



WHITE PAPER

# The Comprehensive Guide To Photo Chemical Machining



## **Table of Contents**

What Is Photo Chemical Machining?

Why Choose Photo Chemical Machining?

Understanding Photo Etching Costs

Industrial Applications For Photo Etched Metal Parts

A Comparison Of Metal Fabricating  
Technologies

Engineering Design Guidelines For Photo  
Chemical Machining

Ten Simple Steps Of Photo Chemical  
Machining

Planning Checklist For Photo Chemical  
Machining

About Conard Corporation

## What Is Photo Chemical Machining?

Whether it be called photo chemical machining, photo chemical etching, chemical milling, chemical etching, photo etching, even the abbreviation “PCM,” all of these names describe the same process.

The photo chemical machining process is a means of fabricating thin gauge metal parts. The metal thickness ranges from .001” to .080” depending on the type of metal.

In the photo chemical machining process a mylar stencil, called a “photo tool,” is used to expose multiple images of the parts to be made on both sides of a sheet of raw material that has been coated with a light sensitive and acid resistant material, called “resist.”

After the images of the parts have been developed, and the uncured “resist” is washed away, the metal around the part is dissolved using an etching chemistry.



## Why Choose Photo Chemical Machining?

Photo etched metal parts have no burrs or deformations of the raw material that can occur with other processes, such as stamping, punching, waterjet or laser cutting.

## Inexpensive & Effective Tools

Photo chemical machining provides a fast, flexible and relatively inexpensive way to produce a wide variety of precision metal parts. Phototools replace conventional steel tools and dies. These tools can be generated in a matter of hours rapidly and inexpensively, and regenerated to accommodate revisions to parts. Phototools can be generated in 24 hours.

The phototool, which operates like a stencil, is the foundation of accuracy with light being its only working exposure, ensuring that there is no “tool wear” that needs to be monitored.

Phototools are produced on a 7 mil and dimensionally stable mylar using an 8000-dpi photoplotter. The locational tolerances for part features typically meet the nominal dimensions of the specification.

## Photo chemical machining is effective for many kinds of metal:

Aluminum	Brass	Chromium	Copper, Oxygen Free
Copper, Rolled	Copper, Electrolytic	Beryllium Copper	OFHC Copper
Inconel®	Monel®	Nickel	Nickel Silver
Nichrome®	Ni Span C	Permanickel®	Phosphor Bronze
Carbon Steel	Electrical Steel	Stainless Steel, 300 & 400 Series	PH15-7 Stainless Steel
PH17-7 Stainless Steel	Custom 455®	Spring Steel	90-10 Copper Nickel
Kovar®	Rodar®	Nicoseal®	Therlo®
Sealmet 29-17®	Glass Sealing 42®	142 Alloy®	Glass Sealing 46®
146 Alloy®	Glass Sealing 49®	Alloy 4750®	Glass Sealing 52®
152 Alloy®	Glass Sealing 42-6®	Sylvania No. 4®	44-50 Nickel Iron
High Permeability 49®	Hipernik®	High Permeability 45®	Hymu 80®
4-79 Permalloy®	Hymu800®	Hipernon®	Supermalloy®
5-79 Permalloy	Invar 36®	TC-30®	Molybdenum
Conetic AA®	Metal on Polyamide	Metal on Kapton®	Metal on Rubber
Metal on Ceramic			

## Why Choose Photo Chemical Machining?

### Fast & Easy to Produce

The photo chemical process can create quantities from handfulls to 100,000s.

From initial tooling to finished parts, the entire photo chemical machining cycle can be completed in 3 to 5 days. Given a normal backlog, typical lead times for new parts are 3-4 weeks. Often, repeat orders can be processed more quickly, especially if the raw material is in stock. Prototype orders may be done in 2 weeks. Additional time is required to accommodate secondary operations such as plating, forming, heat-treating, silk screening, assembly, or the addition of surface components.

