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Photolithography

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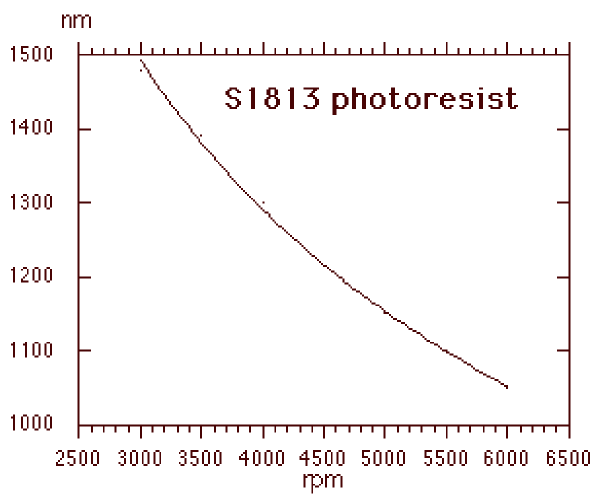
Photoresist

Photoresist is a light sensitive liquid used to form thin film. There are several types of photoresists and we will look into some of them, to see how to use them and how they work. The main thing with photoresists is that they change chemically when exposed of light of high energy. The chemical reaction is different in various resists, but generally, they become either more or less acidic. The more acidic the resist are easier it is to remove with an alkali solution such as photoresist developer or NaOH. Because of this property, we can form the photoresist into patterns.
The resist that becomes more acidic while exposed is called positive, because the exposed resist is removed. Likewise, the resist that becomes less acidic is called negative resist.

Thin film photoresist
Whenever use of photoresist is necessary it has to be applied as a thin film. The reason is that the total energy needed for exposure is dependent of the thickness of the film. Therefore, for high resolution a thin and smooth film is necessary.
Thin film photoresist is created with a high-speed spinner that can rotate the sample with a specific velocity for a specific time. All resists have specific rotation vs. thickness dependence and it is necessary to control and decide rotation speed (see *graph 1* for the thickness dependence of S-1813, which is the resist we are going to use).



*Graph 1.*Thicknessdependence for s-1813

Soft and hard-bake of photoresists can be different depending on the type of resist. All photoresists need to be dried (soft baked) before exposure, but some needs special care, so it is always a good idea to check out datasheet before usage (at Chalmers these can be found at http://fy.chalmers.se/assp/snl/).

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Hard-baked photoresist becomes tolerant to exposure and is not solved in same way as soft-baked resist. This is used to ensure the resistance against etching.
The specifications for s-1813 are that it is soft-baked at 110^{o}C and hard-baked at 130^{o}C).

<u>Exposure</u>
When exposing a photoresist film with correct light it becomes more or less acidic (pos. or neg.) and therefore there is important to ensure that the correct areas are exposed. It is also important to expose correctly (right amount of time). If we expose to short, the photoresist will not be acidic enough, and there will be areas of resist remaining after development (*Fig.1a*). But there is also problems with to long exposure, where the diffraction and "focus resolution" can make the protected areas exposed (*Fig.1b*). These effects are present at all exposures, but during short exposure, the parasitic effect is very small.

