Process 01. An open source 2 layer PCB process.

Documentation v1.1 (updated 2023-08-04)

Warning: some of the reagents used in this process are harmful. Although the preparation and use of the chemical solutions described here is not difficult, experience in the safe handling of chemicals is required. Read the material safety datasheet of every reagent and work in a fume hood.

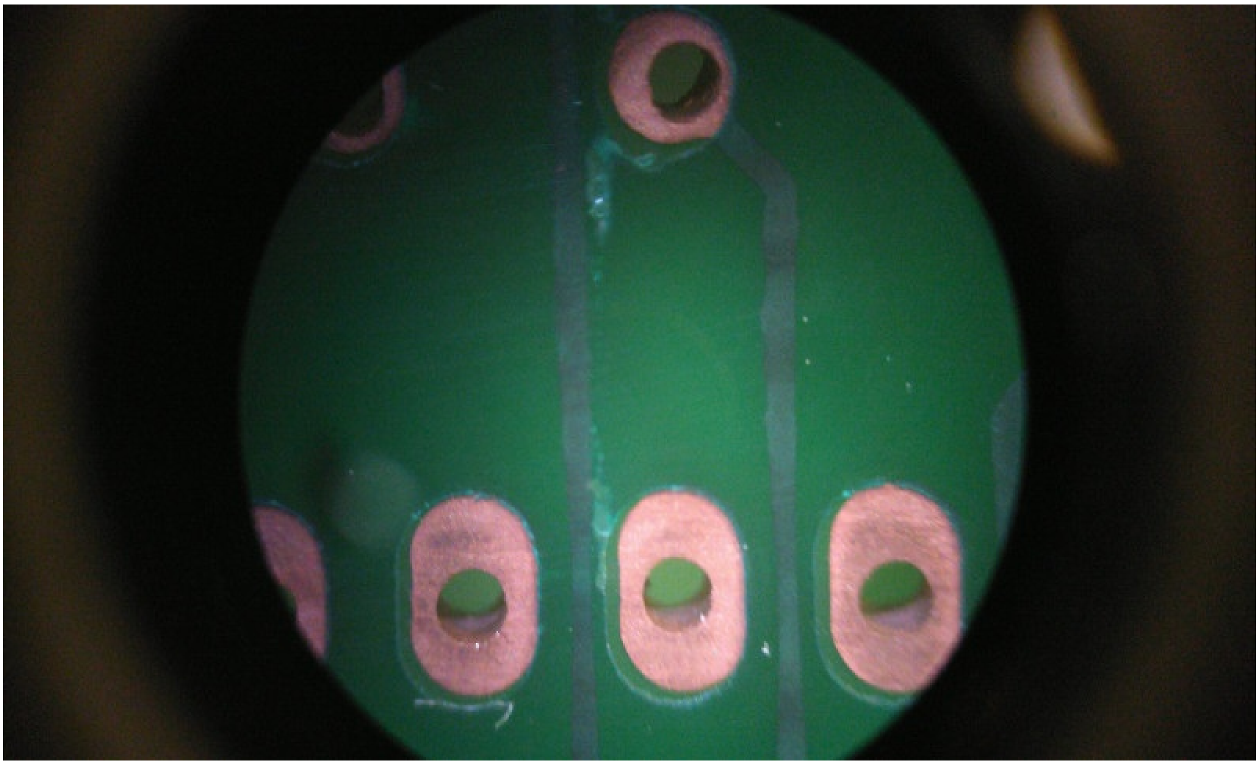


Figure 1: plated-through pads made with Process 01.

Changelog

- v1.1:

  Updated solutions long term storage information.

  Switched to using acetone for stripping photoresist (step 24), as suggested by @HennerZeller on youtube.

  Added a note regarding sludge formation to step 11.

- v1.0:

  Initial document version.

Video documentation

The steps described here are also available in the form of youtube videos.

- Part 1: https://youtu.be/Kn92cLf69iw
- Part 2: https://youtu.be/J3ROTfGLZDw

Input

To make a PCB with process 01, you will need four masks printed on acetate or similar transparent plastic film of your PCB artwork. Two will be the copper top and bottom, and two for the soldermask top and bottom.

