Glass gobo patterning process

By Maarten Rymenans, Belgium, 22/08/2002
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Introduction

This paper describes the necessary steps for successful patterning of glass gobo's manufactured by Drix. The paper describes patterning of both aluminium and chrome gobo's, with or without black layers.

The patterning process consists of four steps:

- Exposure
- Development of the photoresist
- Etching of the black and/or aluminium layer
- Stripping of the photoresist

Exposure is done by placing a film on a UV exposure unit and aligning the gobo on that film. Care must be taken that the gobo is in good contact with the film during exposure.
After exposure the gobo is developed. This is done in a alkaline solution. The exposed photoresist will dissolve and the underlying aluminium layer is cleared.
Then the gobo is etched in an acid solution. All metal that is no longer protected by photoresist is etched out, and the image becomes visible.
After etching the remaining photoresist is stripped using a ketone dissolver, eg acetone.

In order to obtain good and repeatable results, several precautions must be taken and good processing technology must be maintained.

Film requirements

Before starting, it must be ensured that a good quality film is made to obtain a well defined image. The film requirements are:

- Pin-hole free
- Dust-free
- Dot size compatible with imaging and etching process
- Good flatness

Pin-hole free means that the film must be free from voids. To ensure a pin-hole free film, the photoprinter must be maintained very well: rollers must be clean, air filters need to be replaced regularly and the machine in general must be kept dust-free. When handling the film care must be taken not to scratch or damage the film in the image area. Also the film must be kept as clean as possible.

When using FM rastering (stochastic raster), the dot size of the image must be compatible with the imaging and etching process. This applies to the making of greyscale gobo's. The dot size of the image should be an integer multiple of the pixel size of the film. It is generally not advisable to make the dot size equal to the pixel size since most photoprinters are not able to produce a crisp image at maximum resolution. If a clear pixel is surrounded by dark pixels on a film, generally the clear pixel will be grey due to the limited resolution of the photoprinter, making it unusable for further processing. It is strongly advised to make the dot size equal to two, three or four pixels, so that crisp clear and dark dots are defined. Eg: if the printer resolution is 3600dpi, the pixel size will be 25.4mm/3600=7.055µm. Then the dot size should be 14.11µm or 21.165µm or 28.22µm, …etc. It is extremely important that the dot size is an exact multiple of the pixel size to avoid variations in the dot size. If the dot size would be set at 20µm instead of 21.165µm using a 3600dpi photoprinter, then the result will be a film with mixed dots of 21.165µm and 14.11µm. This may result in undesirable horizontal and/or vertical lines in the image, but worse it may also result in unreliable patterning if the exposure unit is not able to transfer the smaller dots reliably into the gobo photoresist.

When using a normal raster (lpi), too small dots can be avoided by setting the contrast curve in such a way that single dot pixels cannot occur. This way small isolated dots which cannot be repeatably printed or etched are avoided.

The film should be checked for pinholes prior to use. Pinholes on the film can be corrected with black or red film corrector ink on the reverse side of the film.

Finally, check the properties of the film under a microscope. Make sure that the smallest white dots in the film are really open. If the photoprinter is out of focus, or if the film exposure dose is wrong, a grey shade may reside inside the smallest white dots. Such a film cannot be used for successful gobo making, as it would force you to overexpose the gobo to allow exposure of the smallest openings. This overexposure will then lead to a loss of resolution on the isolated black dots.

In general: make sure you have a good film, then make sure you have good gobo exposure, correct development and correct etching. This sounds trivial, but very often people try to compensate a poor film or poor exposure by making changes to development or etching, with heavy loss of resolution as a result.

Gobo Exposure

The photoresist is sensitive to blue light and broadband UV. The maximum sensitivity is around 400nm. The energy required to expose the photoresist is $100mJ/cm^2$. All processing can be done in a room with red, orange or yellow light. Fluorescent lamps with an orange-yellow colour filter are recommended. To test if the room light does not harm the gobo, take one gobo and cover it halfway with black tape. Then allow the gobo to be exposed by room light for several hours. After that, remove the tape, develop the gobo normally and check if a print from the tape is visible. If no print is visible then the room light is safe for processing gobo's.

To determine the correct exposure time of a gobo, it is required to have set up the development chemistry first. It is a general rule that the development chemistry has to be correct and that exposure dose should be adjusted to get the correct result. Never adjust the developer concentration or developing time in an attempt to correct bad exposure.

