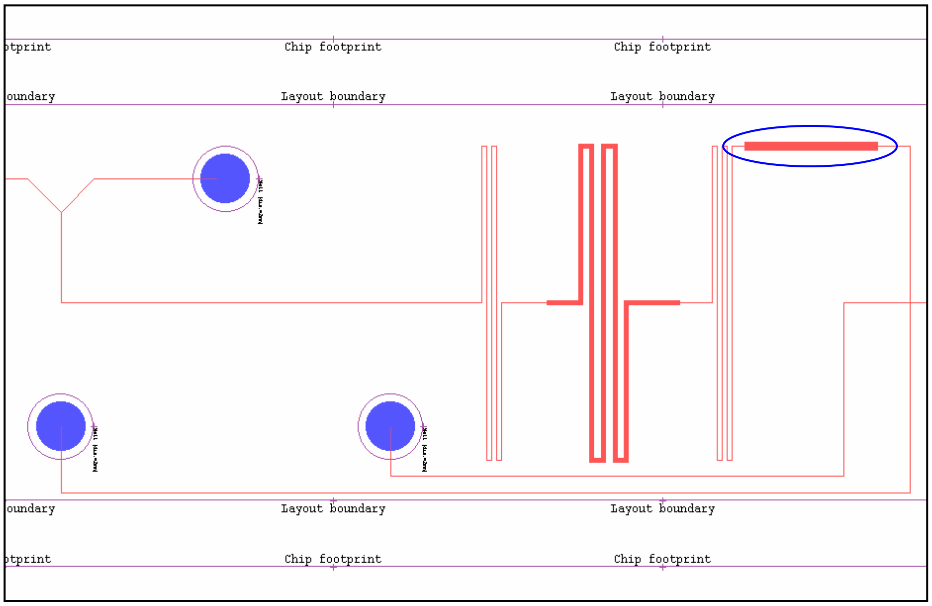


Figure 8: Details of Different Parts of the Design (Y-channel, Meander, Reaction Channel)

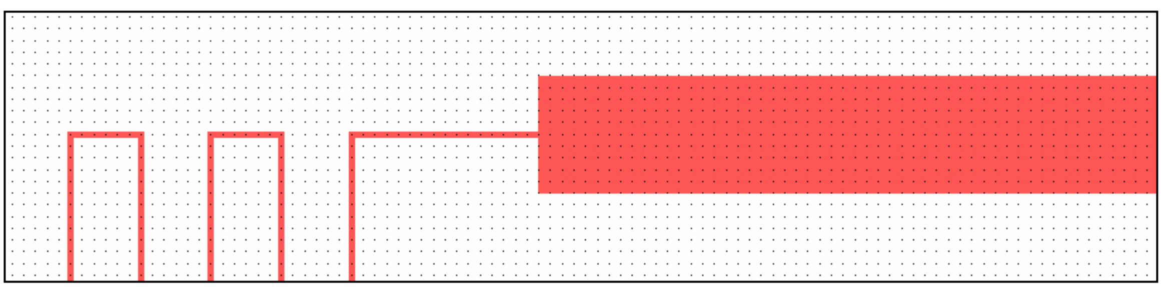


Figure 9: Enlarged View of Meander and Reaction Chamber Connection Area

An alternate design is shown in Figure 10 with an "inside" acute (45°) angle, which is not allowed, and an "outside" acute (45°) angle, which is permitted. Recall that inside and outside refer to whether the acute angle is inside or outside of the (red) feature drawn.

