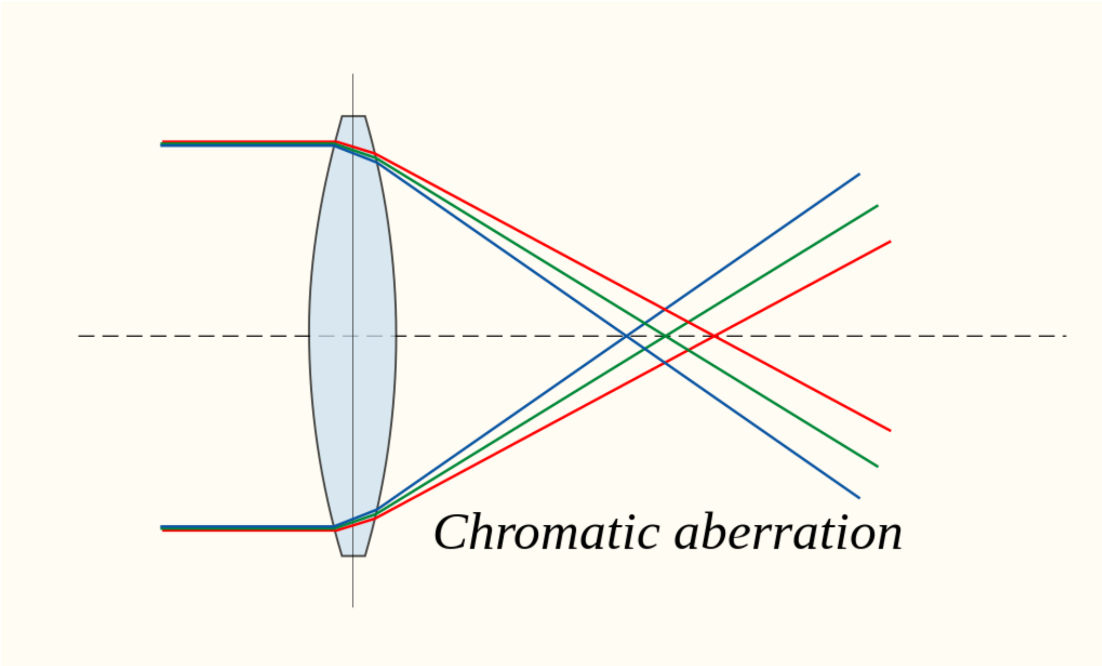
mamiya apochromatic lenses

Jun 15, 2024

This article is commentary about the Mamiya apochromatic (APO) series of lenses for RB67 and RZ67, issues that plague these lenses, and practical notes on repairing the 210mm and 250mm versions.

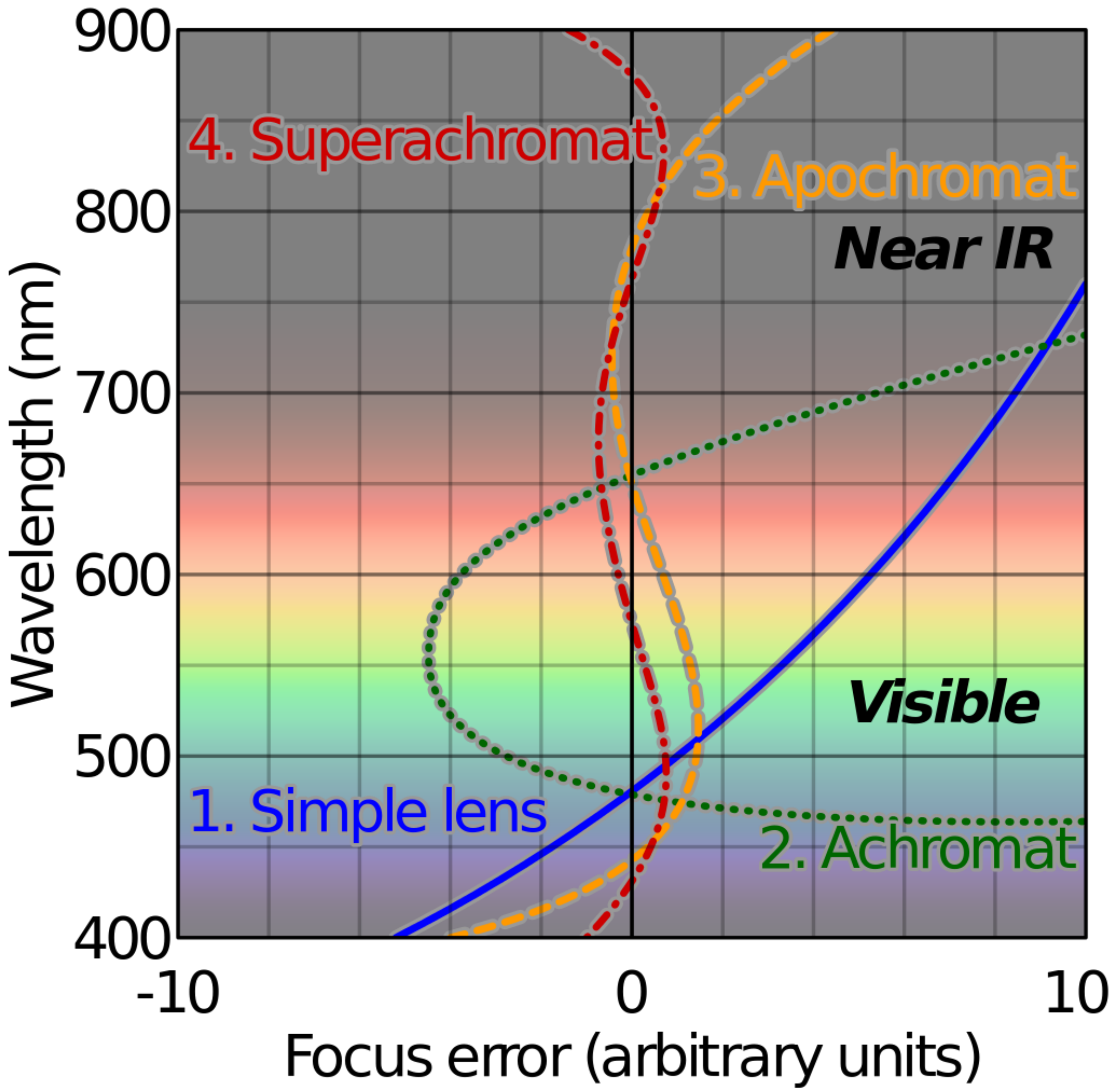
but first, wtf is apo

Through a single-element lens, the plane in which light will focus is dependent on its wavelength. For example, red, green, and blue light will focus in three different planes. That's not ideal for photography.



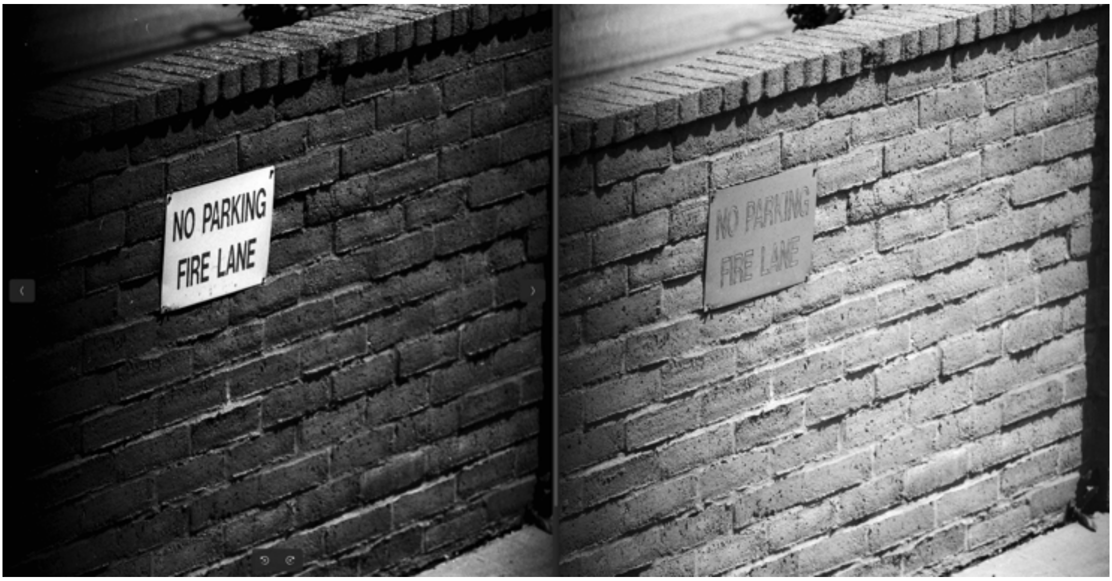
The achromatic lens is able to focus two wavelengths, and is the most common type of compound lens, with reduced error for the uncorrected wavelengths. This is good enough for most photography.

