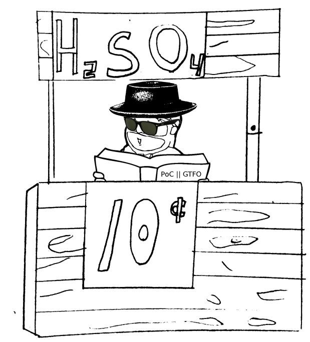
9 Introduction to Reflux Decapsulation and Chip Photography

by Travis Goodspeed

Howdy y'all,

Unlike my prior articles for PoC||GTFO, this one is an introductory tutorial. If you are already stripping and photographing microchips, then there will be little for you to learn here. If, however, you want to photograph a chip and don't know where to begin, this is the article for you.



I'm also required by my own conscience and by good taste to warn you that if you attempt to follow these instructions, you will probably get a little bit hurt. Please be *very fucking careful* to ensure that you only get a little bit hurt. If you have any good sense at all, you will do this in a proper chemistry lab with the assistance of professionals rather than rely on this hobbyist guide. If you don't know whether to add water to acid or acid to water, and why you will hurt yourself *a lot* if you don't know, please stop reading now and take a community college course with a decent lab component.

9.1 Chemistry Equipment

At a bare minimum, you will need high-strength nitric acid (HNO_3) and sulfuric acid (H_2SO_4). Laws for acquiring these vary by country, and if you're in a jurisdiction that cares too much about the environment, you might need to use a different method.[14] In addition to the two acids, you will need isopropyl alcohol and acetone as solvents for cleaning.

Beyond the chemicals, you will need a bit of glassware. Luckily, the procedure is simple enough, so some test-tubes, beakers, and a ring stand with buret clamps will do. If you get second-hand clamps, be aware that metal should not directly touch the glass of the test tube; your clamp might be missing a rubber or cloth piece to prevent scratches.

The acids that you are working with can attack metals, so get several acid-resistant tweezers. I learned a while ago that tweezers get lost or bent, so buy a dozen and you won't have to worry about it again.

Because the acid fumes, particularly the nitric acid fumes, are so noxious, you will need a fume hood to properly contain the acid gas that boils out of the test tube when you screw up the heat.

As a handy indicator of where the acid fumes are going, I save thermal paper cardstock from air and rail tickets. They turn red or black in the presence of acid fumes, and by balancing one above the test tube I get a visual warning that the fumes have spread too far.

You could get by with a toothbrush and solvent for cleaning the chip surface, but an ultrasonic bath with solvent is better. Cheap ultrasonic cleaners are available for cleaning jewelry, and they work well enough, but be careful not to let your cleaning solvents dissolve their exposed plastic.

Finally, you will need a source of regulated heat. At this point, you're probably itching to strike off a Bunsen burner, but those are really a terrible choice. Instead, I use a cheap SMD rework soldering station, the Aoyue 850A. By turning the airflow near maximum and slowly raising the temperature, I can heat the test tube to a consistent temperature.

9.2 Chemistry Procedure

Your sample should be the smallest package of the target chip you can purchase. For a specific example, the Texas Instruments MSP430F2012 is available as PDIP (Plastic Dual Inline Package) and QFN (Quad Flat No-leads) among other packagings. While this procedure works for either, the QFN package is much smaller and has less plastic to be etched away, so it will consume far less of your nitric acid.

Begin by connecting the buret clamp to your ring stand as shown in Figure 6, with the SMD rework station's wand held just beneath the bottom of where the test-tube will be. Do not turn on the heat yet.

[14] I've heard that the Germans get good results with kolophonium, better known as rosin.