All masks need to be negatives, as the photosensitive materials we're using are negative. A negative copper mask is one where copper traces are transparent, while the space between traces is black. A negative soldermask mask is one where pads are black, while the area to be covered by the photoresist is transparent.

You also need as input the hole placement locations on your board. If you're going to drill the PCB with a CNC, then there is no problem, but if you are set up for manual drilling you'll need to print another mask with the hole placement, likely to use as a guide to leave marks on the copper with a center punch. As the PCB needs to be drilled first, you can't use the already etched traces as reference for where to drill your board. Also, any misalignment in a via or pad above your annular ring size will leave that hole unprotected by the solder mask causing the etchant to destroy the plated copper, so you need either be precise or use oversized annular rings.

Process 01 uses standard double sided copper clad boards, not coated in any photoresist, as the photoresist needs to be applied later in the process. I tried this process with both standard thickness (1.6mm) and reduced thickness (0.8mm) PCB material with no problem.

Steps

1. Drill

   Start with a blank PCB cut to size, and drill all the holes that you want plated. Usually, there is no special need to leave holes unplated, so it is best to drill all holes right at the beginning.

2. Sandpaper

   The next step is a light sandpaper step to remove burrs left by the drilling process. This is important as rough surfaces may damage the photoresist and lead to via failure. Of course both sides need to be sandpapered. Wetting the sandpaper with water helps. I use 320 grit sandpaper but this is not critical. Just don't use too coarse sandpaper, and don't go as far as to remove the copper.

3. Water rinse

   The next step is a simple water rinse, to remove dust particles. At this step it is best to visually check the holes to make sure no air bubble is trapped in them. Doing so at the first step also solves the issue for all subsequent steps, as the liquid surface tension will make sure no air bubbles will form while transfering the PCB from one bath to th next one. Obviously, an air bubble during the activation or plating steps will prevent copper plating.

4. Clean

   For the plated copper to adhere perfectly to the surface of the PCB, the board needs to be cleaned from any dust and oils. Even if it looks perfectly clean to the eye, a step of chemical cleaning is basically necessary. This is done with a roughly 10% by weight solution of sulfuric acid, although the concentration of sulfuric acid is not critical. The cleaning step requires heating at 65°C and stirring for around 10 minutes.

5. Water rinse

   The next step is again a water rinse to remove sulfuric acid residues.

6. Activate

   Step 6 is the electroless activation of the PCB surface. It is done by dipping the PCB in an acidic palladium chloride solution. Be careful as palladium salts are toxic. This step requires the PCB to remain in the activation bath, with occasional agitation, for around 5 minutes at ambient temperature.

7. Post-activate

   The next step is the post-activation. The PCB is dipped in an acidic tin chloride solution, with stirring, for five minutes at ambient temperature. The purpose of this step is to reduce the palladium chloride to palladium metal, leaving an invisible coat of palladium atoms on the PCB. These palladium atoms will catalyze the decoposition of the next solution, the electroless plating one, plating copper onto the PCB.

8. Water rinse

   Again, we find a water rinse step, to prevent cross-contamination of the solutions. Note that dragging free palladium in the plating bath can cause the electroless copper plating solution to decompose also outside the PCB surface, requiring it to be discarded.

9. Electroless Cu

   The next step is the actual electroless plating. If the pH of the bath is sufficiently basic, and the PCB has been correctly activated, hydrogen will start bubbling from the PCB surface, possibly after an induction period of a couple of minutes. What you are seeing, is formaldehyde in the solution reducing copper salts to copper metal. As anticipated, the reduction only occurs in the presence of palladium atoms, thus the entire solution does not decompose to copper metal and the reduction only occurs at the PCB surface. Moreover, the process is also autocatalytic, meaning that once the palladium atoms have been occluded by the formed copper layer, the process does not stop, as the newly formed copper with hydrogen bonded to the surface catalyzes the decomposition just as well as the palladium, allowing the formation of a thick copper layer, without stopping at just a few atoms thickness. Electroless plating needs to be continued, with stirring at ambient temperature, until the sides of the PCB appear fully plated. Time is between 20 to 40 minutes. Please note that formaldehyde is carcinogenic, so this step must be performed inside a fumehood.