In contrast to the achromatic lens, the apochromatic lens brings three wavelengths of light into focus in a single plane, and further reduces the focusing error of uncorrected wavelengths. Cost increases as well.



An added benefit of APO lenses is that photography in the ultraviolet and near-infrared spectra avoids many of the focusing problems from which achromatic lenses tend to suffer (“focus shift”).

Ultraviolet test, comparing an APO lens under visible vs. ultraviolet light, no focus adjustment:



Infrared test, no focus adjustment between the initial focus and adding the IR 720nm filter:

Lens designers must strike the right balance between space constraints, materials cost, complexity, and desired corrections. Not all APO lenses (between and within manufacturers) are created equal. Not all APO lenses are true apochromats. But APO lenses tend to be better corrected for color and distortion.

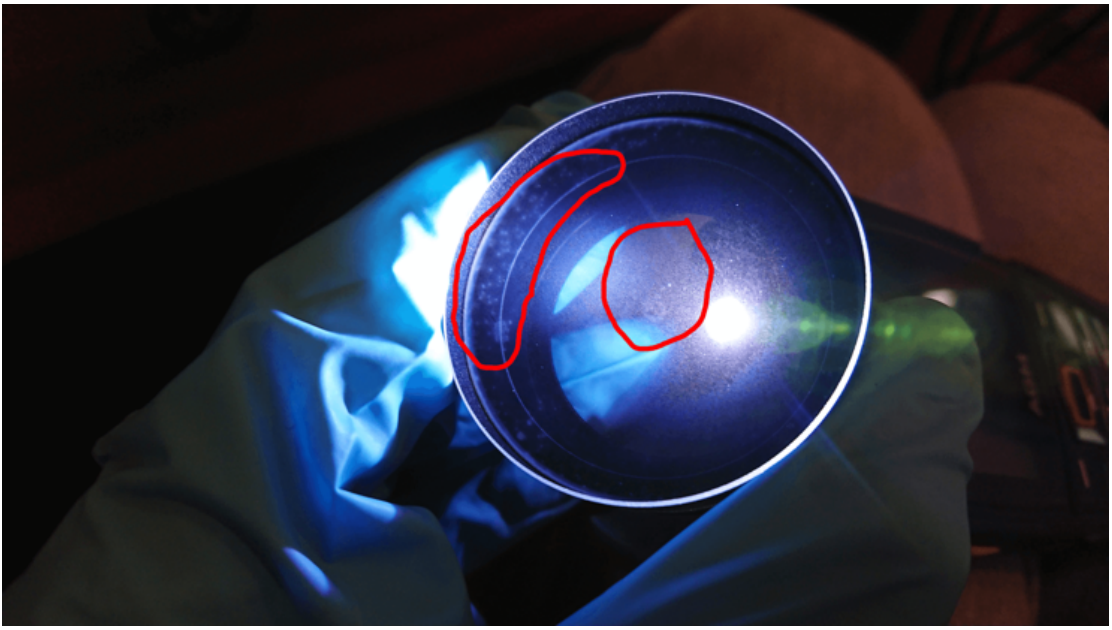
mamiya's apo series

The Mamiya apochromatic series for RB67 and RZ67 are some of the finest medium format lenses available, but tend to suffer pathologically from balsam separation even when properly stored.

Balsam separation is where the glue that cements two or more optical elements (i.e., pieces of glass) together begins to dry out or separate. This can manifest in several forms, ranging from haze to spots to rainbow patterns. Repairs can be costly, and it often makes more sense to replace, not repair, the lens.

Traditionally, organic Canada balsam was used to cement lenses because it it has similar optical properties to glass. Modern lenses use synthetic resins and urethane-based compounds.

In this example, the balsam separation is the haze covering the whole area, and there appears to be a sort of mottling around the edges. I'm not sure if that's biological growth, but it must be removed. These defects are between two pieces of glass; the outer surfaces are perfectly clean. It can't be wiped away.

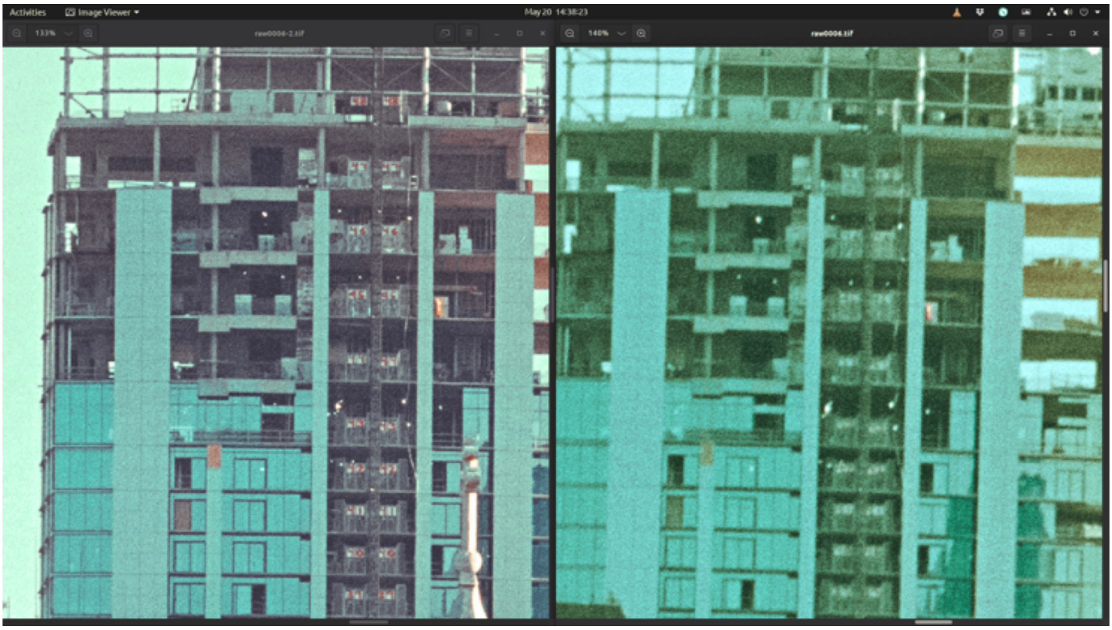


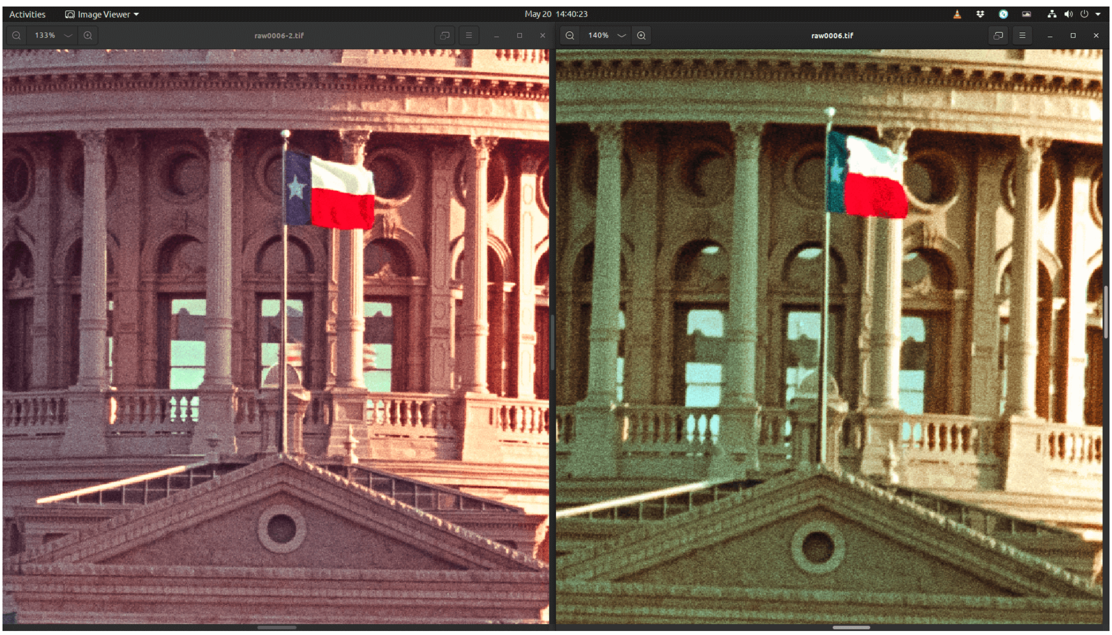
The RB and RZ APO series includes just four focal lengths: 210mm, 250mm, 350mm, and 500mm, and are major upgrades over the non-APO K/L 180mm, 250mm, 360mm, and 500mm lenses respectively.