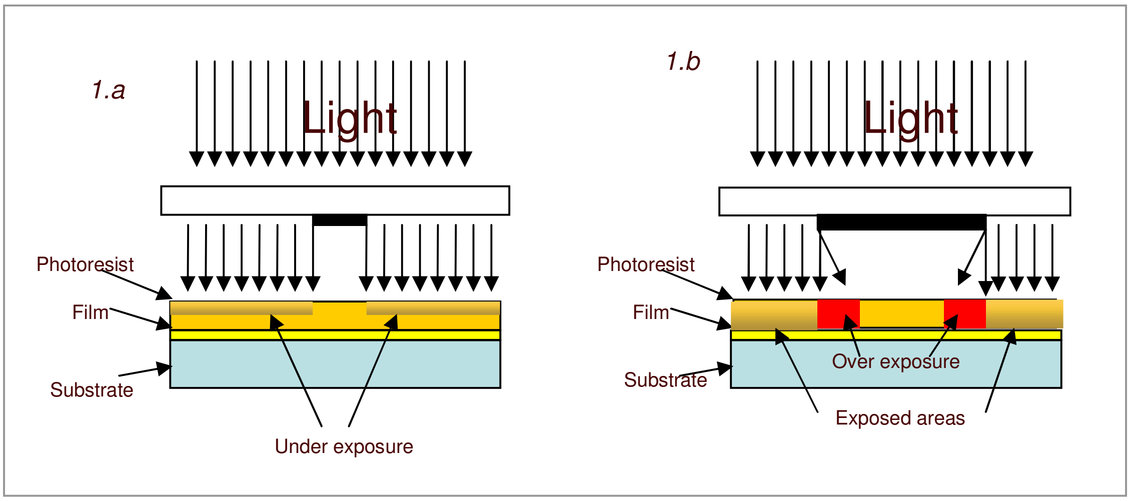

Fig 1.a) the result of to short exposure is a semi exposed film where some additional film will be remaining after development. b) the result of overexposure is exposed areas under the mask.

<u>Development</u>
The development is the process where we remove the acidic parts of the photoresist. This is done with an alkali solution optimized for the photoresist used (for s-1813 the developer MF-319 is used). When developing the pattern it is important to use correct development-time. The developer will also remove the less acidic film (but much slower). So if the film is developed for to long time, the less acidic parts will be partially solved (*fig 2a*). Therefore, it is better to start with a short development and then additionally develop if the film is not fully developed. Even when the film is fully developed, there will be some rounded edges due to both "parasitic" exposure and this "parasitic" development (*fig 2b*). Most of the times this will not affect the continuous processing, but it can be problems if this thinned resist is removed later.

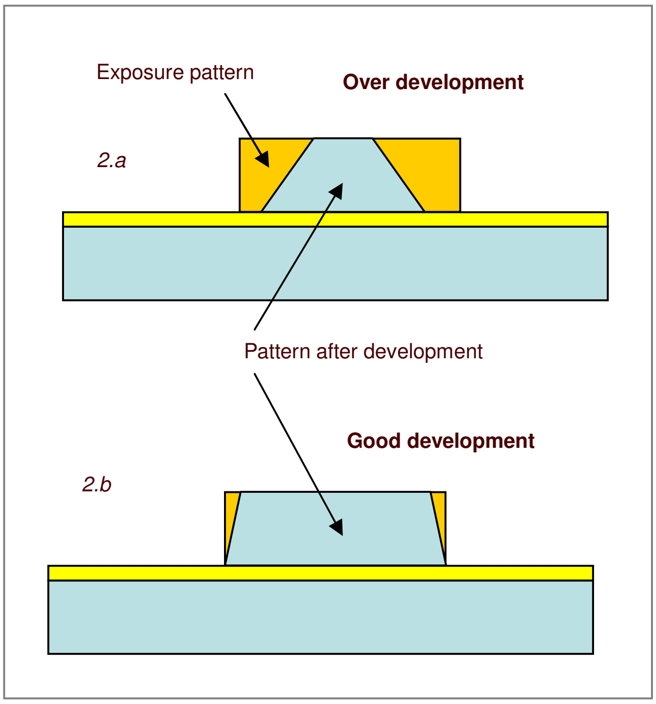

fig:3. a) Here the pattern has been developed to long and a lot of the less acidic film has been removed. b) This pattern has been developed correctly and there are only small defects at the edge.

The Maskaligner

A maskaligner is used to transfer a specific patter to a sample with high precision. To do this we will need a parallel UV light (~400 nm) source that shines threw a mask with the pattern we want. Here at Mc2 we have two types of maskaligners, contact aligner and projection aligner.

Contact maskaligner is the most common aligner, and alignment operates with the mask pressed to the sample. For adjusting alignment, it is necessary to lift the mask to not scratch the surface of the sample. Then the parallel light is applied for exposure through the mask and pattern is transferred. This maskaligner can also be used for proximity alignment, which is when we have a small space between the mask and the sample.