10. Water rinse

    After electroless plating, the PCB requires another water rinse. The color of the formed copper layer is usually a bit dull.

11. Electrolytic Cu

Electroless plating allowed us to deposit copper also on the non conductive surface of the hole walls, and that's its strength. However, its weakness is that it's rather slow. So, once a thick enough layer has been deposited to carry an electrical current, we can boost the copper thickness with electroplating. The electroplating bath is an acidic solution of copper sulfate. For electroplating, we need to attach two copper electrodes to the sides of the beaker, connected to the positive of a constant current power supply. The negative, will be connected to the PCB we are plating. The plating solution is heated at 60°C and stirred, and plating is continued at a current of 25mA/cm^2 for 20 minutes. During the plating some copper sludge may detach from the electrodes and deposit on the PCB. To prevent this, it is possible to enclose the anodes in bag of a porous material to contain the sludge, even though this was not tested. Use low resistance connections to both electrodes. In my first tests I used the common cheap alligator clips that you can find online, but the wire resistance was so high that resulted in different potential at the two electrodes. When I switched to making my own alligator clips with 0.75mm^2 copper wire, sludge formation was considerably reduced. Step 13 is still needed to get good photoresist adhesion, though. When the PCB is removed from the beaker, it should have the characteristic salmon orange color of freshly electroplated copper.

12. Water rinse

    The next step is, as usual, another water rinse.

13. Sandpaper

    Step 13 is a light sandpaper step, used to remove the copper sludge particles that have been deposited on the PCB during the electrolytic plating. This step can be omitted if sludge containment is used, and the resulting surface finish is proven to be good enough for photoresist adhesion. Use gloves to keep the PCB clean from fingerprints and other contaminants.

14. Water rinse

15. Acetone rinse

    An acetone rinse helps clean the PCB and ensures a quick drying at low hotplate temperatures, minimizing the formation of copper oxide. As anticipated, plating the copper on the hole walls is useless unless it can be protected from the etchant, and for this, good photoresist adhesion is fundamental.

16. Dry

    Step 16 is to let the PCB dry on a warm 60°C hotplate. It should take no more than a couple of minutes.

17. Apply photoresist

    The next step consists in applying the photoresist to both sides of the PCB. The photoresist used can be easily found on ebay (look for the trade name "Riston"), and it is a gelled negative photoresist, resembling sheets of double sided tape, as the actual photresist is sticky and sandwitched between two layers of thin protective plastic. As this photoresist is very sensitive to light, around 5 times more than the positive photoresist used in single sided presensitized boards, it is best to avoid exposure to white light. A 1 Watt yellow LED can be used to make an improvised darkroom. The rolled-up photoresist is cut to size with a pair of scissors, one of the two protective plastic layers is peeled away with the help of some scotch tape, and the photoresist is applied on the PCB. After the photoresist has been applied on both sides of the PCB, it needs to be hot rolled using a modified document laminator, and then immersed in cold water to cool it immediately.

18. Expose + Polymerize

    The mask is placed on a glass plate ink side up, a few drops of water help it stick to the glass just enough. The PCB is then placed on the mask and carefully aligned so that all holes line up with the mask. Exposure is done with ultraviolet light. The exposure time depends on the power of your UV light, so you'll need to experiment. Usually, there is a sweet spot that gives the best results, and deviating from it either side will not only require too short or long development times but will usually cause adhesion problems and traces dissolving away. As a reference, With my UV set-up, exposure lasts only 50 seconds, while ordinary positive presensitized boards take 4 minutes, so if you've developed negative photoresist before, divide that time by 5 as first guess. After the exposure, it is important to let the photoresist polymerize by placing it on a 60°C hotplate for 5 minutes in the dark or under yellow light, as negative photoresist works by hardening upon exposure to UV. Missing this step will likely leave you with traces washing away.

19. Develop

    The developer is usually prepared just before use. This step is quick enough that it can be performed with lights turned on. The last protective plastic foil is removed from both sides, and the PCB is dipped in the developer. Note that, as the photoresist is gelled, it does not wash away, and gentle scrubbing with a sponge is needed to remove it.