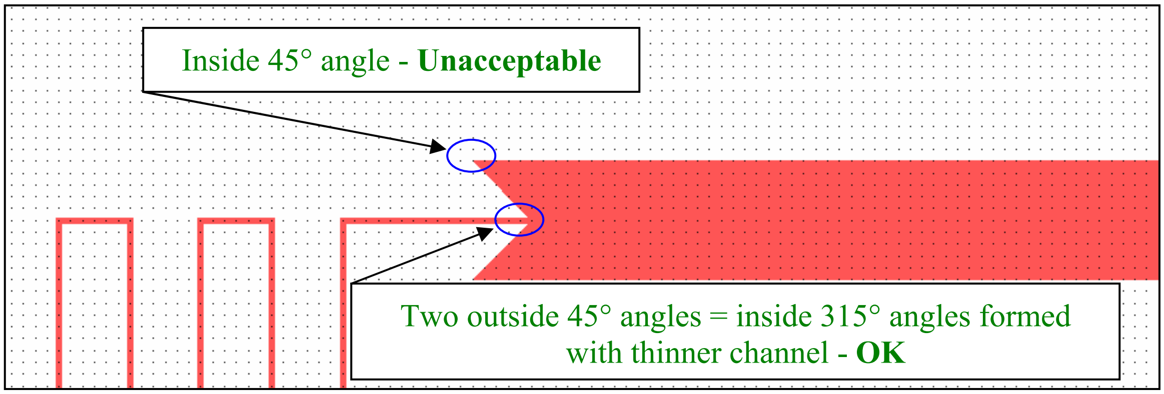
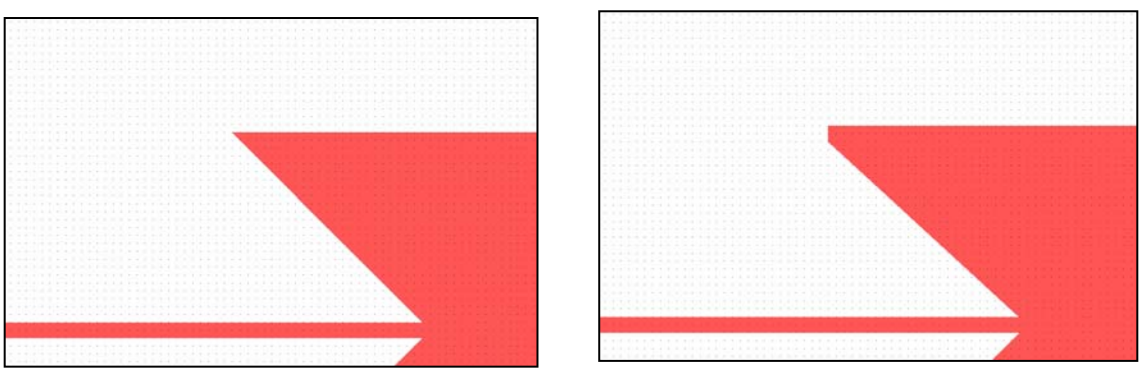


Figure 10: When Inside Acute Angles Are Less Than 90 Degrees

Rule 6: No line segment can be smaller than 6 μm.

If an acute angle were desired, the design could be modified slightly by 'blunting' the corner, as shown in Figure 11(b). Note that the new right-angle side added to the polygon must meet the minimum feature size of 6 μm; in this case, it is 10 μm (grid dots at 5 μm).



(a) (b)

Figure 11: (a) Unacceptable "Inside" Acute Angle
(b) Acceptable 10μm "Blunted" Corner

Figure 12 shows another example of angled microchannels, which illustrates how designers can avoid inside acute angles of less than 90 degrees.