It is strongly recommended to start with a known good developer and correct development time and temperature (eg Arch HPRD402, development time = 90-120sec at 20°C. Use 90s for greyscale, 120s for vector images).

When having a good developer chemistry, the correct exposure dose can be determined by gradually increasing the exposure time. This can be done on the same gobo by moving a sheet of black paper between the gobo and lamp and moving it further in steps of 15s or so.

Please note that it is always required to make a slight overexposure. If exposure is too critical some area's will not be fully developed, and the slightest amount of photoresist on the gobo will block etching action. For greyscale gobo's an overexposure of 50% is recommended. For black and white gobo's (without fine dots) an overexposure of 100% is recommended. The best amount of overexposure will vary depending on the exposure unit used.

When exposing gobo's care must be taken that the gobo is in good contact with the film. Please note that both the film and the gobo are not completely flat, which will result in diffused light between film and gobo. This diffusion will result in incomplete exposure of small clear dots and will reduce the size of small black dots. To avoid diffusion, the UV beam from the lamp should be as parallel (collimated) as possible, the glass plate on which the film is placed should be strong enough to avoid bending and the gobo should be pressed to the film during exposure.

Before exposure the gobo has to be aligned to the film. The film should have marks or a round circle around the image to assist for positioning of the gobo. When aligning the gobo to the film, care should be taken not to damage the gobo or the film. No force should be exercised on the gobo during alignment and only a minimum of movement should be allowed. A major source of pinholes is the movement of the gobo over the film, damaging the photoresist.

The gobo must always be exposed with the emulsion side of the film in contact with the gobo. Film corrections should be made on the non-emulsion side of the film. Otherwise the ink will form a bubble on the film, hampering flatness and causing diffusion.

Care must be taken that both the gobo and the film are very clean prior to use. As the photoresist layer on the gobo is only a few µm thick, and as many dust particles are larger than that (eg human hair or pieces of it have an average thickness of 60µm) dust particles between film and gobo may damage the photoresist layer and/or the film, resulting in pinholes.

When the gobo is properly aligned on the film, it must be pressed to the film with a distributed force, either by applying a weight on the gobo, or by putting a top plate over the gobo and applying vacuum. Make sure not to move the gobo once pressure is applied.

It is important that the film is kept cool during exposure. If the light source heats up the film, then the film will deform during exposure leading to loss of resolution.

A suitable exposure unit

A suitable exposure unit will generate a parallel (collimated) beam of UV light, has a shutter system, allows the gobo to make good contact with the film and is practical to use.

The best broadband UV source is a mercury vapour discharge lamp. Such a lamp produces UV light at 365nm, 406nm and 435nm wavelengths. The photoresist has high sensitivity for these wavelengths. The peak sensitivity is around 400nm.

A suitable setup has a Hg lamp beaming light upwards. Above the lamp is a shutter plate that moves away from the lamp during exposure. The shutter can be either mechanically operated for a simple unit or motor driven for a unit using a timer. The construction of the unit should be so that no light leaks outside the unit while the shutter is closed. Above the shutter a glass plate of 3-5mm can be used to hold the film and the gobo to be imaged. It is advisable to use quarz or borofloat glass since normal window glass will not transmit UV light very well.
The unit will require cooling. It is recommended to force cooling air downwards with cool air coming in under the glass plate and hot air leaving around the lamp. In that way the glass plate and the film are kept cool, which is a basic requirement. The gobo (or several gobo's) can be pressed on the film using one or more weights, or a vacuum system can be used to press the gobo to the film and supporting glass plate.

A Hg lamp needs approx 10 minutes time to obtain full UV intensity. Never attempt to set the exposure dose by switching the lamp on and off: the UV dose will not be stable, the lamp may not restart when it is hot and lamp life will be short. The best way to control the exposure dose is by use of a shutter system. It is recommended to leave the lamp on if the system is to be used again the same day. Please note that the UV intensity will decline when the lamp ages. Generally lamp life with good UV intensity will be 1000 hours.

An experimental exposure system using a 125Watt Philips Hg discharge lamp, with a distance between lamp and film of 230mm and using a regular window glass plate of 3mm thickness results in an exposure time of 2 minutes to image greyscale gobo's. The overexposure time is included in these 2 minutes.