20. Water rinse

21. Dry + visual check

    Dry the board with some tissue paper. It needs to be just dry enough for visual inspection. Check, possibly with a microscope that all vias and pads are covered by the photoresist. In case of failure in critical vias or pads, it is best to strip the photoresist immediately and reapply it.

22. Etch

    The etching step which will reveal if the PCB will be a success or a failure. This process is compatible with most PCB etchants. I use copper chloride as it can be regenerated, but ferric chloride should work just as well.

23. Water rinse

    The PCB is visually inspected from time to time, and when the etching is complete, yet another water rinse follows.

24. Strip photoresist

    The photoresist can be stripped with either acetone or a hot concentrated sodium hydroxide solution. It is recommended to use acetone, not only because it is less dangerous than the sodium hydroxide solution, but also because it is faster and does not oxidize the copper surface.

25. Water rinse

26. Dry

    The board can be dried on a hotplate. The adhesion of the soldermask is less critical than the photoresist, as it will not have to survive etching.

27. Apply soldermask

28. Expose + Polymerize
29. Develop

30. Water rinse

    Steps 27 to 30 are the same as 17 to 20, only the soldermask is applied instead of the photoresist. Also the soldermask can be found on Ebay (trade name: “Dynamask”). The soldermask material I use is a negative one, and it is very similar to the negative photoresist, only the color differs.

    Note that soldermask is, obviously, optional. You can tin plate the board if you prefer, or even leave the copper exposed, even though in this case it will oxidize quicly.

31. Cure soldermask

    The soldermask needs to be UV cured for 30 minutes per side.

Main Solutions

- Step 4: Cleaning solution. Around 10% by weight sulfuric acid. Concentration not critical. Deionized water preferred. You can prepare this solution by dissolving 13mL of concentrated sulfuric in 225mL of deionized water. Stable, can be stored indefinitely and reused many times. So far, two years later the original solution still works.

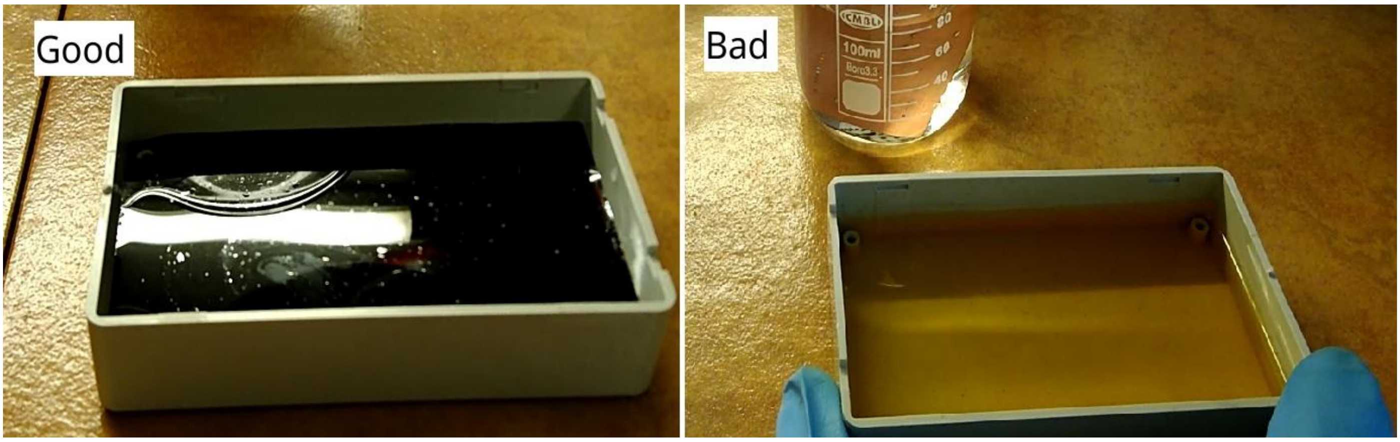
- Step 6: Palladium chloride activator.