The 500mm does not have cemented groups and is therefore unaffected by balsam separation. The 350mm has one doublet, while the 210mm and 250mm have two each. I am not sure how common balsam separation is in the 350mm version, as I've only seen one copy and they are exceedingly rare.

While Mamiya had been transitioning from the RB to the RZ system, releasing the APO series for the RZ system in 1988, they "backported" the same lenses to the RB system in 1990 using the same optical designs, alongside the RB67 Professional SD. These are “end game” lenses for RB67 owners.

Here is a preview of the 210mm APO K/L vs. a mint Sekor C 180mm. Disregard the color and grain differences; they were shot with two different film stocks and not edited. APO (left) vs. non-APO (right):





A more rigorous APO vs. non-APO comparison is ~~underway~~ completed.

Newer lenses (e.g. for Mamiya 7) are better designed and feature more advanced correction techniques, however have a less favorable minimum focusing distance. They cannot be directly compared.

Fun fact: 1998 RB Lens Prices vs. RZ Lens Prices show that only the 500mm APO Sekor Z cost more between systems, but the APO versions cost around twice as much as the nearest non-APO version.

The APO series could be had for around $17,500 in 1998, or $35,000 in 2024 dollars. Meanwhile, DIY repairs and market prices mean you can spend under $2,000 today to obtain the full series.

on balsam separation

The degree to which balsam separation will degrade image quality depends on which lens groups are affected, the severity of the separation, and the type of scene being photographed. Brighter scenes or scenes with bright areas may be affected more. Contrast, sharpness, and shadow detail will be reduced.

This problem is so pervasive in the APO series (except the 500mm lens) that even mint-condition specimens that have been properly stored since the 1990s might be unusable for photography.

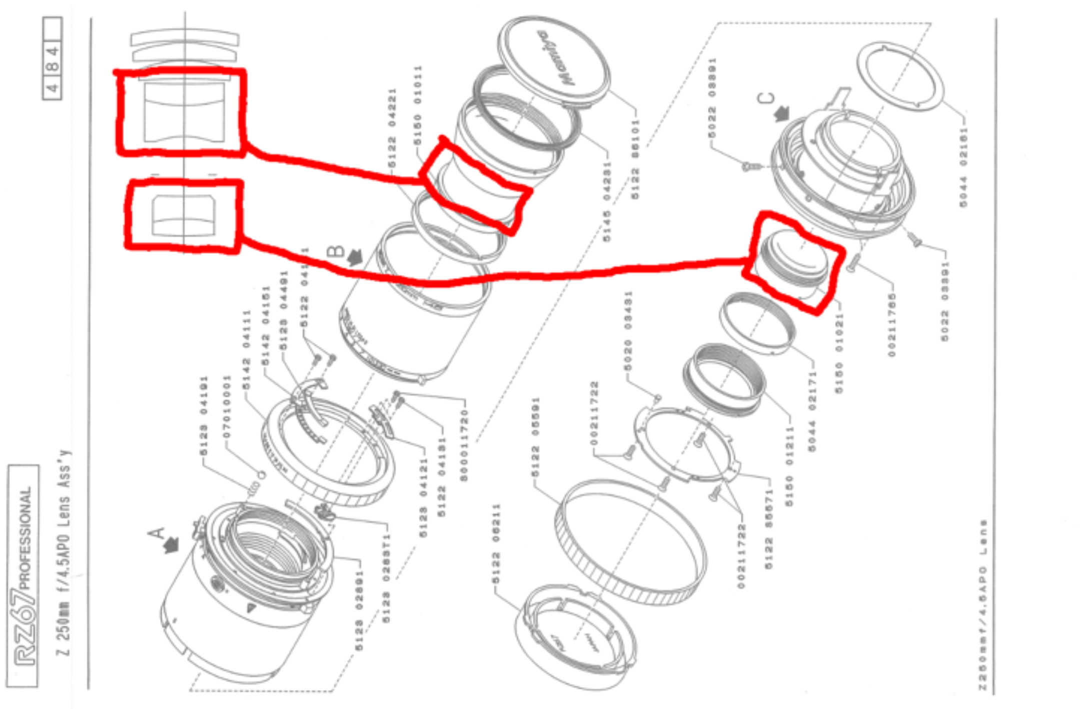
All except one non-500mm APO copy I've seen has suffered from some degree of balsam separation. Most non-APO lenses manufactured during the same time period do not seem to exhibit these symptoms, though I have seen some examples over the years, all less severe than the APO lenses.

Except for the 127mm K/L. Maybe they used the same adhesive?

This greatly reduces resale value, limits the availability of spare parts, and increases the difficulty in obtaining a clean Mamiya APO specimen. How many of these lenses are in storage or landfills?

Given the higher prices and reduced availability, it's no wonder these otherwise excellent lenses are not more common, especially when the non-APO versions are good enough for most professionals.

Official Mamiya repair manuals prescribe replacing entire lens groups as a single unit and do not recommend the type of repair that we will be doing (necessitated by the absence of spare parts).



As you can see, the glass is held in place by metal tubes. We will take advantage of this fact later to save some time and effort during the final stages of the repair. It also means we need to play on “hard mode.”

If you were to send your lens to a shop specializing in Mamiya repairs, it is unlikely they’d be willing or able to help. These repairs are simple in theory but fairly advanced in practice, and could take weeks.

These lenses are rare enough that spare parts are hard to come by.

the market

The APO series was not intended for a mainstream audience; it is for a niche market of professionals demanding the absolute highest performance of their equipment. The RB lenses were already available and “good enough” for 18 years, therefore many fewer copies of the APO lenses were ever produced.

The K/L versions were produced in fewer numbers than the Sekor Z versions. The current state of the market is that APO K/L lenses are rare, and seldom appear in public secondhand marketplaces in good condition with clean optics. When they do, they fetch astronomical prices–upwards of $2,000 USD.

Defective K/L APO lenses might cost more than mint non-APO K/L lenses.

The Sekor Z versions are more abundant and can sometimes be found for less than one tenth of the price of the K/L version, if they suffer from balsam separation.

I reached out to Bill Rogers to see if he had more detailed information about the APO series:

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   From : Bill Rogers <brctek@gmail.com>
     To : Zach van Rijn <me@zv.io>
Subject : Re: RB67 / 500mm APO

While the optical formulas are the same on many of these len
(K/L and Z), the physical barrels are not always the same so
there is not always a direct match.

It really depends on the lens. In some lenses, the front ele
group is the same part number in K/L and Z while the rear is
different part number and configuration.

While I have all Mamiya manuals, the 500mm APO service manua
just a parts breakdown and does not have details on element
spacing and other technical details, that would be with some
engineering drawings. The Mamiya 500mm service manual just t
the front element group as a unit...
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This is important for the following reason: many, but not all, of the optical elements are identical between the K/L and Sekor Z versions. The barrel design will certainly differ, but in many cases the glass is exactly the same. I know for a fact that the 210mm is one such case where the glass is exactly the same.

In the event that you find an APO K/L lens with damaged glass, you might be able to use the Sekor Z version as a lower-cost donor for spare parts.

This could also be relevant if you crack or scratch the glass on an existing repair because of the extreme temperatures or carelessness. Glass can handle the heat, but uneven heating or cooling will crack it.

As of writing, I do not have a comprehensive list. Barring documentation, this would require obtaining, then carefully disassembling, precisely measuring, and testing these rare and expensive lenses.

on repairs

You assume all risk in conducting such repairs. I am not responsible nor will I be held liable for any damage you might cause to your lens, your self, or your property. Read and understand all steps in their entirety before proceeding. Replacement parts may not be available, period.

At a high level, a repair is as simple as disassembling the lens, heating and/or using solvents to separate the affected cemented group(s), cleaning the elements, re-cementing them, and re-assembling the lens.

In practice, this is difficult and time-consuming, not to mention risky in terms of safety to both the person and the lens. The lens needs to be heated to nearly 400*F, or about 200*C, while applying force.

At these temperatures, the risk of fracturing the glass is high. You must take care not to burn the existing cement or it will be much more difficult, or impossible, to remove it without abrasives or nasty solvents.

It may not be necessary to heat the lens at all; it could be kept in solvents for weeks or months and come loose on its own, but there's no guarantee. Anecdotally, 3 days in acetone does nothing.