Please note that both our matted aluminium and reverse black gobo's have the photoresist sitting on a reflective side. This means that UV energy which passes the photoresist is reflected back into the photoresist, almost doubling the amount of light which passes the resist. With our forward black gobo's, the resist is sitting on the black side. While this black coating is not fully absorbing in the UV area, the amount of UV reflected back into the resist is less than with the other gobo's. Therefore the exposure time of forward black gobo's may need to be increased somewhat.

On the market systems can be found to expose printed circuit boards using fluorescent UV discharge lamps. These systems have three major disadvantages : The exposure dose is controlled by tuning the lamps on/off, the lamps are placed close to the glass plate leading to heat buildup and since there are many lamps in such a system the light comes into the film under a wide angle leading to excessive diffusion. Because of these reasons, it is almost impossible to make consistent exposures on such a system.

Gobo Development

Once the gobo is imaged, it can be developed. The developer will dissolve all exposed photoresist. It is very important to keep the developing chemistry stable and to adjust the exposure dose only. To startup a new process, it is important to get started using a known good developer, such as the Arch chemicals HPRD402. Developing time in this developer is 90-120 seconds at 20°C. Use 90s for greyscale images and 120s for solid images.
Most other commercial developers will also develop the photoresist in the 60 - 120 seconds range.

It is important to keep the temperature of the developer stable within +/-2°C. Since it is used at room temperature, the lab room must be either heated or cooled to keep the temperature stable. If the developer is to be used in a hot area that has no cooling facilities, then the best way is to choose a shorter developing time and a higher working temperature (eg 25°C) and to keep the bath at that temperature at any time.

Gobo's can be developed a little tank in the same style as is used to develop photo's.

When developing the gobo, the exposed area should turn purple within five to ten seconds. If not, the developer concentration is too weak or the gobo is underexposed. During development mild agitation should be applied to get the best result. Once development is done, rinse the gobo in clean water. Please note that developing action will continue until the gobo is immersed in water. So the development time should be from immersion in the developer to immersion in water. For maximum consistency, it is important to keep the development time stable within a few seconds, and to keep the developer chemical fresh.

It is recommended to use fresh developer every day. If the developer is used extensively, it will turn purple and needs to be replaced. Never put used developer back into the bottle of fresh developer. Any attempt to recycle developer may ruin the whole bottle and end up very costly in badly developed gobo's. Please also keep in mind that most developers react with carbon dioxide, which is present in air, and will thus degrade over time. Because of this reason, only fill the bath with the required volume and close the developer bottle immediately.

The developer chemical is hazardous and must be disposed in an environment friendly way and according to local regulations. For personal safety, use chemical resistant gloves while developing the gobo. Always manipulate the gobo by the edges only while processing.

If errors are visible after development, allow the gobo to dry, or blow it off using nitrogen or oil-free pressurized air and apply a small piece of tape over the error prior to etching.

When a new process has been established, it may be useful to increase the development time by 50% while keeping the exposure dose stable as a matter of experiment. If rastered gobo's which have been overdeveloped by 50% look the same as normally developed gobo's, then the exposure unit is yielding good resolution and consistency. If a rastered gobo which has been overdeveloped by 50% looks much brighter after etching (more metal etched off), then the resist at the edges of the features has been partially exposed, with the most probable causes being either strong overexposure or diffusion of light between film and gobo.

Gobo Etching

1) General considerations

After development, the gobo must be etched. The etching acid will remove all unwanted aluminium and/or black metal. The determination of the minimum dot size will have to take the etching capabilities into account. To ensure consistent etching, usage of quality chemicals is highly recommended.

Our matted aluminium gobo's have a thick aluminium layer, offering the best durability and scratch resistance. Etching a tick layer poses difficulties that can be resolved using the right etching chemical. When etching aluminium, hydrogen bubbles are formed. When etching a thick aluminium layer, these hydrogen bubbles can stick in the small dots that need to be etched, thereby effectively blocking further etching action. The net result is loss of resolution. This problem can be solved easily by using an etching solution that uses a good surfactant. The surfactant dissolves the hydrogen bubbles and keeps the smallest features open.

Etching of aluminum is done with aluminium etchant and can be done in a small tank of the same style as used to develop photo's. To obtain the best results, this bath should be heated, which can be accomplished in three ways: by placing the etching tank in a larger water tank that contains water heated to 35°C ... 45°C, by immersing a glass covered heater with integral thermostat into the etching solution (of the type that is used to heat aquariums) or even better by placing a teflon coated heating element and a teflone coated thermocouple in the etching bath in conjunction with a good temperature controller. If a high power heater is used, make sure temperature distribution is good.