Photo chemical machining has similarities to a printing process in that the part designs can be immensely intricate without having an impact on the tooling or production process. Photo chemical machining can produce complex parts that would be either impossible or impractical to produce by stamping or laser cutting. The etching process produces parts that are free of burrs and mechanical stress.

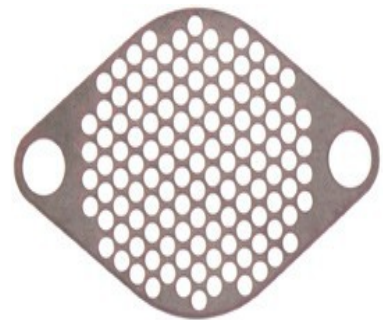
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### Etching As An Alternative To Other Processes

Etching is often a better alternative than stamping, laser cutting, punching or wire EDM.

Photo chemical machining imparts no mechanical stresses on metal substrates. Where stamping, punching and die cutting impart shearing deformation and laser and EDM cutting can leave ablative deformation, photo chemical machining simply dissolves the unneeded metal, leaving a flat and burr-free part.

Photo chemical machining is frequently the process of choice because the tooling is inexpensive and can be produced very quickly, the parts are very precise and consistent, and the process is particularly effective when the shape of the part is complex and/or the part contains many holes or internal cut-outs.



## Understanding Photo Etching Costs

### Major Cost Elements

Like any other manufacturing process, chemical etching costs are the sum of a number of elements. The direct cost elements in photo etching are: metal and photoresist, labor, and machine time. The indirect costs consist of etching chemistries including developer, etchant and stripper.

Power, water and waste treatment are figured into the overhead cost rate.

Considering alloy and thickness, metal costs vary widely. Common alloys and gauges of copper, steel, or aluminum might run between \$5 and \$10 per pound. Thinner materials cost more per pound: .001" thick stainless is about \$50 per pound. However, .0005" stainless costs more than \$100 per pound. Beryllium copper is around \$35 per pound. Molybdenum is more than \$150 per pound. The cost of photoresist is a constant value per square inch.



### Labor Cost Accumulation

The unit of labor in photo etching is the sheet. There are seven manufacturing operations during which labor is accumulated: cutting, cleaning, laminating, printing, developing, photo etching and stripping. Each of these steps requires that the sheet be handled into and out of the operation. The amount of labor required is fairly consistent per sheet, regardless of the size of the sheet. Indirect labor is applied in inspection and packaging.

In most cases, smaller sheets accumulate labor at essentially the same rate as the larger sheets. The application of labor is relatively indifferent to the sheet size. So the sheet size is an important factor in photo etching costs.

Machine time costs accumulate in cleaning, developing, photo etching and stripping. During machine time, multiple sheets are transported by conveyors at speeds determined by the processing requirements. The etching process itself is the slowest, usually running at a few minutes per inch of travel.

We measure capacity at each step in "sheets per hour," which takes into account both the labor and the machine time. Each work step has a through-rate based on sheet size. The through-rate in the etching process is based on sheet size, alloy and metal thickness. Metal alloys etch at known rates per mil (.001") of thickness so the required duration of the exposure to the etching chemistry is predictable.

## Understanding Photo Etching Costs

### Design Factor Costs

Dimensional tolerances also affect the sheet size for photo etching as the tolerance variance from the center of the sheet to the edges increases with the distance. So, even a simple part with tight tolerances might have to be produced on a very small sheet. Tight tolerances also affect etching costs because the production yield of parts within tolerance decreases.

At the most generous end of the tolerance spectrum is what we refer to as “decorative.” This applies to jewelry, giftware and hobby- type projects where the absolute dimensions are not critical. We etch to a gauge pin dimension and inspect to appearance. This is the most economical sheet we produce. Typically, the decorative sheet is 18 x 24 x

.020. In photo etched brass or aluminum, in quantities of 10 or more, these sheets are under \$70 each. Parts are shipped tabbed in the sheet.