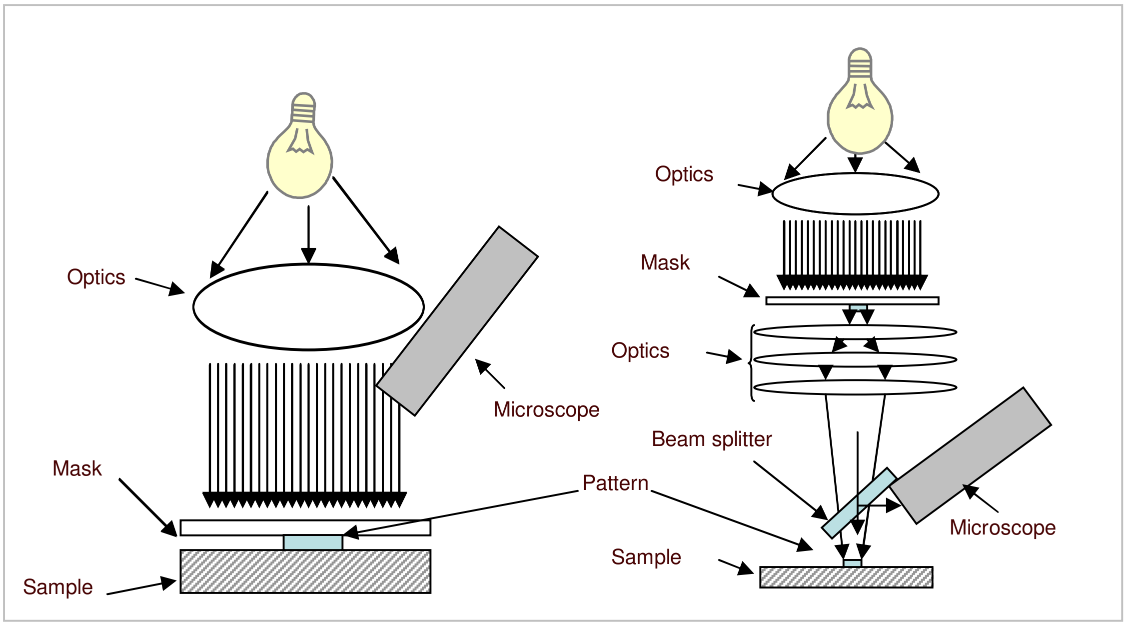

Fig 3. LH. Contact aligner with optics creating parallel beam and mask pressed against sample. RH. Projection maskaligner where the mask is placed on a optical package that will project structure down on sample.

If we look at the Projection Maskaligner, we have a different setup where the mask is placed on an optical package (almost like in a camera) that will project the mask image down to the sample. With this system, you have the possibility to look also under the mask (This can make alignment of dense patterns easier). In the projection aligner, good focusing is necessary to obtain good result. However, it is possible to make some adjustments, like magnification, with the optics. There is also one difference with this microscope. It is designed with a beam splitter, which will let the light from the pattern through at the same time as the microscope can look at the sample. This is necessary for alignment, and result in the possibility to look at areas (of the sample) covered by the mask. In this lab, we will use a projection maskaligner, and in *appendix* we have a better image of the optics of the maskaligner we are going to use.

The light source is very important in a maskaligner. Standard photoresists (ex. s-1813) needs to be exposed with light around 400 nm (UV), and there is some resists that needs DUV (~260 nm). This light is created with a high power (~500 W) mercury-lamp mounted in a safety-box in the maskaligner (Both to protect samples from the light and to protect eyes). The safety box also contains a positioning system for the lamp, so that it can be positioned correctly for the optics (impossible to create parallel light otherwise). These lamps must be warm before they deliver the correct wavelength and intensity. Therefore, first thing to do before apply the photoresist-film is to turn on lamp.

Optics and mask in maskaligners needs to be transparent to UV and DUV, and therefore all the optics and the masks is made out of, for example, quartz or other special glass. The glass also needs to be optically perfect, to avoid deformation of the pattern from the mask. The mask is created with e-beam lithography (to obtain high resolution) on a quartz glass covered with chrome, and then the chrome is etched away chemically, to not destroy the glass.

Different fabrication steps including photolithography

Etching

One common usage of lithography pattern is as an etch-mask. In this process, the pattern is created on a film that is to be etched in a pattern. Then the sample is etched chemically or with ion-bombardment, until all the uncovered film is etched away. The chemical etch can cause under-etch in the film (the chemicals is etching in under the edges of the pattern) *fig 5b*. The ion-etch can also create some edge problems, and will etch down in the underlying structure.

