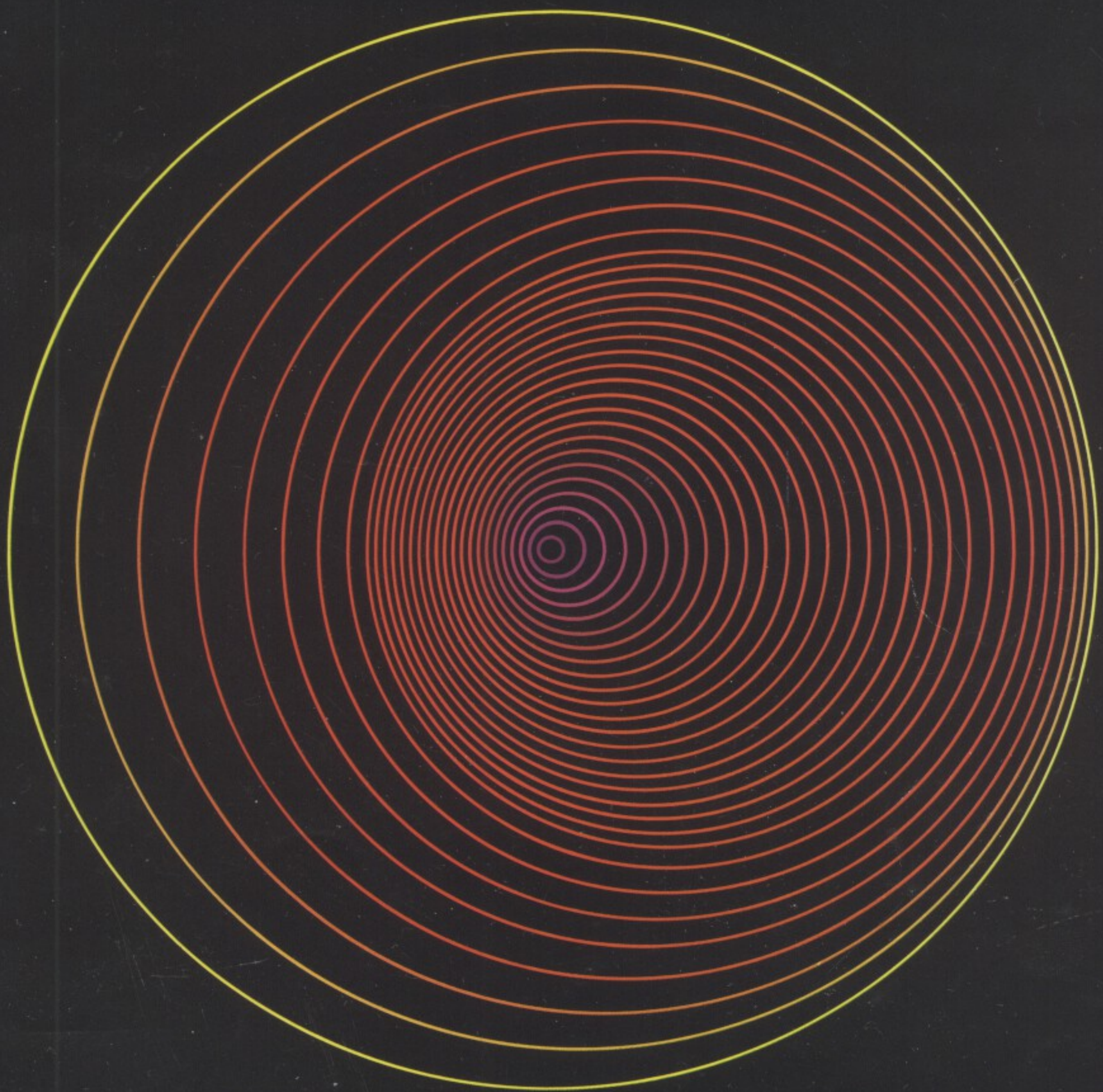
TECHNICAL INFORMATION

HOLOGRAPHIC FILM

RED SENSITIVE HOLOGRAPHIC FILM



ILFORD

PLEASE NOTE: ILFORD RED HOLO FILM
HAS BEEN MODIFIED TO WORK ALSO WITH
HE/NE LASERS.

1 INTRODUCTION

ILFORD has over a century's involvement in photography. Today, this is reflected in a black and white range of films and papers that is world renowned. Alongside this commitment to quality exists a similar striving to innovate.