Razor blades may be needed to extract the glass and could slip. Chemicals can cause irritation. Glass could crack due to thermal expansion. The lens coating could get scratched or be damaged.

Crimped metal needs to be bent.

Fortunately it is possible to conduct such a repair at home, if one is careful. There is always a risk that you will permanently damage your lens. Do not attempt such repairs if you cannot risk breaking it.

Anecdotally, I suspect the APO lenses used a synthetic cement with a higher melting temperature than the non-APO versions of the same period. This difference in cement might be the root cause for why only the APO lenses seem to be so severely affected. If any repair professionals know, email me.

Typical industrial epoxy resin will fail around 400-500*F, so it is a logical conclusion in my opinion.

I will be using an organic Canada balsam from The Art Treehouse. If you opt for a UV-cure cement, then you will be granted exactly one chance to make the repair without a mistake. You have been warned!

The refractive index of the original Mamiya cement is unknown (to me). By definition, the RI of the two elements will be different. We want to match one of them as closely as possible.

Canada balsam has been used on lenses for hundreds of years, and I've had perfect success with it on Mamiya APO lenses. UV-cure optical cement comes in many forms and can be costly.

Balsam is sticky as hell, so be careful. Anything it gets on will need a thorough cleaning with acetone. It will ruin clothing. I use 1 mL syringes (such as for feeding rodents) to dispense it.

I recommend heating and cooling each doublet separately to avoid leaving glass in the oven longer than it needs to be, should the elements come apart at different temperatures.

materials

- I assume you already have the tools needed to disassemble your lens
- Canada balsam (2oz will cover hundreds of repairs)
- Powder-free nitrile exam gloves
- 1 mL syringes (without needle) to dispense the balsam
- Fresh razor blades, ideally in a utility knife or safe holder
- Acetone; up to one pint if you are not efficient, or as low as 4oz
- Small bowls or shot glasses for small quantities of acetone while you work
- Plenty (up to 50) of cotton swabs with paper sticks
- Lint-free cloths and/or plastic sheets to safely store lens components; I'd recommend keeping all the pieces together in a plastic food storage box
- Oven mitts with sufficient dexterity, or thick cotton kitchen towels, to separate 400*F fragile glass
- Canned air
- A pen light, or phone light, for closer inspection of dust/residue
- Small bar clamps with rubber pads (jaw size of 2" should be fine)

repair guide

250mm

I'll start with the 250mm APO K/L because there is an equivalent 250mm K/L and 250mm Sekor C lens for the RB system, and I want to conduct a thorough comparison test between them once repaired.

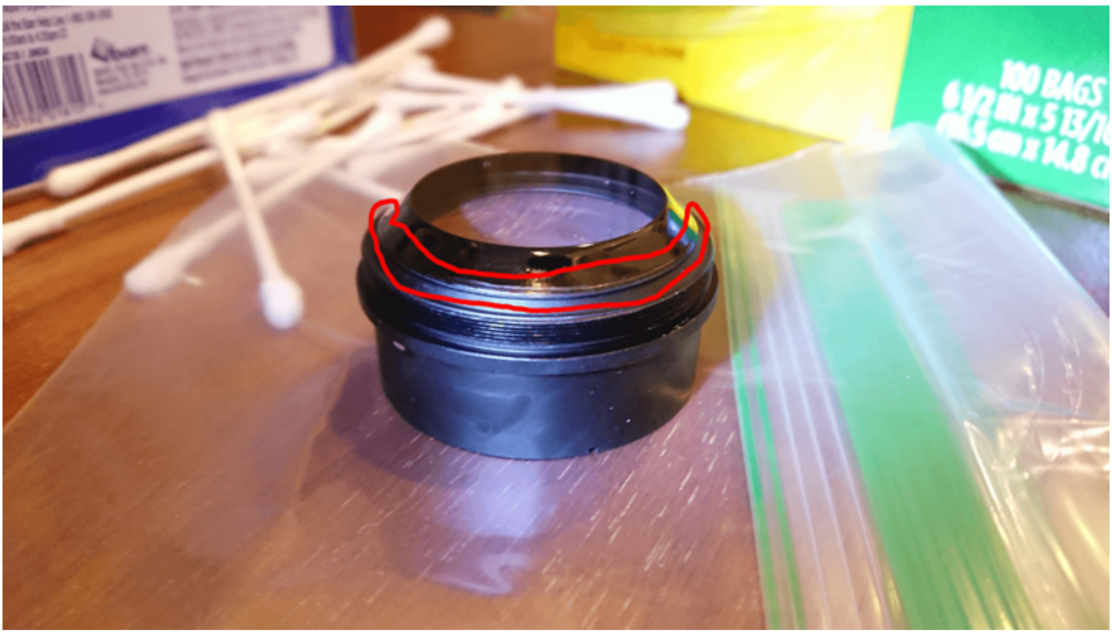
Some of these repair techniques would be better explained in a video, and I may release a video in the future, but for now my focus is on the process overview and discussion. Experience and technique are important but everyone will have their own opinions on what is the “right” way of doing it.

In contrast to the 500mm lens, the 250mm APO K/L is substantially longer than the 250mm K/L. I’m not sure why, since the Mamiya APO brochure mentions a shorter 500mm lens as being an achievement.

I bought a mint-condition (except for balsam separation) copy for under $300. Fun fact, it’s the second production copy, serial #1002. The front group separation can be seen at the beginning of this article.

This is not an amazing deal, but it’s acceptable given that it can be repaired for under $1 with just three hours of work over the span of a week. The rear group separation is not as severe but is still substantial:

The rear group is going to be much more difficult to repair because of a specific Mamiya design decision: they crimp/bend metal over the glass to secure it, then paint over it with a black urethane-like substance.



I'll address the rear doublet later. The technique is the same once the glass is removed from the metal.

Before you separate a doublet, draw a straight line on the side (perpendicular to the seam) with a pencil. This is to remember the exact orientation of the glass, and it will survive the oven and solvents.

Heating in the oven required temperatures of approximately 380*F (almost 200*C). You'll know it's ready when the rancid fumes fill your kitchen and make breathing difficult. This is not a joke or hyperbole.

This was not the pine-scented balsam I was expecting. Again, I suspect it's synthetic.

On a serious note, the fumes are actually irritating, and while I have no idea if they're hazardous to human health, you should have adequate ventilation.

I lined a Pyrex baking pan with two layers of aluminum foil, including the sides of the pan, to provide some cushion to prevent chipping the glass if the lens rolled into the sides. I kept the doublet on its side to avoid prolonged contact between the metal and the coatings, being careful to avoid letting it roll.

You'll want to start at 170*F or 180*F (the lowest your oven goes) and use a secondary oven thermometer for accurate temperatures. Increase the temperature by approximately 20-25*F every 10-20 minutes. This may take a few hours. Is it slow? Yes. Is the glass rare, heavy, and expensive? Yes.

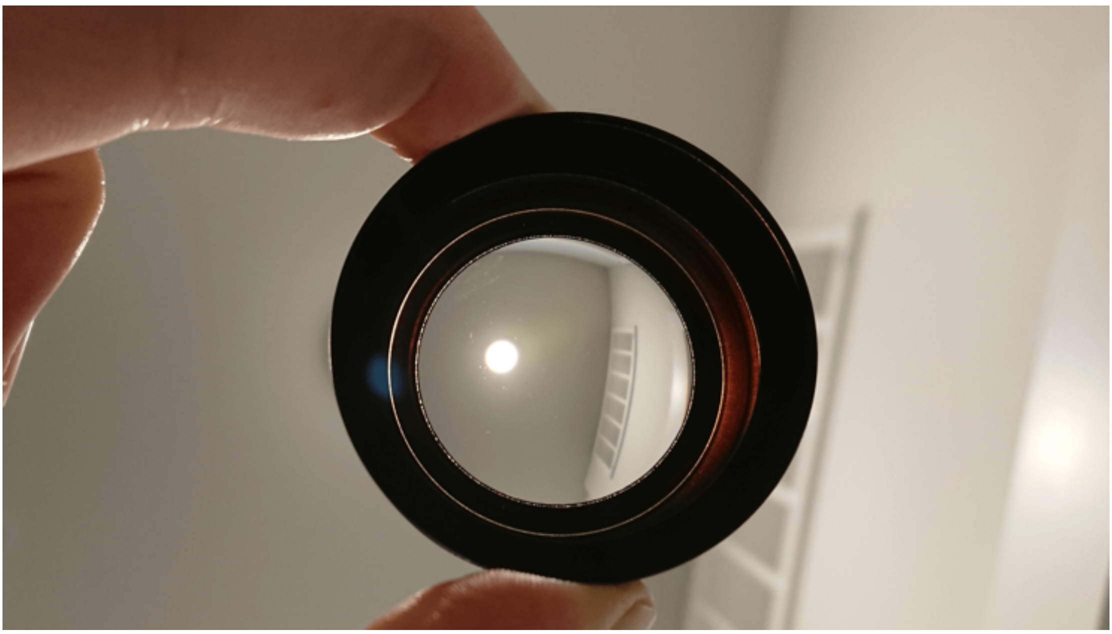
I've found that substantial force may be needed to separate the elements; in one case they slid apart, while in three other cases they "popped" apart with some force. I wrapped the glass in a thick cloth and applied shear force to slide the elements apart. The amount of force was "leaning into it pretty hard."