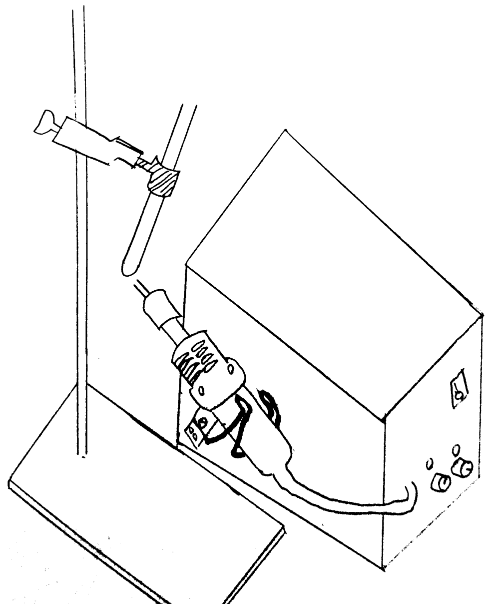
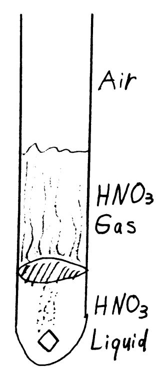


Figure 6: The clamp stand holds the test-tube next to the SMD rework station.

Place the chip into the test-tube with enough nitric acid to cover the chip and optionally add just a splash of sulfuric acid to make it attack the plastic instead of the bonding wires. For safety reasons, you will very quickly learn to do this while the glass is cold, just as you will very quickly and rather painfully learn that cold glass looks exactly like hot glass.

Place the test tube into the buret clamp. The tube should be slightly tilted, with the bottom closer to you than the top so that any explosive eruptions of boiling acid go away from your face.



With the chip covered in acid, turn the SMD rework station on with high speed and low heat. Slowly raise the temperature while watching the well-lit column of the test tube. The idea here is to create a poor man's reflux, in which the acid boils but the column of acid vapor above it remains beneath the lid of the test tube, unable to spill out. Shining a laser pointer into the tube will reveal the exact height of the column, as the laser is scattered by the acid but not by clean air.

Overheating the test tube will cause the acid to steam out, filling either the fume hood or your lab with acid fumes. All of the iron in the room will rust, your lungs will burn, and the fire alarm will trigger. Don't do this.

As the chip boils in nitric acid, the packaging will crumble off in chunks. This crumbling should continue until either the chip's die is exposed or the acid is spent.

You might notice the acid solution changing color. HNO_3 turns green or blue after dissolving copper, which greatly reduces its ability to break apart the plastic. Once the acid is spent, let the test-tube cool and then spill its contents into a beaker.

At this point, the acid might not be strong enough to further break apart the packaging, but it's still strong enough to burn your skin. HNO_3 burns don't hurt much at first, and light ones might go unnoticed except for a yellowing of the skin that takes a week or so to peel off. Sometimes you'll notice them first as an itch, rather than a burn, so run like hell to the sink if a spot on your hand starts itching. H_2SO_4 burns more like you'd expect from Batman cartoons, with a sharp stinging pain. It results in a red rash instead of

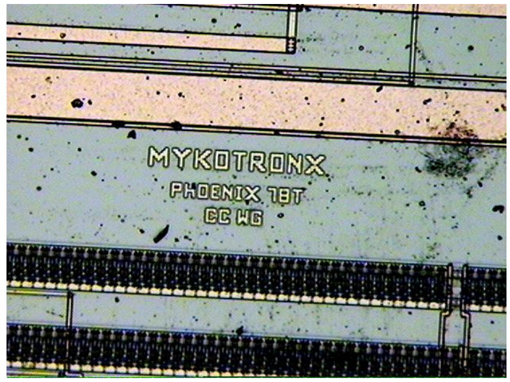


Figure 7: This is one photo of 1,475 that I took of the Clipper Chip.

yellowed skin.[15]

So now that you know better than to stick your fingers into the beaker of acid, use tweezers to carefully lift the die out of the acid and drop it into a second beaker of acetone. This beaker–the acetone beaker–goes into the ultrasonic bath for a few minutes. At this point the die will be partially exposed with a bit of gunk remaining, but sometimes larger chips will still be covered.

For best quality, the HNO_3 should be repeated until very little of the gunk is left, then a bath of only H_2SO_4 will clean off the last bits before photography.