  Instructions for preparing 50mL

  - 40mL deionized water
  - 0.02g $PdCl_2$
  - 2.25g $SnCl_2 \cdot 2H_2O$
  - 7.75g NaCl
  - 2.5mL 34% HCl
  - adjust the volume by adding deionized water till 50mL

  Stir until every added reagent dissolves before adding the next one.

  Solution lasted between one and two years in a capped container. When the solution goes bad it changes color from dark brown to transparent yellow. Trying to make a PCB with the yellow solution coats the copper with a dark layer that is not catalytic for the eletroless copper solution and is very hard to remove, requiring to restart from scratch with a new board.



- Step 7: Post-activator.

  Instructions for preparing 200mL

  - 182mL deionized water
  - 18mL of 34% HCl
  - 4g $SnCl_2 \cdot 2H_2O$

  Originally thought to decompose in just a few weeks, the solution surprisingly lasted between one and two years in a capped container. A white deposit of Sn^{4+} salts progressively form, but this is not by itself an indication that the solution is spent, as there may be still Sn^{2+} in solution. It is suggested after long term storage to try using the solution. If no hydrogen formation occurs at step 9 even after an attempt to replenish step 9 solution with formaldehyde, it is possible to restart from step 5 with a fresh post-activator without having to throw away the PCB.

- Step 9: Electroless copper.

  Instructions for preparing 200mL

  - 2.52g copper sulfate pentahydrate
  - around 150mL deionized water
  - 5.8g disodium EDTA
  - 2g NaOH
  - 4 drops of Triton-X 100, which is a surfactant used as brightener
  - 1.6mL of 37% formaldehyde
  - adjust the volume by adding deionized water till 200mL

  Stir until every added reagent dissolves before adding the next one, except the EDTA which only fully dissolves after the NaOH is added.

  The solution can be reused many times if acidified after use with H_2SO_4, basified with NaOH again before the next use, and stored in a capped container. So far, two years later the original solution still works although formaldehyde addition is sometimes needed.

  - If taken from storage and is no longer acidic, it has gone bad.
  - If taken from storage and it does not work despite enough NaOH has been added to bring pH to strongly basic, try adding more HCHO.

- Step 11: Electrolytic copper.

  Instructions for preparing 200mL

  - 150mL deionized water
  - 12g (around 6.5mL) of concentrated sulfuric acid
  - 40g copper sulfate pentahydrate
  - 0.2g polyethylene glycol, used as brightener
  - 2 drops of copper chloride PCB etchant
  - adjust the volume by adding deionized water till 200mL

  Stir until every added reagent dissolves before adding the next one.

  Stable, can be stored indefinitely and reused many times. So far, two years later the original solution still works with no need to replenish its components.

- Step 15: Plain acetone.

  Just a few mL poured on PCB, no need to immerse the entire PCB in an acetone bath.

  One time use only.

- Step 19: Negative photoresist etchant.

  3g K_2CO_3 in 100mL water. Tap water can be used.

  One time use only.

- Step 22: See NurdRage video on PCB etchants.

  https://www.youtube.com/watch?v=V8mHiFYmlBc

- Step 24: Negative photoresist stripping solution.

  It is recommended to use plain acetone for stripping. Just a few mL poured on PCB, no need to immerse the entire PCB in an acetone bath. Alternatively if for some reason sodium hydroxide is preferred, use 2 spoons of NaOH in 100mL water. Concentration not critical. Tap water can be used.

  One time use only.

Reagents table

4.	**6.**	**7.**	**9.**	**11.**	**15.**	**19./29.**	**22.**	**24.**	
X			X	X					H_2SO_4
	X	X					X		HCl
	X								$PdCl_2$
	X	X							$SnCl_2 \cdot 2H_2O$
	X								NaCl
			X	X					$CuSO_4 \cdot 5H_2O$
			X						NaEDTA
			X					(X)	NaOH
			X						Triton-X100
			X						37% HCHO
				X					PEG
				X			X		$CuCl_2$
					X			X	Acetone
						X			K_2CO_3
							X		H_2O_2
X	X	X	X	X					Deionized water
						X	X	(X)	Tap water