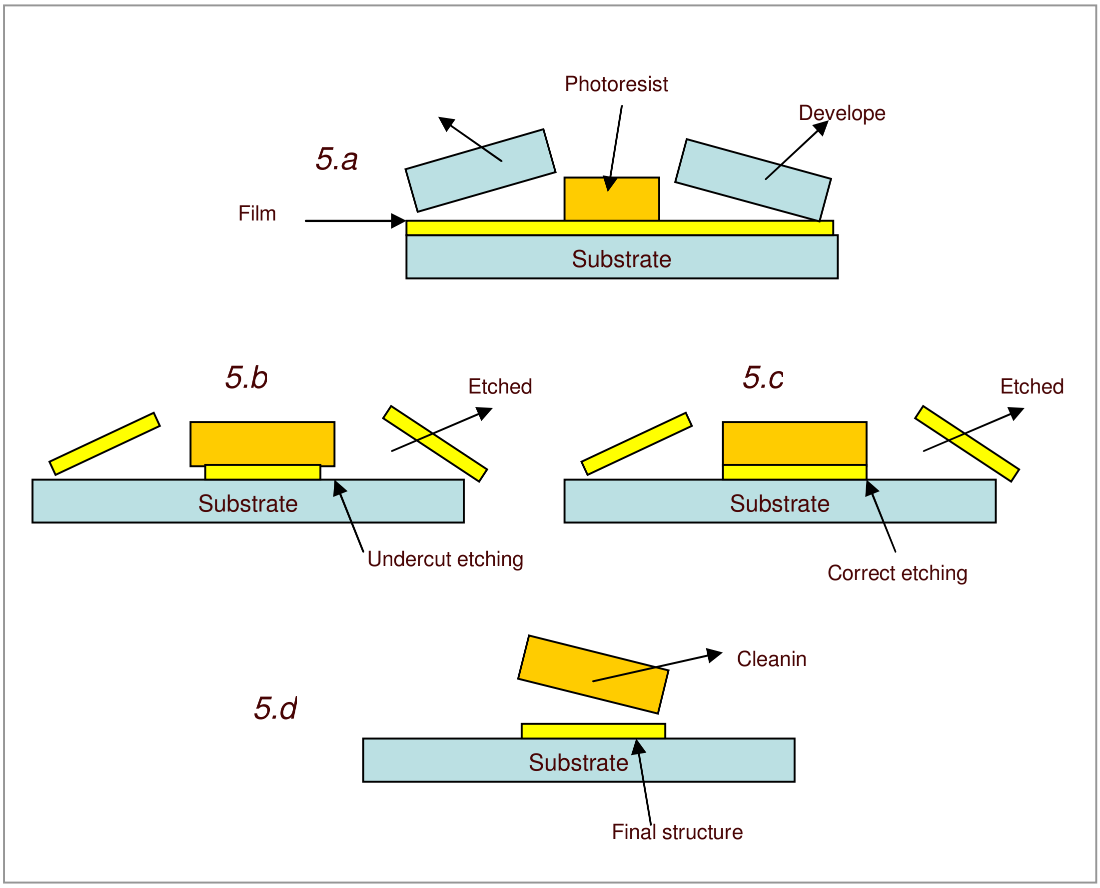

Fig 5. a) Pattern is developed to open up where we want to remove film. b) Here the film has been under-etched and pattern has changed. c) This etching has no undercut and the pattern is still ok. d) Cleaning the sample to remove resist is finishing the fabrication.

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Liftoff

Another method to create a patterned film is with liftoff. This method is based on two-layer lithography, where the top layer is photoresist placed on a liftoff-layer (like lol-2000) that will be completely removed in specific solvents *fig 6*. During the development of patterns in this film, the liftoff-layer will be "under developed" creating an edge structure like in *fig 6b*. If a film is deposited onto this structure, it can be removed with a liftoff and, the film deposited in the opened areas will remain *fig 6c*.