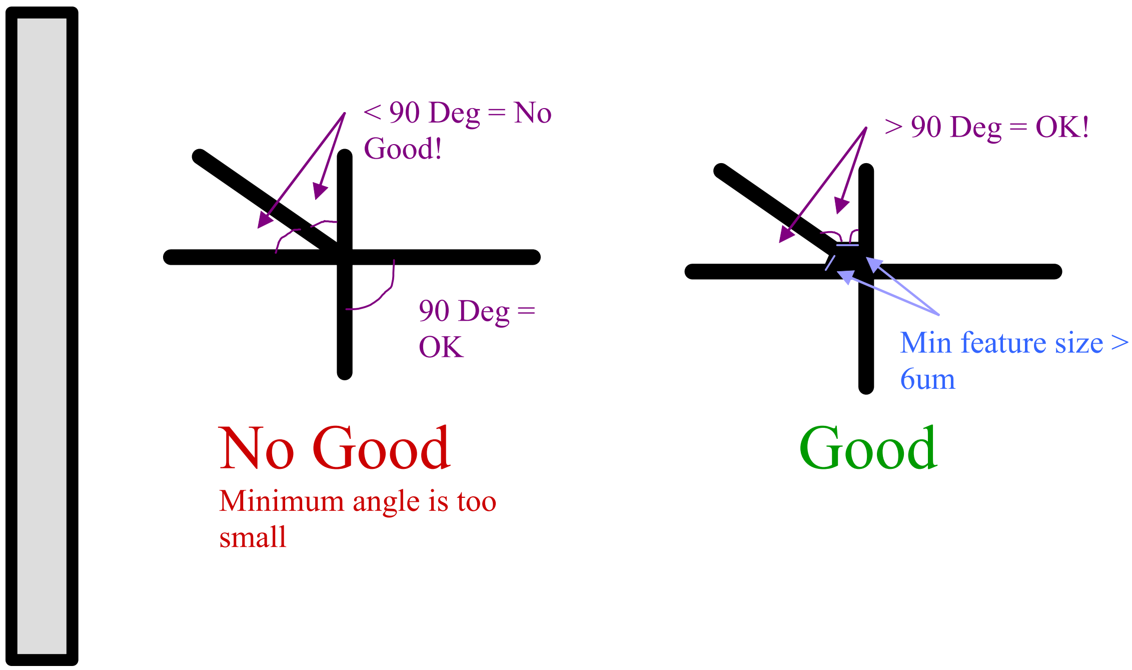


Figure 12: Minimum Feature Angle Should be 90 Degrees of More (Rule 1) Minimum Feature Size Should be 6μm or More (Rule 6)

Figure 13 describes another example, which shows two overlapping layers where an extended feature appears from the two overlapped objects. If this is desired then the minimum length of the feature should greater than 6 μm. Otherwise, it should be removed.

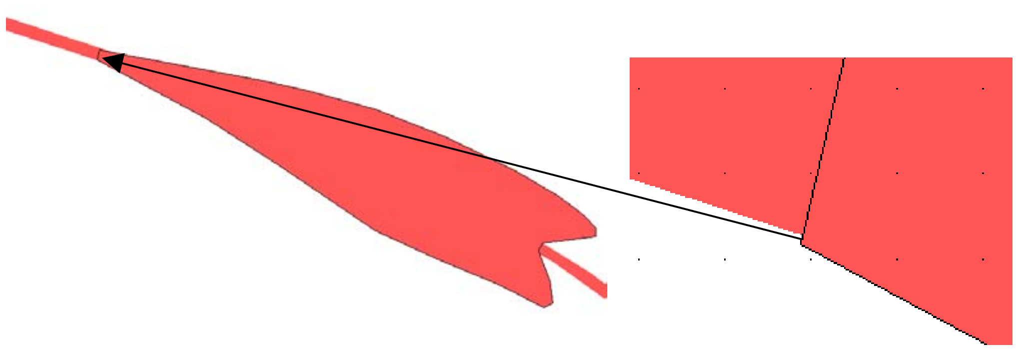
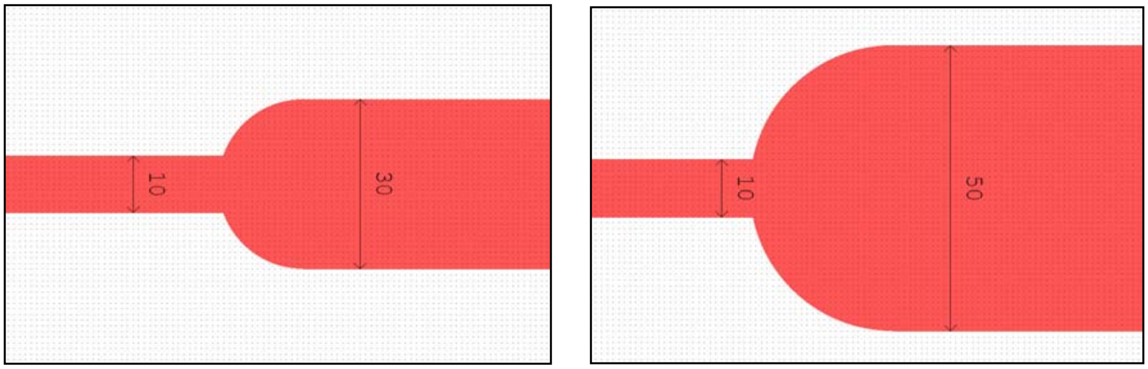