Use only clean water for rinsing. DI water is the ideal solution. Alternatively, filtered and softened water is also suitable. If you see drying marks on the gobo's, either the rinsing time is too short or the water quality is poor.

The etching chemicals are hazardous and must be disposed in an environment friendly way and according to local regulations. For personal safety, use chemical resistant gloves while etching the gobo. Always manipulate the gobo by the edges only while etching.

The gobo can be etched by placing it into the etching acid for a fixed time. The position of the gobo in the bath can be either vertical or horizontal. It is not required to agitate the etching bath if a surfactant is used. If the bath is heavily loaded with gobo's, etching speed can be affected. There should always be a sufficient volume of etching acid in the bath for the amount of gobo's being etched.

Alternatively, a glass etching tank can be used with a light unit below the tank. In this case the etching endpoint can be determined visually.

After etching the gobo must be rinsed in water. Beware that the etching action continues until the gobo is immersed in water. It is recommended to put the etched gobo in a water tank for ten minutes or put it under running water for a minimum of two minutes after etching. Then the gobo can be dried in air, using nitrogen or oil-free pressurized air.

At this point the gobo should be inspected. In case the image is not fully etched, the gobo can be put back into the etching solution for longer etching. If the image etches poorly due to bad development, do not attempt to make further development and re-etching, since putting an etched gobo back into the developer may heavily contaminate the developer solution. If the image etches poorly due to bad imaging (most likely case) then resolve the imaging problems before continuing production. Never attempt to correct poor imaging by altering the etching process.

2) Etching reflective aluminium

For etching reflective aluminium basically any aluminium etcher can be used. A standard mixture is 3:1 phosphoric acid/nitric acid. For obtaining the highest resolution we recommend using the Arch chemicals aluminium etchant (see below). The maximum obtainable resolution in this type of material is approx 2µm dot size.

3) Etching matted hardened aluminium

The matted aluminium can be obtained in three variants: light matted, medium matted, heavy matted. Etching is more or less equal for the three variants, with the heavy matted variant needing a slightly longer etching time.
For etching matted hardened aluminium, we strongly recommend to use the Arch chemicals Al etch 16:1:1:2 with aes surfactant. The etching time is 200 seconds to 300 seconds at 45°C. The maximum obtainable resolution in this type of material is approx 10µm dot size. Some time ago, Arch chemicals was acquired by Fujifilm, so it may be listed now as a Fujifilm product.

4) Etching aluminium forward black gobo's

This material is basically light matted aluminium with a blackened surface. It will etch in one step in aluminium etchant. We strongly recommend to use the Arch chemicals Al etch 16:1:1:2 with aes surfactant. The etching time is approx 200 seconds at 45°C.
The maximum obtainable resolution in this type of material is approx 10µm dot size.

5) Etching aluminium reverse black gobo’s

This material has a blackened surface to the glass with reflective aluminium over it. It will etch in one step. It can be etched with both a standard aluminium etchant, but we recommend using the Arch etchant for this product also. Etching is the same as reflecting aluminium. Obtainable resolution is approx 5µm dot size.
Attention: as this type of gobo will be placed with the glass side to the lens and the reflecting metal side to the lamp, take care the reflecting properties of the aluminium layer are kept intact. Otherwise the gobo will start dissipating heat and may burn.

6) Etching reflective chome gobo’s

Reflective chrome gobo’s can be etched with a commercial chrome etcher. We recommend either the Transene 1020QC or Cyantek CR-7S etchers. Other commercial chrome etchers may work as well. The obtainable resolution in this type of material is approx 1.5µm.
You can make your own etchant by mixing ceric ammonium nitrate with water. Ceric ammonium nitrate is available in solid form, as an orange powder. The recommended mixture is 10mg of ceric ammonium nitrate in 100ml-200ml of water.

7) Etching light matted chrome gobo’s
Same as etching reflective chrome gobo’s. The obtainable resolution in this type of material is approx 5µm.