In many ways, the company's development has mirrored the development of photography: ILFORD has consistently been at the forefront of sensitised photographic materials manufacture. In addition to the more familiar range of general purpose photographic materials - black and white and colour - processing chemicals, equipment and accessories, ILFORD manufactures sensitised emulsions for a variety of specialised applications. These are as varied as aerial photography, electron microscopy, autoradiography, and more recently, holography.

Holography is now rapidly growing into a most important new communications/imaging medium; ILFORD is advancing its research effort to match this growth so that it can offer dedicated materials, processing solutions and accessories.

Holographic plates were first produced by ILFORD in the early 1970s. More recently, interest has increased because of a joint venture started between ILFORD and Applied Holographics, in the manufacture of new holographic emulsions and modified processing chemicals needed to complement their unique holographic mass replication system.

Recent advances in ILFORD UFG (ultra fine grain) emulsion technology enable holographic materials to have extremely fine grain, outstanding resolution and exceptionally low scatter characteristics. Other advances provide another important characteristic: that of extremely high signal to noise ratios being possible, in both the transmission and reflection modes, which result in unprecedentedly high diffraction efficiencies.

Such features have been incorporated into two new films for customer use, namely, ILFORD HOLOGRAPHIC FILM SP673, a red sensitive film and ILFORD HOLOGRAPHIC FILM SP672, a blue-green sensitive film.

This leaflet describes SP673 film; for full information on SP672, please refer to publication 15717.

2 FILM DESCRIPTION

SP673 film has been optimised specifically for use with Q-switched pulsed ruby lasers, and was developed for the manufacture of Lippmann-Bragg reflection holograms replaying in the yellow region of the spectrum. It is also ideal for the production of all low noise, non-wavelength shifted reflection and transmission holograms. The emulsion has maximum sensitivity to red light at 690-700nm, with reciprocity characteristics such that it responds optimally to short bursts of irradiation.

The film has an ultra fine grain emulsion with very high resolving power, greater than 7000 cycles/mm, and extremely low scatter characteristics. The optical clarity of the unexposed emulsion brings two benefits: higher definition in recorded holographic fringes and lower noise in the finished image.

Principal areas of application include:
Mastering for pulsed portraiture;
Contact copying by pulsed ruby laser;
Lamination into security documents;
Non-destructive testing.

2.1 Physical characteristics

SP673 has an emulsion layer 7 microns thick. To facilitate the incorporation of holograms into security documents and minimise problems of birefringence, the emulsion is coated on thin polyester substrate (63 microns). It is also available on thick triacetate substrate (200 microns) for optical clarity and ease of handling.

2.2 Storage

Unopened packages of SP673 film should be stored in a cool place, preferably 10°C (50°F) or below. If stored in a refrigerator, remove packages at least three hours before opening to enable the film pack to reach room temperature and thus avoid problems associated with condensation forming on the surface of the film, such as emulsion softening.