### Tooling Cost

Phototools are another element of photo etching costs. Most tools cost less than \$300 for sheets up to 24” x 30”. Composite tools containing images of different parts have a one-time set up charge for the additional parts. The phototool is the film master used to transfer the images of the parts onto the resist- coated metal. Phototools are produced from customers’ CAD data. They are inexpensive, long-lived and easily regenerated. Tooling charges are one-time, unless the customer changes physical dimensions of the part. If a phototool becomes damaged while in our use or care, we will replace it at no charge to the customer.



## Understanding Photo Etching Costs

### Cost Variables

The two biggest variables affecting the cost of photo etching are metal thickness and sheet size. Metal thickness bears directly on the length of time it takes to etch through a given metal thickness measured in minutes per mil (.001") of thickness. Sheet size drives the amount of labor that accumulates.

The photo etching process has seven essential steps: cutting, cleaning, laminating, printing, developing, etching and stripping. For each of these steps, a sheet of material must be handled. Each time a sheet is handled into and out of a step in the photo etching process, labor is applied. The effect of sheet size on the cost of photo etching is illustrated in the table below:

The "test part" is a 1" x 1" x.010" thick part. It doesn't make any difference whether the part is a simple disk (cheese pizza), a washer (pepperoni pizza), a spring form (pepperoni, sausage and mushrooms), or a screen (the "works"). The photo etching process doesn't care.

**Prices shown do not include any material cost.**

Sheet Size	12 x 12	12 x 18	12 x 24	18 x 24
<b>Min Tolerance</b>	+/- .002	+/- .0025	+/- .003	+/- .004
<b>500</b>	.59	.43	.41	.38
<b>1000</b>	.56	.39	.36	.31
<b>2500</b>	.52	.38	.29	.25
<b>5000</b>	.45	.33	.29	.23
<b>10000</b>	.42	.31	.27	.22
<b>25000</b>	.40	.30	.26	.21
<b>50000</b>	.39	.29	.26	.20
<b>Sheets/ 1k Parts</b>	15	9	7	5

## Understanding Photo Etching Costs

### Cost Effects of Dimensional Tolerances

The minimum tolerances shown apply to .010 thick material at the sheet sizes indicated. So, the evidence is clear. The larger sheet sizes are definitely more cost effective in photo etching. Over the course of 50000 pieces, the accumulated labor for the 12 x 12 sheets will be more than double compared to the 18 x 24 sheets.

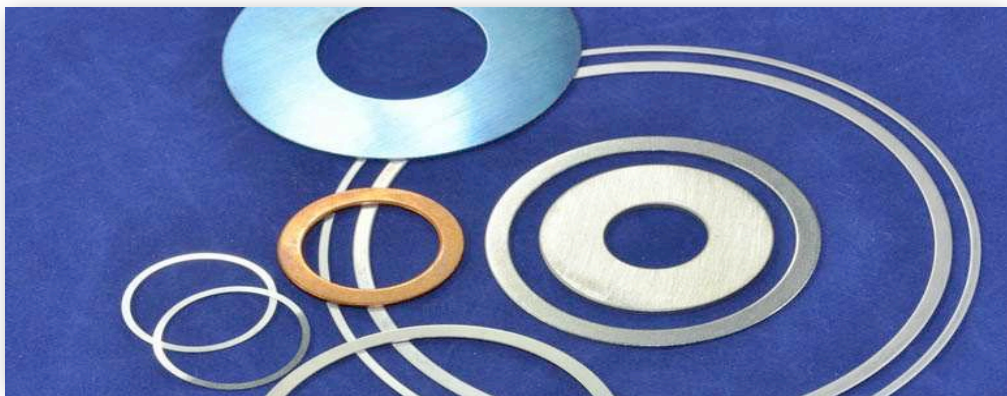
Remember, too, that allowance must be made for the dimensional tolerances the larger sheets require.

Dimensional tolerances are often the determining factor in planning the sheet size for chemical etching. Most engineering drawings have a standard tolerance of  $\pm .005$ " for three-place decimals. If you are designing for photo etching, that dimensional tolerance band is adequate for materials up to .030" thick. The location tolerance in photo etching is  $\pm .001$ " to drawing nominal. Locations are established in your CAD file which is exactly the data from which the photo tool is made. If your data is right, the phototool will be right.