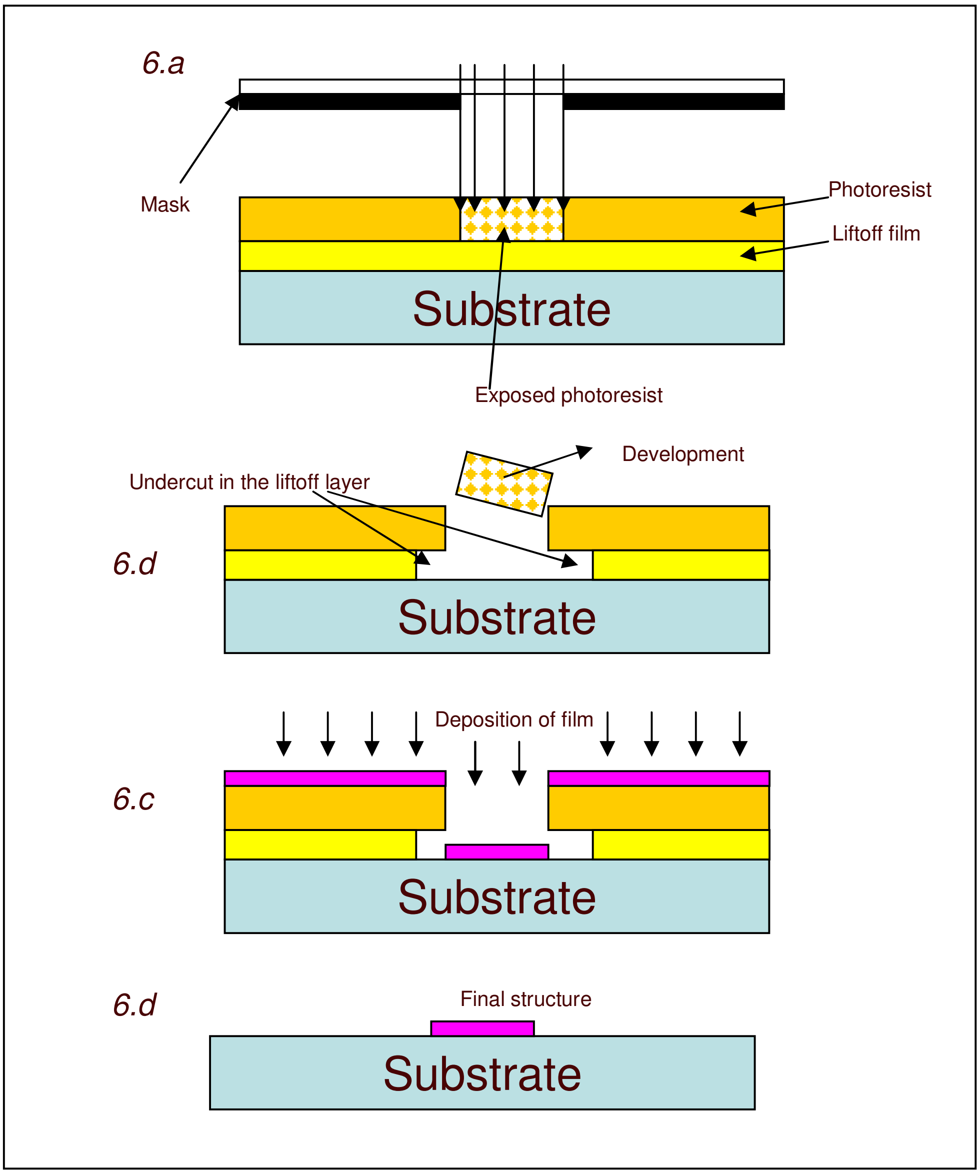

Fig 6. a) The photoresist is exposed with a negative pattern. b) Under development the liftoff-layer forms an undercut structure. c) When a film is deposited it will stick to the substrate at the opened areas. d) When the liftoff layer is removed the film stuck to the substrate will remain.

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Lab instructions (projection aligner)

1. Power up the maskaligner
    - Turn on the power to the lamp and press ignite, until lamp on (change in sound from source). The lamp needs to warm up about 10 min.
    - Open vacuum, pressured air and nitrogen valves on the wall.
    - Press power on maskaligner.
2. Place photoresist
    - Turn on workbench with spinner
    - Set hotplate to 100 ^{o}C
    - Clean a pipette and fill with some photoresist (S-1813)
    - Place sample at spinner and start rotation (foot pedal)
    - Set rotation speed to 5000 rpm and time to 60 s
    - Stop rotation, place a drop of resist in centre if substrate and start
    - When the spinner stops, place the substrate at hotplate (100 ^{o}C) for 2 min to dry the resist
3. Alignment and exposure
    - Place the mask at the mask holder (Make sure the mask is clean)
    - Place the sample on the plate under optical package in the area where your desired structure is located
    - Focus the microscope on the surface of the sample (impossible to focus pattern with bad microscope focus)
    - Place the structure where you want it and focus with top ring of the optical package
    - When structure is focused and in correct position, move microscope away from light and expose for 20 sec
4. Development
    - Fill a bottle with photoresist developer MF-319 and one with pure water
    - Wash substrate 20 sec in developer and immediately wash in water
    - Dry with nitrogen blow or in spinner
    - Check pattern in microscope
5. Etch
    - Etch sample several seconds, until you can see that all the cupper is gone and immediately clean in water
    - Dry sample and clean resist away with acetone

Congratulations, you have now preformed a full lithography and etching process.