At 400*F. Be careful! Also, be quick with the glass out of the oven. It could crack within minutes at room temperature (I tested this once with worthless optics from a different lens).

Once the elements are separated, you’ll want to let them cool slowly in the oven. Depending on whether you live in a cold or warm climate, you might consider slowly lowering the temperature of your oven over a similar duration. In my case, I let the oven cool on its own undisturbed overnight.

Cleaning is accomplished with a huge amount of patience, acetone, and cotton swabs (with paper, not plastic sticks). Wipe in a circular pattern, with the diameter of the strokes matching the radius of the glass, and going slowly in a counterclockwise manner around the glass.

Cleaning could take anywhere from five minutes to more than an hour per element. Patience is the key to success. The marks in the above photo are not scratches; we will clean those off before cementing.



Once all of the residue is removed from both surfaces, remove any dust with canned air, and inspect the glass carefully under a bright light. I recommend turning off any fans for an hour before doing this.

Apply enough balsam, up to 0.25 mL, or a few drops, to the center of the concave surface while it is on a level surface. Gently place the corresponding convex surface of the other element on top, and slowly slide the upper element around to spread the balsam. Take your time. Let gravity do most of the work.

There may be air bubbles. You can see them better with a bright light. The trick to removing air bubbles is to slowly slide the upper element to one side (preferably in the direction minimizing the travel distance of the bubble to the edge), and once the bubble crests the edge, slide the element back to the center.

Stubborn bubbles may require a circular technique that is difficult to describe in writing.

If you mess up, you can separate the elements, clean them as before, and retry this procedure.

Recall that pencil mark? Ensure it's aligned by slowly rotating as needed.

In an optical manufacturing facility or laboratory, lasers and other expensive(tm) equipment would be used to ensure perfect alignment. This is one downside to a DIY approach, however I doubt you'll notice any difference unless you're conducting scientific experiments with this lens.

Once you have the balsam applied correctly, the doublet will need to set for at minimum 4-5 days, up to a month, in a room-temperature environment away from heat or direct sunlight.

If you have access to and are handy with the right tools, you could make a vise or custom block to align the elements perfectly. Be sure to do this before you separate the doublet.

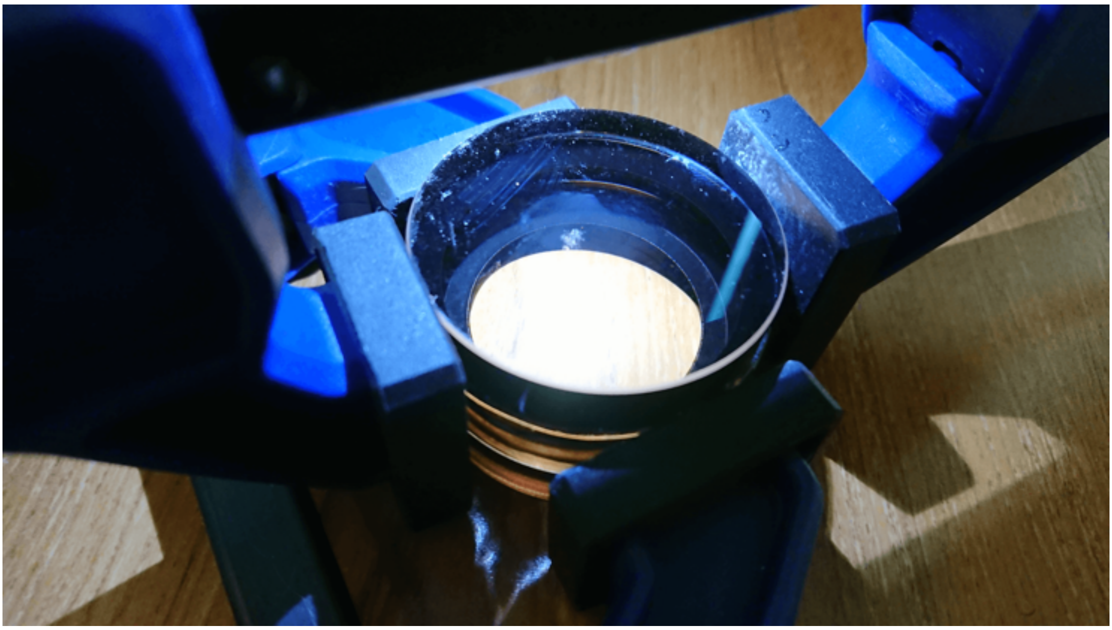
Or, if you're impatient, you'll remember that the glass originally slid into a metal tube with tight manufacturing tolerances, and will be arguably the most accurate way to align the elements.

Since the balsam takes at least 4-5 days to set just enough to stand on its own, but not long enough to need to be heated again, we can take advantage of this fact and use regular bar clamps to keep it together well enough for a few days, and then slide it into its final resting place, the metal tube.

One simple alternative to clamps is to use sewing pins and a piece of rigid foam to construct a “cage” around the doublet. Place a 35mm film canister filled with coins or nuts on top to provide some weight.

Start by securing two degrees of freedom. Don’t worry about clamping the elements together yet.

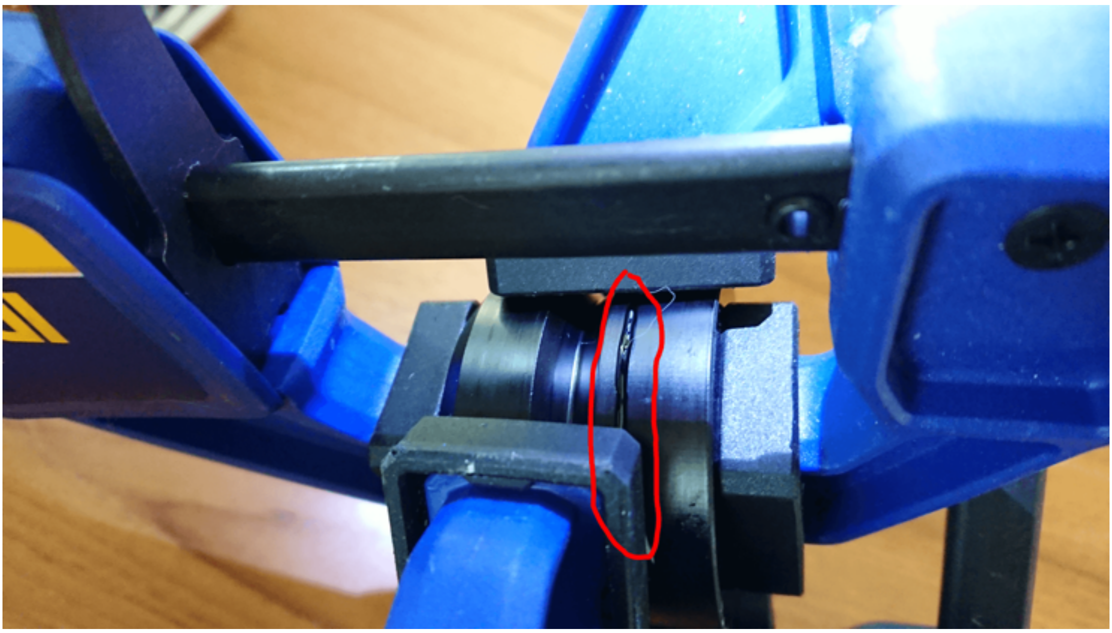
The amount of force I use is just enough to hold the clamp onto the work piece under gravity. It need not be any tighter. Wait a minute or two and observe any drift. Adjust as needed.



When applying the third clamp, note that you are clamping convex and concave pieces together. If you apply force anywhere except the center, the elements will slide apart. You don’t need to be perfect here, but try to ensure that if any sideways force is applied, it’s directed into one of the other clamps.

Once again, wait a few minutes to see if there’s any drift. Adjust as needed.