### Designing for Economy

Metal thickness and dimensional tolerances play a major role in planning the sheet size for etching. Our experience suggests that it is often the case that a designer will be overly generous with the material thickness and stingy with tolerances. And, when you have an actual conversation about the part and its application, you discover that neither needs to be that way.

To design for economy in photo etching, watch for these money-wasting flaws: too much metal, too tight tolerance, feature sizes that are too small for the thickness, inaccurate specifications and unavailable material selections.



## Industrial Applications For Photo Etched Metal Parts

Photo etching is used to manufacture an extensive variety of mechanical and electrical/electronic parts serving many industries.

### Aerospace and Defense:

Etched metal components can be found in fuel systems, avionics packages, helicopter drive shafts, heat exchangers; RF, microwave and radar systems, space-rated batteries, fusing systems, fire detection and suppression systems, anti-EMP arrays and many more.

### Electronic and Electrical:

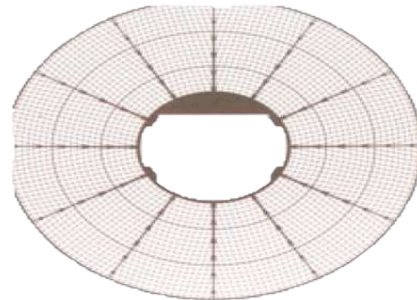
Microelectronic packaging includes a multitude of leadframe configurations. Lead frames are the conductive devices that connect the semiconductor chips to the circuit board. Some types of electronic circuits are packaged in full metal enclosures known as “cans,” which are then sealed with fitted lids. Photo etching is a popular method for producing both “step” and flat lids.

Despite its cost, direct bond copper (DBC) on ceramic is gaining popularity as devices become smaller and more powerful. Photo etching is the only practical solution for creating circuit patterns in the bonded copper foil. DBC finds many applications in wireless communications from the hand-held—and now *worn* – devices to the towers and to the cloud beyond. It also has numerous uses in industrial, medical and scientific instruments and controls.

RF and microwave technologies rely extensively on photo etched components. Beryllium copper and phosphor bronze are popular alloys for making springy electrical contacts. The ability of these alloys to be formed into resilient detents assures positive connections.

### Sensors:

Sensors, in general, are both electrical and mechanical devices. They detect a physical force and translate that to an electrical signal. Sensors are used in an ever-growing host of industrial, scientific and medical systems. From smoke detectors to mass spectrometers to seismometers and strain gauges, to name but a few, the need for sensors will continue to expand as the “Internet of Things” reaches 40 billion connected devices in the next ten years.



### Mechanical:

Precision metal parts made by photo etching include gaskets, seals, shims, spacers, shields, retainers, flexures, flat springs, pressure membranes, diaphragms, clips, masks, apertures, encoders and more.

Parts such as these are used in lasers, relays, turbines, MRI machines, PVD and CVD systems, bearings, printers, photonics, dispensers, and measuring devices, to name a few.

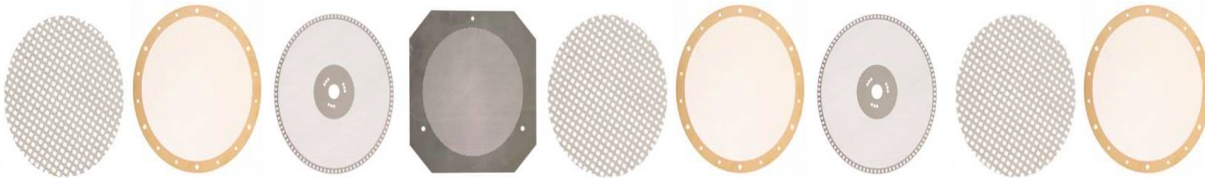
## Industrial Applications For Photo Etched Metal Parts

### Filtration/Perforated Products:

One of the things that photochemical etching excels at is making holes. Unlike any other process, there is no incremental cost for additional holes, either in tooling or cycle time. One hole, a million holes—it's all the same.