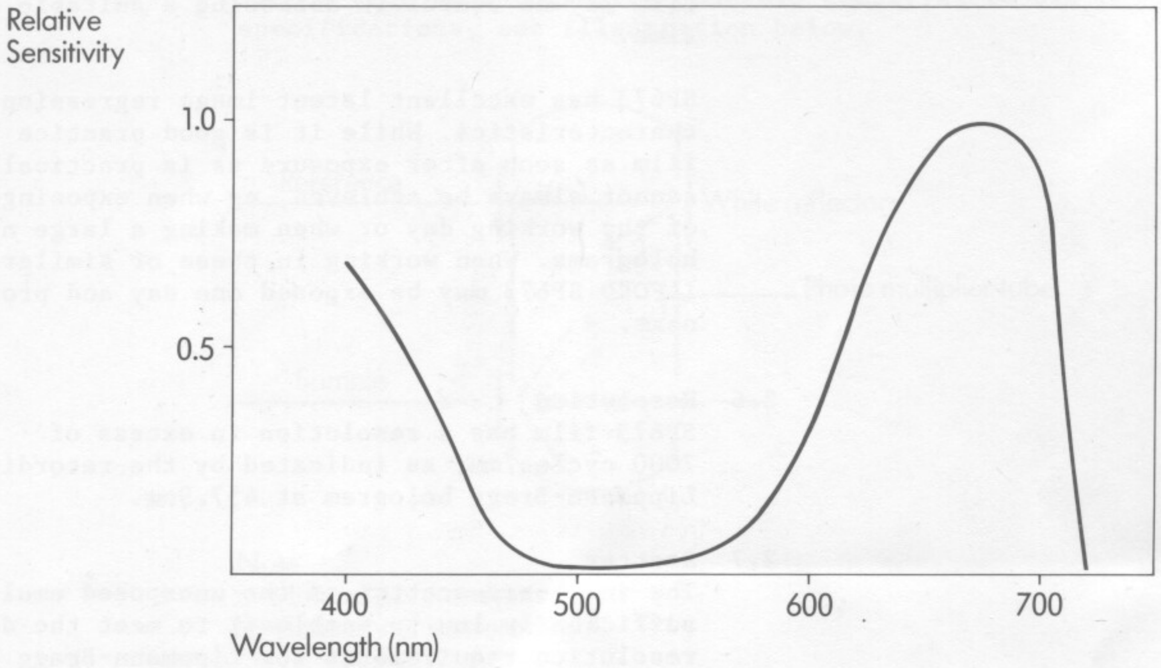
2.3 Safelight recommendations

SP673 film should be handled in blue/green safelight illumination provided by the ILFORD SP677 safelight used in an ILFORD DL10 darkroom lamp. This should be fitted with a 15W bulb. The minimum recommended distance of the safelight from the film is 1 metre.

Red sensitive films can be safely and conveniently handled in lighting from this safelight illumination; other safelights for red sensitive film are either not safe or are too dim to be of any practical use. If the SP677 safelight is not available, handle SP673 in total darkness.

2.4 **Spectral sensitivity**

SP673 emulsion is specially sensitised to light of 690-700nm. This makes it particularly useful when making holograms with Q-switched pulsed ruby lasers.



The above curve shows the relative spectral sensitivity of SP673 to white light flash exposure (10^{-4}s). This curve shows that SP673 has a maximum sensitivity at 694nm.

It can be seen from the above that the spectral sensitivity at 633nm is low compared to that at 694nm. It is not possible to compensate for this low speed to He/Ne lasers by increasing the exposure time. It is, however, possible to take advantage of the reciprocity characteristics of the emulsion and use a high intensity light source for a short time, such as achieved with scanning techniques.

2.5 **Speed characteristics**

It is not practical to recommend a single effective exposure for SP673 as this depends primarily upon laser wavelength and to a lesser extent on processing technique.

When working with this film, it is recommended that an initial series of trial exposures be made to determine the correct exposure time best suited to complement the exact laser set-up and processing conditions. During such trial work it is important to ensure that the processing recommendations given in the subsequent sections are followed carefully, so that a generally high level of image quality is obtained at the outset. Deviations in processing may then be made to suit individual requirements.

In certain cases, the spectral energy curve for this film may be useful in assessing a suitable exposure time.

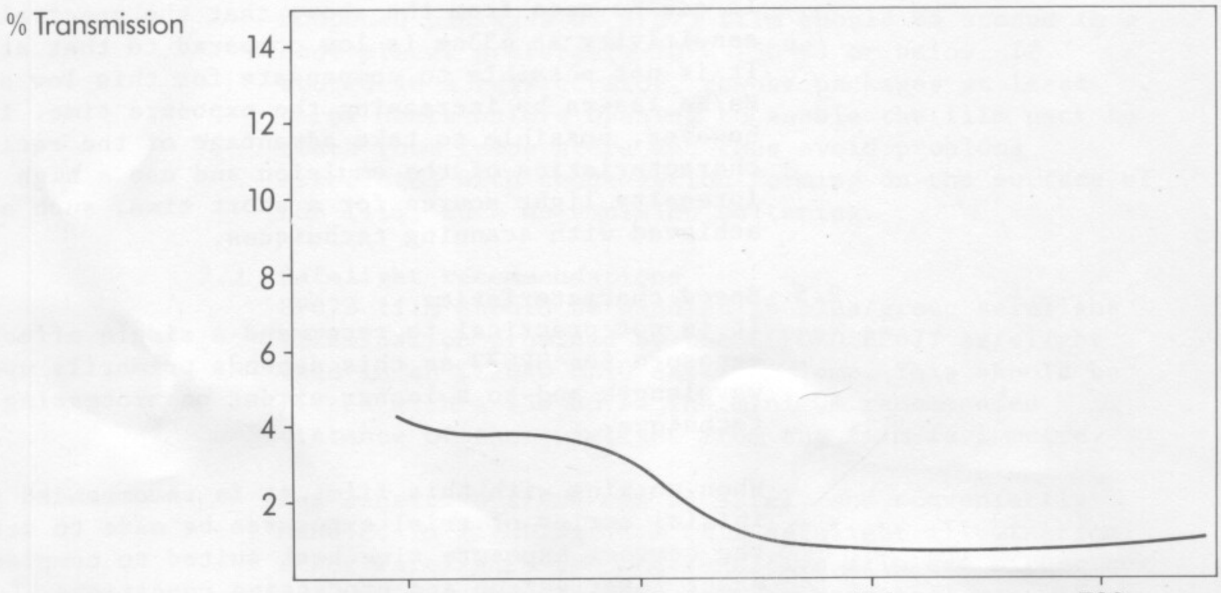
SP673 has excellent latent image regression characteristics. While it is good practice to process film as soon after exposure as is practical, this cannot always be achieved, eg when exposing at the end of the working day or when making a large number of holograms. When working in these or similar conditions, ILFORD SP673 may be exposed one day and processed the next.