Here is a view from the side showing how large and thick this glass really is:



Do not worry about excess balsam leaking out of the seam. Once it hardens enough (in 4-5 days) we can scrape it away with a clean razor blade. **DO NOT APPLY SOLVENTS!** You'll want to clean it as well as possible, so as to ensure it is still possible to remove the glass in the future should that be necessary.

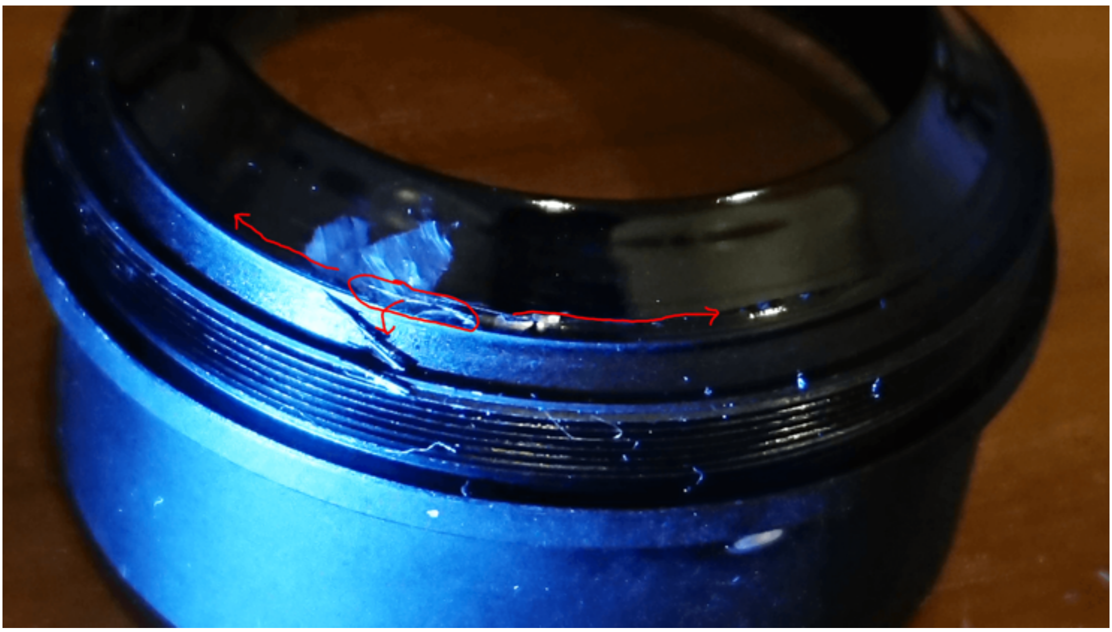
By this point only the edges of the seam have hardened up, so the elements may begin to slide apart if too much sideways force is applied. That's all right, just be gentle. We're almost finished with the repair.

(Worst case scenario: after months, you would need to soak the whole assembly in acetone for a while).

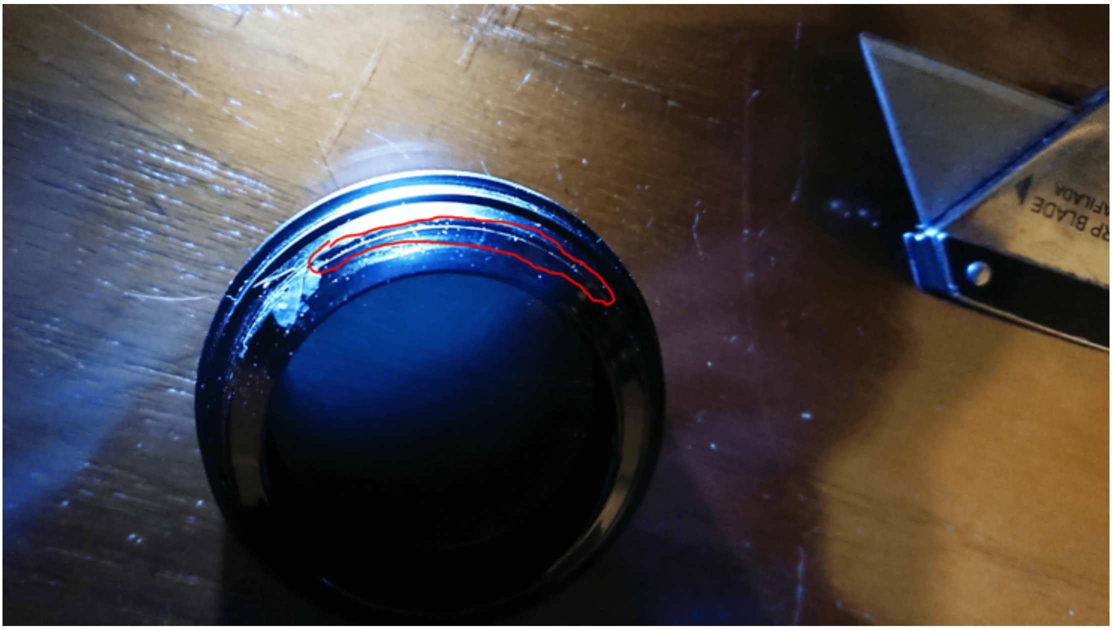
Carefully clean the polished glass surfaces with fresh acetone to remove any balsam, fingerprints, dirt, and dust. Any balsam or fingerprint residue on the edges or along the seam should not be touched.

Insert the doublet into the tube and assemble the front half of the lens. Put it aside.

Let's tackle the rear doublet. To give you a sense of just how tedious this is, I've scraped away some of the black plastic paint down to the underlying glass. The shiny line is where a thin bit of metal starts. This is crimped over the bevel of the glass the whole way around the lens. There is no other way forward.

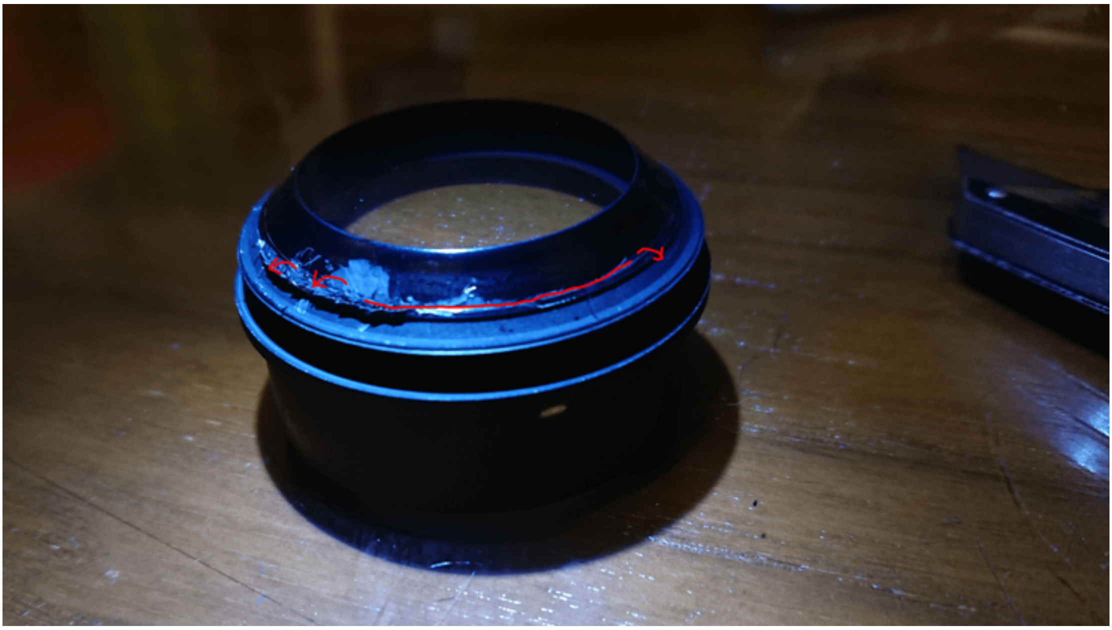


To simplify the process slightly, I've scored right above the metal (down to the glass) with a razor so that solvents will penetrate and help to loosen the plastic paint. The paint is important; we'll restore it later.