The etching process can make some very small holes, down to 100 microns (.004" or .1mm). And, the holes don't have to be round. They can be polygons of nearly any shape, keeping in mind that all "corners" will be radiused.

Photo etched screens are used to filter light, gases, liquids and solids in many different applications: photonic transmission filters, atmospheric testing equipment, from orange juice to hydraulic oil, from particle sizing to gravel grading.... Military aircraft windows are embedded with etched copper meshes to protect against electromagnetic pulses. Etched metal screens are far superior to woven wire for pressure drop applications in filtration.



### Customers Using Photo Etched Parts: A Sampling

Hamilton Sundstrand	Pratt & Whitney	Goodrich
Parker	Timken	IBM
General Dynamics	3M	Northrop Grumman
Teledyne	GE	Honeywell
Tyco	ITW	Kaman
Pall	Raytheon	Tenneco

## A Comparison Of Metal Fabricating Technologies

**Stamping** utilizes hardened steel dies in the exact shape of the part and creates the part in a single strike of the die. The die costs can run from hundreds to tens of thousands of dollars and may take months to build.

**CNC Punching** utilizes standard die sets in a variety of configurations under computer control to create various features of a part. It may take a number of automated tool changes and a multiple of strikes to produce the part. Individual dies are generally less than a thousand dollars, but many may be needed. Generally, dies are available in a matter of days to weeks.

**Photo Etching** utilizes a film based phototool to transfer the images of the parts on to metal. All of the features of the part are created simultaneously in a single pass through the etching machine. It takes exactly the same amount of time to produce a simple part like a washer as it does to produce a complex part like a screen. Phototools are typically less than \$500 and can be created in a day.

**Laser and Plasma Cutting** utilize guided beams of high-power energy to burn through the metal. The beams trace each feature of a part, just as you would with a pencil. Depending on the material and thickness, typically these devices will cut 200-300 linear inches per minute. The time to produce a part is determined by the complexity of the design. There is no tooling required but the parts must be programmed.

**Water jet cutting** is very similar to laser or plasma, however the rate is slower and the cutting agent is a high-pressure slurry of water and abrasive.

**CNC Wire EDM** utilizes a copper wire electrode to burn through metal by arcing an electric current between the electrode and the work object. Typically, multiple layers of metal are clamped together so multiple parts can be cut. This is a relatively slow process, particularly compared to laser and water jet. No tooling is required, but programming is.

Process	Tooling	Set up	Volume	Process
Stamping	\$\$\$---\$\$\$\$\$	Physical	Thousands to Millions	One strike
CNC Punching	\$-\$\$\$	Physical & Programming	Dozen To Thousands	Mul@-strike
Etching	\$	N/A	Dozens to tends of thousands	Concurrent
Laser/ Plasma/ Water Jet	N/A	Programming	Dozens to thousands	Linear
CNC Wire EDM	N/A	Programming	Dozens to hundreds	Linear

## Engineering Design Guidelines For Photo Chemical Machining

**RULES:** When designing a working Phototool all of the following have to be considered.

### Cost impact of sheet size

1. Sheet Size has largest cost impact on piece price.
2. Thicker material ( $>.020$ ) with tighter tolerance ( $\pm 15\%$  of metal thickness) requires a smaller sheet with fewer pieces.
3. Thinner material ( $<.019$ ) with broader tolerance ( $\pm 15\%$  of metal thickness) will determine larger sheet with more pieces per sheet.
4. The larger the sheet and the more pieces per sheet the lower the piece price to the customer.

### Sheet size vs. metal thickness vs. required tolerance

1. Best tolerance available with etching is usually  $\pm 15\%$  of metal thickness.
2. Exception would be  $.001$  to  $.004$  thick metal, best tolerance would be  $\pm .0015$ "
3. Typical production tolerance would be  $\pm 15\%$  of required metal thickness by customer.
4. As discussed above tighter tolerance will also require smaller sheet size and wider tolerance will allow larger sheet size.
5. Location tolerance is routinely held to  $\pm .001$ " regardless of the metal thickness. Location dimensions can be held to tighter tolerance at the customer's request.