These two acids are very different chemicals, and you will find that the H_2SO_4 bath behaves nothing like the HNO_3 baths you've previously given the chip. H_2SO_4 has a much higher boiling point than HNO_3, but it's also effective against the chip packaging well beneath its boiling point. You will also see that instead of flaking off the packaging, H_2SO_4 dissolves it, taking on an ink-black color through which you won't be able to see the sample.

After the final H_2SO_4 bath, give the chip one last trip through the ultrasonic cleaner and then it will be ready to photograph.

9.3 Photographic Equipment

Now that you've got an exposed die, it's time to photograph it. For this you will need a metallurgical microscope, meaning one that gives an image by reflected rather than transmitted light.

Microscope slides work for samples, but they aren't really necessary, because no light comes up from the bottom of a metallurgical microscope anyways. Small sample boxes with a sticky surface are handier, as they are less likely to be damaged in a fall than a case full of glass microscope slides.

For photographing your chip, you can either get a microscope camera or an adapter for a DSLR. Each of these has its advantages, but the microscope cameras are very often just cheap webcams with awkward Windows-only software, so I go the DSLR route. Through either sort of camera, you can take individual photos like the one in Figure 7.

[15] Here's a handy rhyme to remember safety:

Johnny was a Chemist's Son,
but Johnny is No More.
What Johnny thought was H_2O,
was H_2SO_4*!*

9.4 Photographic Procedure

Whichever sort of camera you use, you won't be able to fit the entire chip into your field of view. In order to get an image of the whole chip, you must first photograph it piecemeal, then stitch those photos together with panorama software.[16]

Begin at a known corner of the chip and take a series of photographs while moving in the same direction and keeping the top layer of your sample in focus. Each photograph should overlap by roughly a third its contents with the image before and after it, as well as those on adjacent rows. Once a row has been completed, move on to the next row and move back in the opposite direction.

Once you have a complete set of photos, load them in Hugin on a machine with plenty of RAM. Hugin is a GUI frontend to panorama utilities, and it allows you to correct mistakes made by those tools if there aren't too many of them.

Hugin will do its best to align the pictures for you, and its result is either a near-perfect rendering or a misshapen mess. If the mess is from a minor mistake, you can correct it, but for serious errors such as insufficient overlap or bad focus, you will need to do a new photography session. With plenty of overlap, it sometimes is enough to simple delete the offending photographs and let the others fill in that part of the image.

Figure 8 shows the complete, but reduced resolution, die photograph that I took of the Clipper Chip. This was built from 1,475 surface photographs that were stitched together by Hugin.

9.5 Further Reading

While you should get a proper chemistry education for its own sake, textbooks on chemistry as written for chemists don't cover these sorts of procedures. Instead, you should pick up books on Failure Analysis, which can double as coffee table books for their nifty photographs of disassembled electronics.

After mastering surface photography, there are all sorts of avenues for continuing your new hobby. Using polishing equipment or hydrofluoric acid, you can remove the layers of the chip in order to photograph its internals. The neighbors at the Visual6502 project took this so far as to work backward from photographs to a working gate-level simulation in Javascript!

Additionally, you can decap a chip while it's still functional to provide for invasive or semi-invasive attacks. For invasive attacks, take a look at Chris Tarnovsky's lectures, as he's an absolute master at sticking probe needles into a die in order to extract firmware. Dr. Sergei Skorobogatov's Ph.D. thesis describes a dozen tricks for semi-invasively shining lasers into chips in order to extract their secrets, while Dmitry Nedospasov's upcoming thesis is also expected to be nifty.

Neighborly thanks are due to Andrew Righter and everyone who was polite enough not to yell at me for the die photos that I posted with improper exposure or incomplete decapsulation.

Cheers from Samland,
—Travis

[16] For fancy things like recovering gates in delayered chips, more sophisticated software is needed, but panorama software suffices when only the top layer is being photographed.