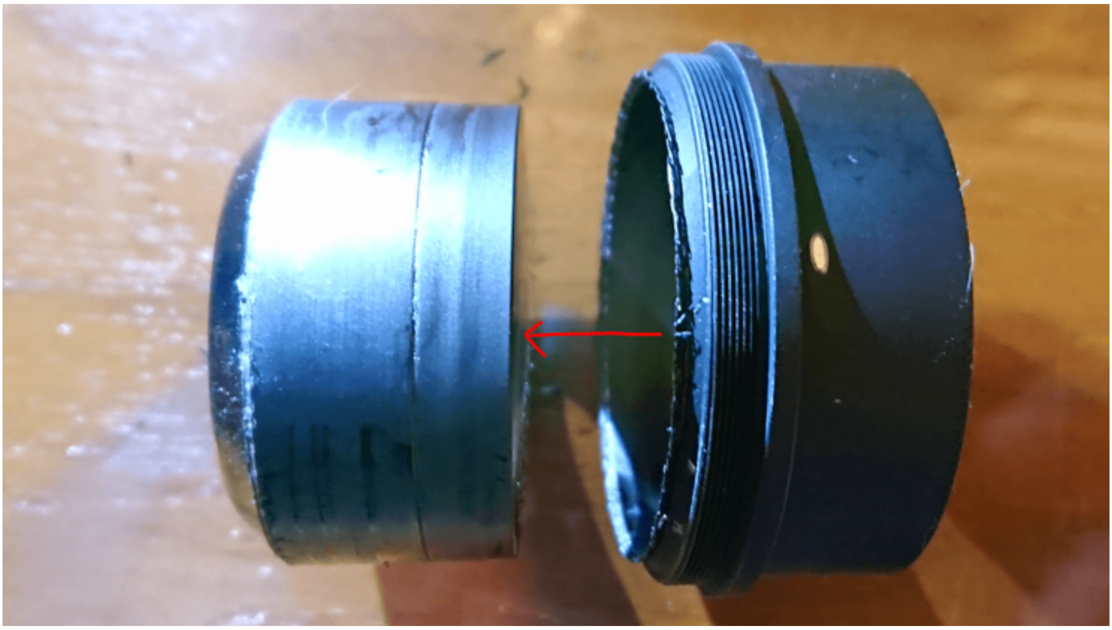
Now we soak it in acetone for a few hours:

Begin by carefully inserting the edge of a fresh razor blade between the metal and the glass, which follows the angle of the bevel, or about 45 degrees. Once the blade is inserted about 0.5-0.7mm, pry the metal outward. Repeat the procedure all the way around. It gets easier once it's started, I promise.



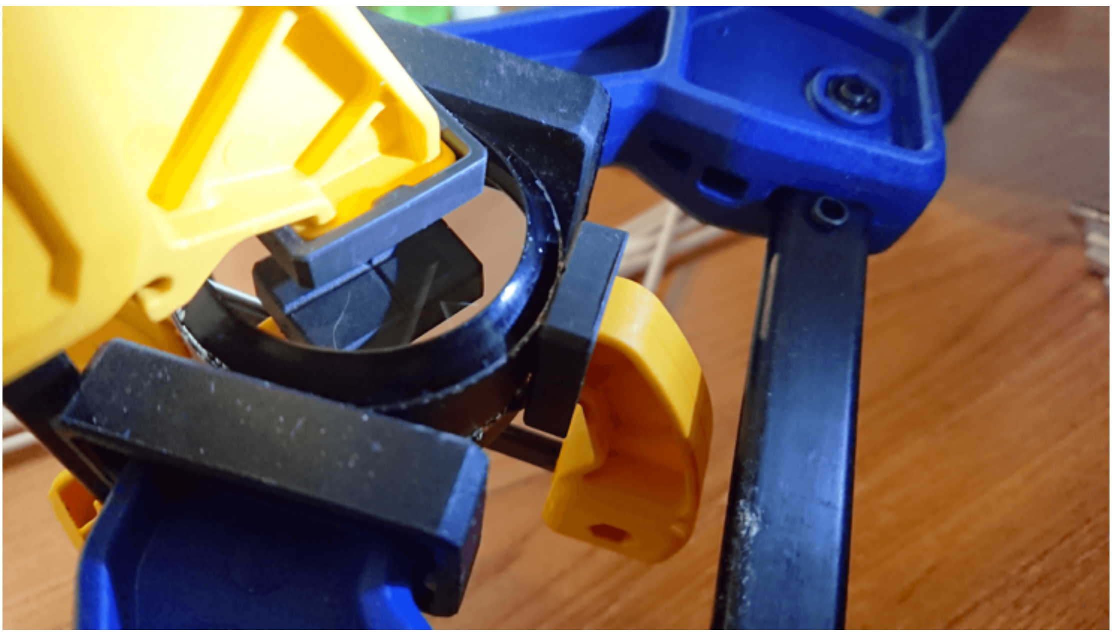
This can take just 5 minutes if you work diligently, but could take up to a half hour. In the end, you should have something like this, with hopefully no blood or chipped glass:

Once the metal is pried open, there is nothing else to hold the doublet in place. No adhesives are used, because the metal was sealed over with plastic. Simply slide it out:



Now that the rear doublet is free, repeat the same separation procedure. Begin by marking it with pencil, and toss it (gently) into the oven as before. With less surface area, it should come apart with less force.

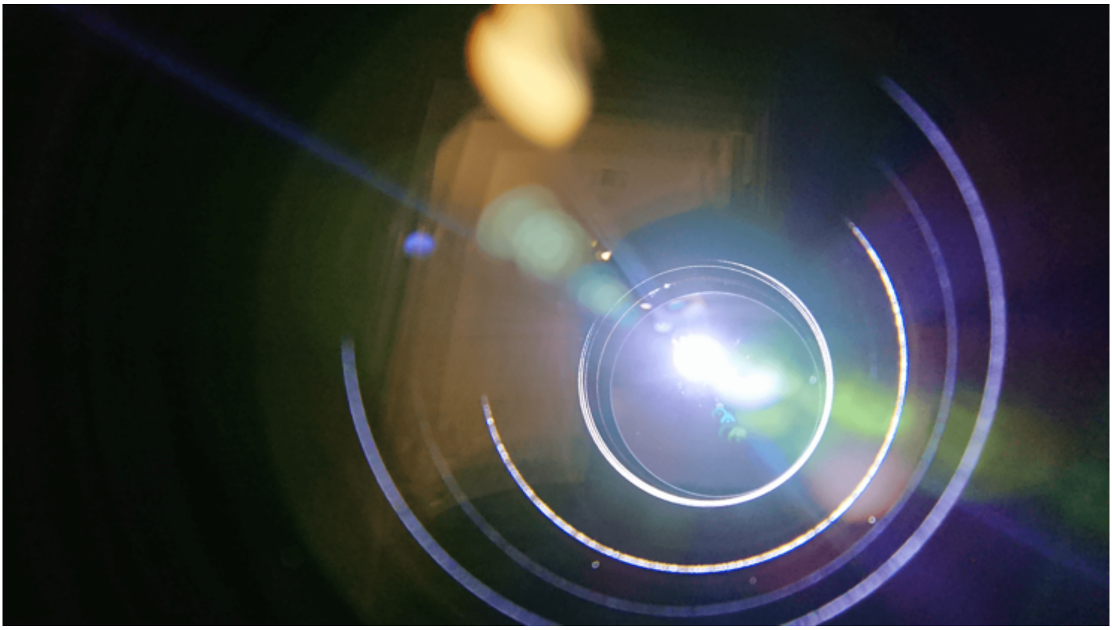
Clean, cement, and clamp the elements. Wait 4-5 days. Scrape the excess balsam, clean the polished surfaces, and blow out any dust. Restore black ink or paint as needed to reduce internal reflections.



When it comes time to return the rear doublet to its metal tube, we'll crimp the metal in the reverse direction using a similar technique and either a razor blade or a flat-head screwdriver. I'd avoid glass or stone countertops, because it is harder to see what you're doing and risks scratching the surface.

Be extra careful during this step. It is easy to slip and you risk scratching the coatings or the glass.

Finally, assemble the rest of the lens. It is ready to use immediately, and will continue to set over the next few months (or longer?). Insert Hoover Dam cement reference? Here are the results after assembly:



210mm

I bought a secondhand K/L on eBay with a damaged front element and balsam separation, and a secondhand Sekor Z with balsam separation for under $100.

In this case, I knew I needed to separate both cemented groups to fix the balsam separation, and in the process swap the chipped front element with the clean one.

I used the same procedure as above, except in the case of the 210mm lens, the front doublet comes out of its metal tube easily, while the rear doublet requires stripping the plastic and uncrimping the metal.

In this case, the metal appears to be stiffer than with the 250mm lens, maybe a type of brass instead of alumimum. It is thicker and takes more force to pry open.

All other steps are exactly the same.

350mm

The 350mm lens has only one doublet (in the rear), but I am not sure if it is held in place by crimped metal or a threaded ring. This would determine the effort involved in a similar repair.

I'll update this article once I learn this information.