### Compensating etch factors for tool design

1. When etching through the metal thickness, for every  $.001$ " etched down into the metal there is a lateral etch of  $.00025$ " per hole side (a hole has 2 sides). The compensating factor for designing the working phototool is thickness divided by four.
2. Example:  $.020$  Brass requires  $.062$  hole etched through the metal thickness. The Phototool used for image transfer would have to be compensated for etch factor of thickness over 4 or  $.005$  per side of the hole. The actual hole size on the tool would be  $.052$ . After etching from both top and bottom of the  $.020$  brass sheet the finished hole size would be  $.062$ .
3. Only land area or physical tolerance has to be compensated. Center to center locations do not require compensation.

## Engineering Design Guidelines For Photo Chemical Machining

### Metal thickness to slot/bar ratio

1. The etch process has limitations regarding slot to bar ratio or any dimensions that would be less than the actual customer required metal thickness.
2. Bars can be 20% thinner than the actual metal thickness, slots need to be 120% wider than the metal thickness. Example: for .010 Stainless steel, the required bar width can be .008 but the required slot would have to be .012 wide.
3. The same ratio is required for holes to bar width ratio.

### Tab configuration, dropouts vs. standard tabbing vs. recess tabbing and tab placement

1. Most etched parts are made in sheet form
2. There are 3 techniques for processing parts in sheet form.
3. Dropouts: Parts are orientated in sheet form with a complete uninterrupted perimeter etch line around the outside profile of a part. When the part is etched it simply drops out of the sheet as a finished complete part. That advantage is no burr on the outside profile of the part. A disadvantage can be the amount of process time it takes to handle individual parts vs. parts that are tabbed into the sheet.
4. Standard Tabbing: Most parts are processed in sheet form with the parts tabbed into the sheet. A round disc may require 2 to 3 connecting tabs holding the part into the sheet during the etch process. Once the etch process is complete the part would stay attached to the sheet by the 2 to 3 thin tabs connected to the OD of the part. The advantage is ease of handling through the process and offers an easy way for customers to store parts at their facility. A disadvantage is the parts will need to be clipped out of the sheet with a fine wire cutter and there will be a slight burr protruding from the OD of the part. If the tab burr is not desirable the parts can be clipped out and deburred at our Conard facility.
5. Recessed tabbing: This is a tab that is actually recessed below the profile of your part. After the etch process is complete the part can be removed from the sheet with a simple twist and the profile has no protruding tab burr. It does leave small open notches in the outside profile that recess from the OD. Advantage is the ability to handle the parts in sheet form saving cost. The customer can receive the parts in sheet for easy removal or the customer can request removal of the parts by Conard.

### Outside corner radius

1. There is a process restriction for square corners internally or externally. The standard rule is .7x the actual metal thickness. Example: a .010 Copper part would have a corner radius of .007".

### Use of serifs, limiting outside corner radius

1. One way to restrict corner radius is to add a small serif to the corner. The serif will restrict the radius affect and limit the actual radius.

## Engineering Design Guidelines For Photo Chemical Machining

### Half etch capabilities i.e. fold lines

1. One of the many advantages of the etch process is the ability to use half etch lines. A line is placed strategically on one side of the phototool and omitted from the other side, when etching the line is only half etched from one side. By creating these half etch lines it makes it possible to create fold lines on one side of a part. Example: RF shielding, the part can be designed flat with fold lines and then simply folded into a 3 dimensional shape. This capability can save the customer expensive forming tool costs.
2. The half etch technique can also allow part marking or orientation marking for identification purposes

### Ratio etch capabilities, 50/50, 60/40, 73/30, 80/20, & 90/10

1. Another advantage of the etch process is ratio etching. Most standard parts are etched to a 50/50 or 60/40 ratios and all the standard process rules apply. (50/50 ratio is 50% of the metal thickness etched from both sides of the metal sheet)
2. If a customer is requesting a smaller hole in a thicker material. Example: .012 holes in .020 metal thicknesses. This is achieved by a ratio etch. The part is etched 80% to 90% from
3. one side and etched 20% to 10% from the other side. By using this technique you are able to hold the smaller hole dimension. The sidewall of the part profile will have a sloped or trapezoidal affect rather than perpendicular.