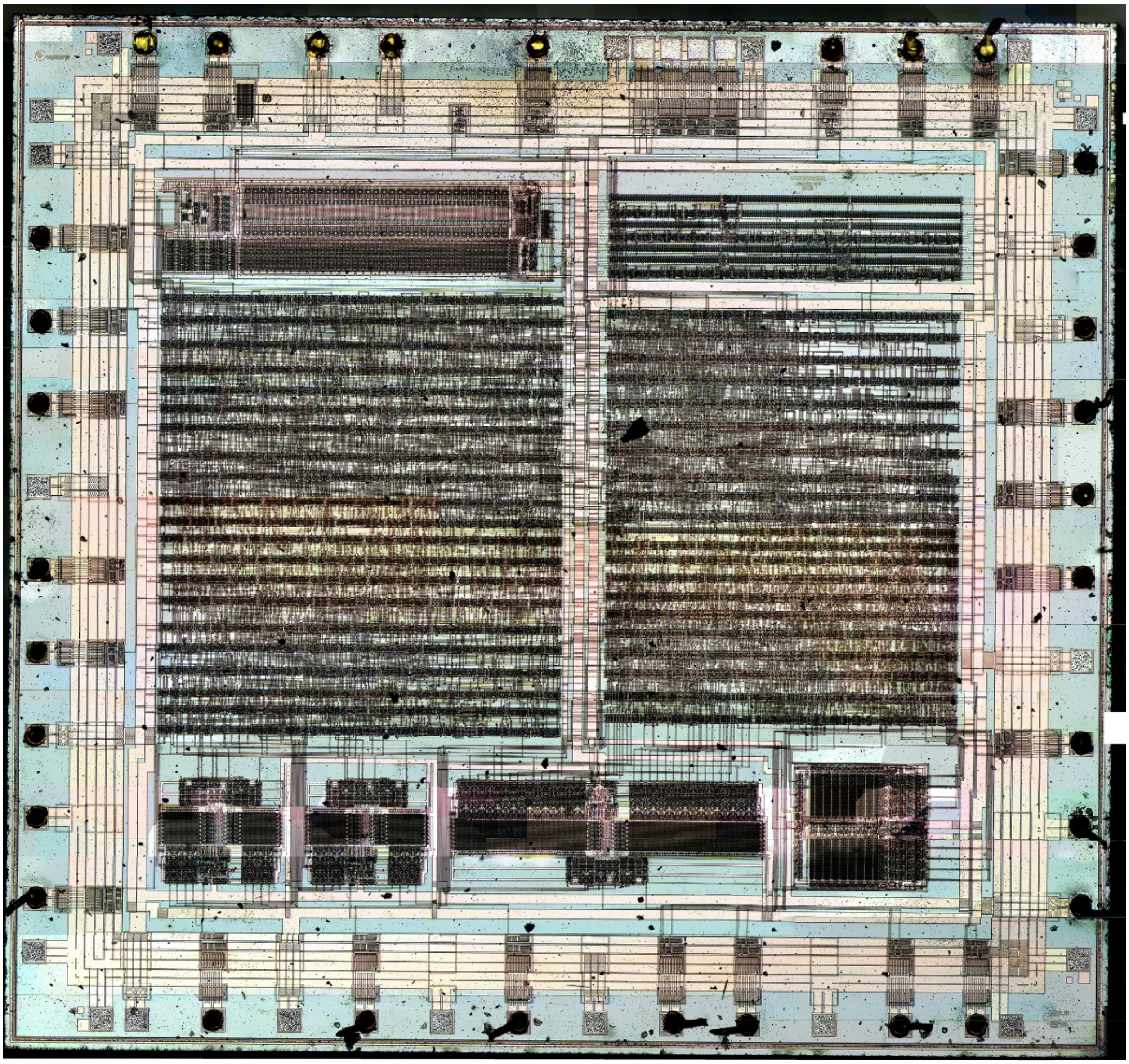


Figure 8: This is the complete die photograph of the Clipper Chip at reduced resolution.