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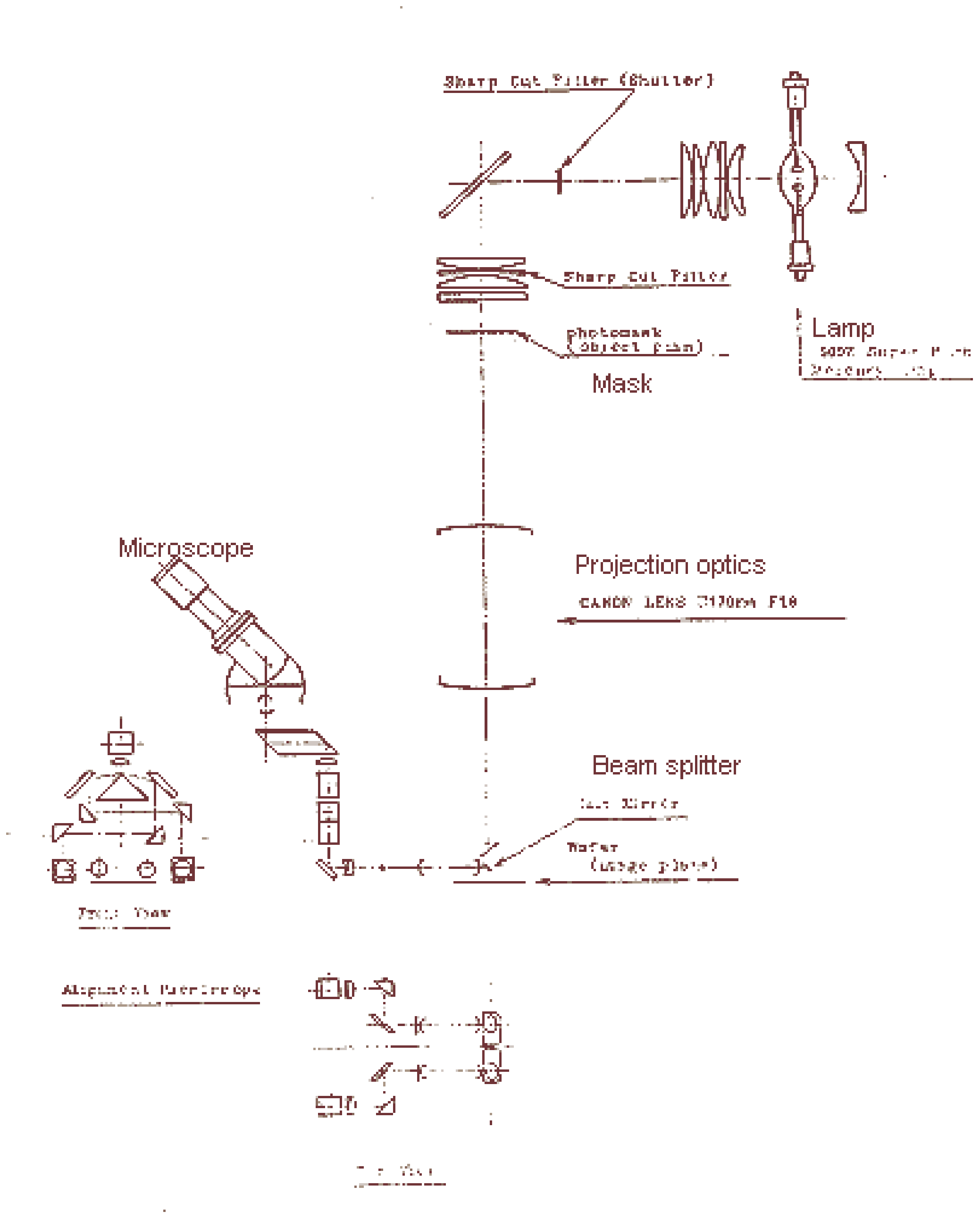
Appendix.



FPC-210 OPTICAL ARRANGEMENT