### Double process capabilities

1. The etch process allows for what we refer to as a double process. Example: a customer is requesting an etched through part with half etch graphics on each side, aligned top to bottom but they do not want it etched through.
2. Two phototools could be designed, the first tool would be printed and processed as a partial etch. Then the part would be reprocessed, aligned to a second tool and processed to its completion with the required etch through pattern and the added feature of half etch graphics aligned top to bottom at a controlled depth per side.

### Composite tooling

1. Another great feature offered by our process is composite tooling. Example: a customer is prototyping a part and has several design types they want to evaluate. Conard can design the photo tooling to include several designs on one tool and produce the various style parts in a single sheet format. This saves the costing of several individual tools. Example #2, a customer has a small quantity of several parts but does not want to spend the money for individual tooling for each part type. Conard can create a composite phototool to include all the parts and save the customer tooling cost.
2. The rule for composite tooling is all parts must share the same metal thickness.

## Ten Simple Steps Of Photo Chemical Machining



1. 2D-CAD files are used to generate a Gerber file for plotting (DXF or DWG format preferred).
2. The Gerber File is output to a high-resolution photo-plotter and mylar phototools are developed and registered.
3. Metal is measured and sheared from coils.
4. Metal sheets are scrubbed, cleaned and rinsed.
5. Clean, dry metal is laminated with photopolymer film in a safe-light clean room.
6. The phototool and the laminate metal are precisely positioned in a vacuum frame UV exposure unit.
7. The exposed sheets are developed to remove the unexposed photopolymer, leaving bare metal to be etched.
8. The heated etching acid is sprayed at the metal from both sides, dissolving the unneeded metal areas. The metal sheets are rinsed four times.
9. The photopolymer is stripped using a heated solution of caustic and water. The parts are rinsed multiple times and dried in a turbo dryer. The clean, dry parts are delivered to our Quality Inspection department.
10. The parts are thoroughly inspected in accordance with our Quality Management System and to the customer's specifications. Conforming parts are packaged and shipped.



## Planning Checklist For Photo Chemical Machining

Alloy Selection: \_\_\_\_\_  
UNS Designation: \_\_\_\_\_  
(Additional Specs Required: AMS \_\_\_\_\_ ASTM \_\_\_\_\_  
Other\_)  
Temper: \_\_\_\_\_  
Thickness (T): \_\_\_\_\_  
Grain Orientation: Y/N  
Material Availability:  
Design Parameters:  
Minimum Hole/Slot Dimension not less than 110% of thickness  
(T)\_\_\_\_\_  
Minimum Land Feature not less than T \_\_\_\_\_  
Minimum dimensional tolerance greater than 15% of T: \_\_\_\_\_  
Production Layout:  
Part may be tabbed: Y/N Tab Type:  
Precision tab  
OR  
Recessed Tab  
Ship in sheets: Y/N

### Other Operations:

Requires forming: Y/N Requires Heat  
Treating: Y/N  
HT Specification: \_\_\_\_\_  
Requires Plating: Y/N  
Plating Specifications: \_\_\_\_\_  
Requires Other Services: Y/N  
• Painting  
• Electropolishing  
• Welding  
• Overmolding  
• Color Fill  
• Passivating  
Other: \_\_\_\_\_  
Quantity Required: \_\_\_\_\_  
Estimated annual usage: \_\_\_\_\_



101 Commerce Street  
PO Box 676  
Glastonbury, CT 0603

**Phone:** (860) 659-0591

**Fax:** (860) 659-8705

**Email:** [sales@conardcorp.com](mailto:sales@conardcorp.com)

**[www.conardcorp.com](http://www.conardcorp.com)**