Figure 13: Extended Feature Appearing After the Overlapping of Two Layers

Rule 6: Diameter of a curve > 40 μm

Another variation on the reaction chamber in Figure 9, is a rounded entrance and exit (Figure 14). However, if the diameter of any such curve is ≤ 40 μm, the object is unacceptable.



(a) (b)

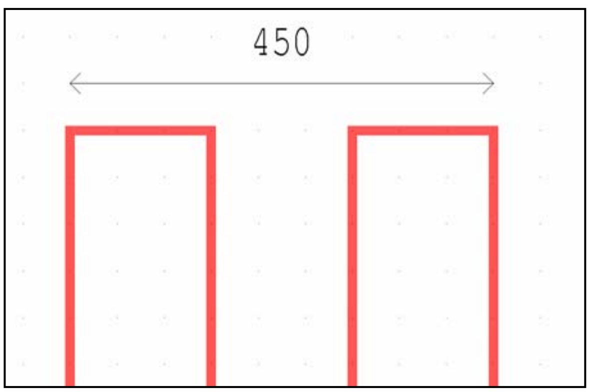
Figure 14: (a) Unacceptable 30μm Circle Feature
(b) Acceptable 50 μm Circle Feature

Rule 7: The separation of the closest edges must be the greater of 100 μm or 75% of the etched channel width.

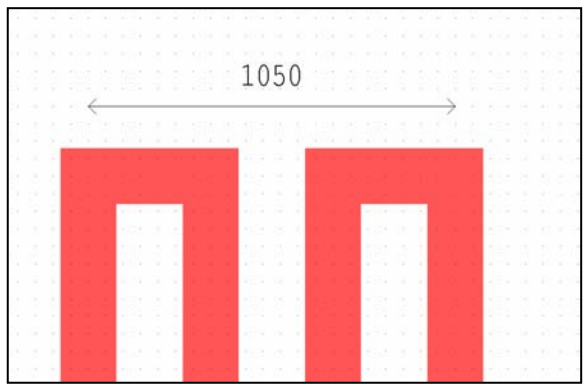
Let’s examine the channel meanders. For an etched channel width of up to 133 μm (line width of up to 93 μm on the mask), the closest edges must be 100 μm apart. For an etched channel width (y) that is greater than 133 μm, the channels must be separated by *y times 0*.75 (75%).

Figure 15 (a) considers the smallest case: a meander with 10 μm line-width channels (grid dots at 50 μm). After the 20 μm etch, the channels will be 50 μm wide, and must have 100 μm between them—so their centre-to-centre separation must be 150 μm.

Figure 15 (b) considers a larger channel meander with 160 μm line width, which will yield 200 μm wide channels that must be separated by 150 μm—thus their centre-to-centre spacing must be 350 μm.



(a)



(b)

Figure 15: (a) Smaller Meander (b) Larger Meander

Rule 8: the total length of all the channels must not exceed 1 m and the total etched surface area must not exceed ¼ of the surface area.

Recall that a Protolyne chip has a surface area of 16 mm X 95 mm = 1520 mm^2.

Rule 9: Objects should not have decimal micron features or positions.

For example, a 20 μm X 30 μm box is acceptable, but a 20.3 μm X 30 μm box is not, nor is a 20 μm X 30 μm box positioned at x=100.6 μm. Similarly, the box should not be placed between two dots which are 1 micron distance apart.