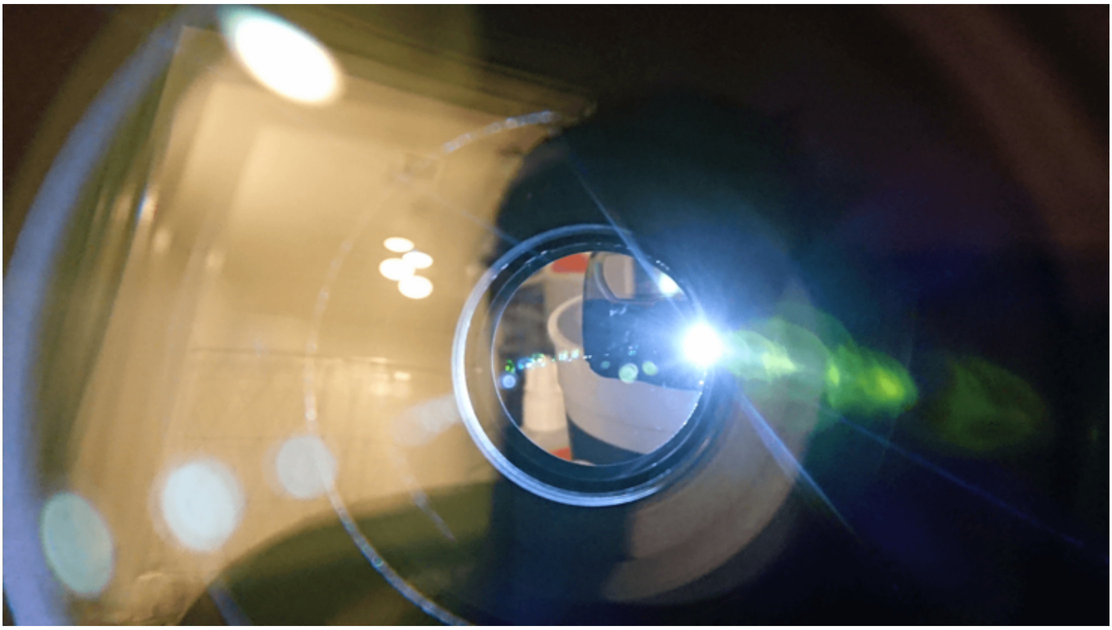
500mm

As mentioned previously, the APO 500mm does not have any cemented groups, and is therefore immune to these issues. If haze occurs, it can be wiped off with acetone.

conclusion

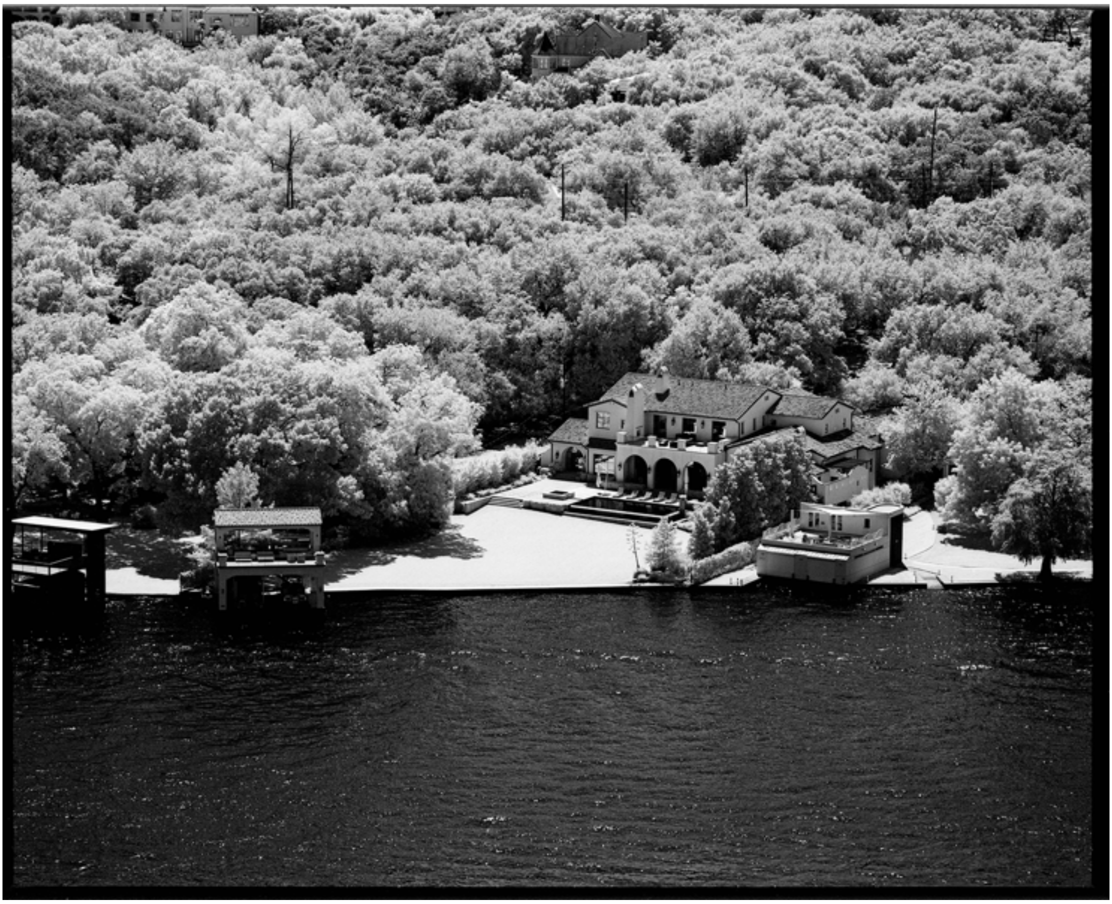
The Mamiya APO lenses are absolutely worth the time and effort to repair them, if you can find good deals on defective copies. RB67 users will have a harder time but find this to be immensely rewarding.

Repairs are not too hard to do at home, especially as repair shops are unlikely to want to take on the job. It might be possible to remove the crimped-in doublets with a hydraulic press and extreme care, but I've found the razor blade method to work reliably every time. Have a better idea? Get in touch.



Be on the lookout for exciting tests. I'll be comparing the 250mm APO to its non-APO counterpart soon, as well as doing more experiments with ultraviolet and infrared photography.

Here's an infrared teaser, 250mm lens with a 720nm filter, no focus adjustment, Rollei IR in HC-110:



Not bad, eh?

commentary

trichromatic photography

Mamiya's APO brochure includes a curious line:

> *An additional striking feature of the negatives produced by the APO lenses is their ability to be precisely overlapped to produce exacting vivid color reproduction.*

In trying to parse this statement, does it refer to trichromatic photography, which is to take three photographs with colored filters on black-and-white film, and overlap them to obtain a color photograph, because distortion has been so well corrected that this is a now a practical endeavor?

- https://www.ilfordphoto.com/the-trichrome-process/
- https://www.ilfordphoto.com/trichromes-colour-photos-with-ilford-hp5/
- https://www.35mmc.com/18/05/2023/creating-trichrome-color-photos-with-ilford-hp5-my-experiences-and-mistakes/

Extensive searching yields no exact results. What does “precisely overlapped” mean? Literally, multiple frames on negative (or positive) film, but why would they be overlapped except in the case of trichromes?

I’ll assume it is. This statement irks me because I think this is an exceptionally niche subject and would be unlikely to appeal to even the APO-interested audience, so why mention it?

I reached out to local photographer Anthony Maddaloni for a second opinion about whether Mamiya is referring to this process or something different, and he confirms my suspicions:

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   From : Anthony Maddaloni [REDACTED]
     To : Zach van Rijn <me@zv.io>
Subject : Re: apochromatic lens question

It does!

It’s so odd that mamyia talks about that.
I’ve very rarely seen this applied to anything!
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And now this is on my TODO list, because most or all of the examples I’ve seen before have been of relatively poor quality. Previously I’d written this off as superfluous masturbation in the context of contemporary film stock offerings, as it is neither simpler nor cheaper than shooting color film.

Except when used to artistic effect, such as a non-stationary subject! This is how opinions are changed. I’m not sure why online resources don’t stress the importance of APO lenses for this process.

physics and lens design

Referring to the first line of this article, the reason that the plane of focus changes with wavelength in an uncorrected lens is because the refractive index is a function of wavelength.

Corrected lenses make use of “low-dispersion” glass, which counteracts the “high-dispersion” glass to net a system with reduced error. Apochromatic designs require “anomalous dispersion” glass.

I won’t pretend to begin to understand the physics involved in designing apochromats nor the materials, but I recommend reading the Schott TIE-29 technical publication and this master’s thesis.

This is awesome.