8) Etching forward black chrome gobo’s (obsoleted)
Drix has two types for forward black chrome. If the gobo is a full chrome gobo, it can be etched in one step using chrome etch. This type of gobo is basically a light matted chrome gobo with a black chrome layer on top. Obtaibale resolution will be approx 5µm. Drix also has a version with the first layer being aluminium and the second layer being black chrome. Such a gobo needs to be etched in two steps. First it must be etched in chrome etch until all chrome is removed, then it must be rinsed and after that it needs to be etched in aluminium etch. Obtainable resolution is approx 10µm dot size. The etching time in unheated (20°C) Transene chrome etch will be approx 80 seconds. The subsequent etching in Al etch is approx 150s at 45°C

9) Etching reverse black chrome gobo’s (obsoleted)
Reverse black chrome gobo’s have a dark layer to the glass and reflective aluminium outwards. Such a gobo needs to be etched in two steps. First aluminium etch, then rinsing and after that chrome etch. Obtainable resolution is approx 10µm dot size.
Forr etching reverse black gobo's, we recommend to use the Arch aluminium etchant to etch the top aluminium part. The etching time is approx 60 seconds at 45°C. The etching time of the black chrome layer is approx 80 seconds at 20°C using Tansene 1020AC.
before continuing production. Never attempt to correct poor imaging by altering the etching process.

Be aware that most chrome etchants have a limited shelf life.

Resist stripping

If the etching result is good, remove the remaining photoresist with acetone. The acetone will also remove any photoresist that may be present on the backside of the gobo, resulting from production. Advanced organic strippers can be guaranteed to remove all resist in one time. Acetone is often used as a cheap solution, but acetone has the disadvantage that as it gets saturated with photoresist it will start to redeposit the resist on the gobo. If acetone is used, the tank must be refreshed regularly, or otherwise a two step scenario must be used. In such a two step system, the gobo is stripped first in a dirty bath, and then in a clean bath. After some time the clean bath becomes the dirty bath, the old dirty bath is refreshed and becomes the new clean bath.

After resist strip the gobo can be dried in air, by nitrogen or by oil-free pressurized air.
Keep the gobo clean after processing. Do not leave fingerprints on the gobo as these might show up in projection, and as the fingerprint may burn into the glass during projection.
Make sure that the tank is compatible with the stripper used. Some materials are not compatible with organic strippers. Polypropylene or teflone coated tanks will be ok.

Organic strippers are hazardous and must be disposed in an environment friendly way and according to local regulations. For personal safety, use chemical resistant gloves while stripping the photoresist. Always manipulate the gobo by the edges only while processing. Be aware that acetone imposes a fire hazard. It has a very low flash point and should not make contact at any time with hot surfaces or sparks that may ignite it. Be aware that pure acetone burns without making a flame or smoke and as such a fire may start unnoticed. Make plans in advance of what needs to be done when the acetone bath starts burning. Also, do not store more acetone than allowed by local regulations or by your fire insurance company in order to avoid discussions of liability.

For health and safety reasons, make sure your lab is equipped with a sensitive fire detector, suitable fire fighting devices and sufficient ventilation.

Handling and installation of gobo's

Keep the gobo's clean and protect them at any time. If handled properly, quality glass gobo's can last forever. Gobo's can be stored in a small plastic bag. Do not leave fingerprints on the glass. A fingerprint may burn into the glass when the gobo gets hot, and under extreme conditions it may lead to the failure of the gobo. Gobo's can be cleaned easily with a alcohol solution. IsoPropyl Acohol (IPA) is most suitable as a cheap cleaning agent. Attention: IPA is flammable.

Gobo's which have a matted aluminium surface spread light reflected from the objective lens, thereby reducing ghost images or halo's. To avoid heat buildup and light leaking around the gobo edge, the gobo should always be placed with the matted aluminium side to the lens. If the matted side is turned to a powerful lamp, and the lamp happens to be misaligned, the gobo may break.

Gobo's which have a black surface absorb light reflected from the objective lens, thereby eliminating ghost images or halo's. A gobo with a black layer should always be placed with the reflective side to the lamp, and the dark side to the lens. Reversing such a gobo will lead to an immediate failure.

Glass gobo's can be focused perfectly offering crisp images. Reverse black gobo's can be used as a black/white substrate for building multi colour gobo's. One or more colour layers can be glued on the reflective side of the gobo, being on the inside of the gobo holder.

Glass gobo's can be used in high watt-density projectors without any problems on the condition that the gobo is clean and no hot spots are generated on the glass, therefore in powerful projectors the lamp must be properly aligned.