2.6 Resolution

SP673 film has a resolution in excess of 7000 cycles/mm, as indicated by the recording of a Lippmann-Bragg hologram at 457.9nm.

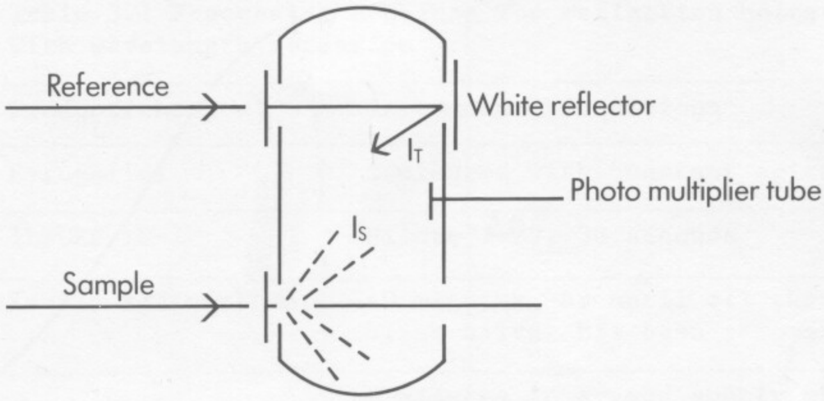
2.7 Scatter

The intrinsic scatter of the unexposed emulsion is sufficiently low to enable it to meet the demanding resolution requirements for Lippmann-Bragg recording, even in the blue spectral region. This same low scatter means that diffraction efficiencies comparable to dichromated gelatin can be achieved through higher fringe definition, and this, coupled with low post-processing scatter yields exceptionally high signal to noise ratios in the final hologram.



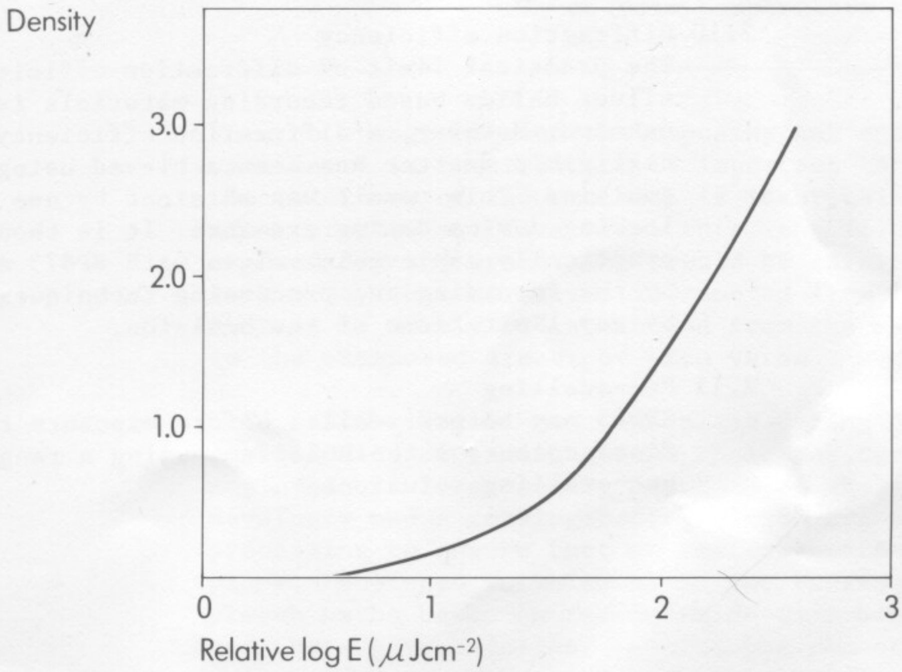
Note: % Transmission = I_S/I_T x 100

The curve above shows the ratio of scattered light to specularly transmitted light for the unexposed emulsion throughout the visible spectrum. Scatter was measured by comparing the ratio of specularly transmitted light to forward scattered light in a spectrophotometer fitted with an integrating spheroid complying to CIE specifications, see illustration below.



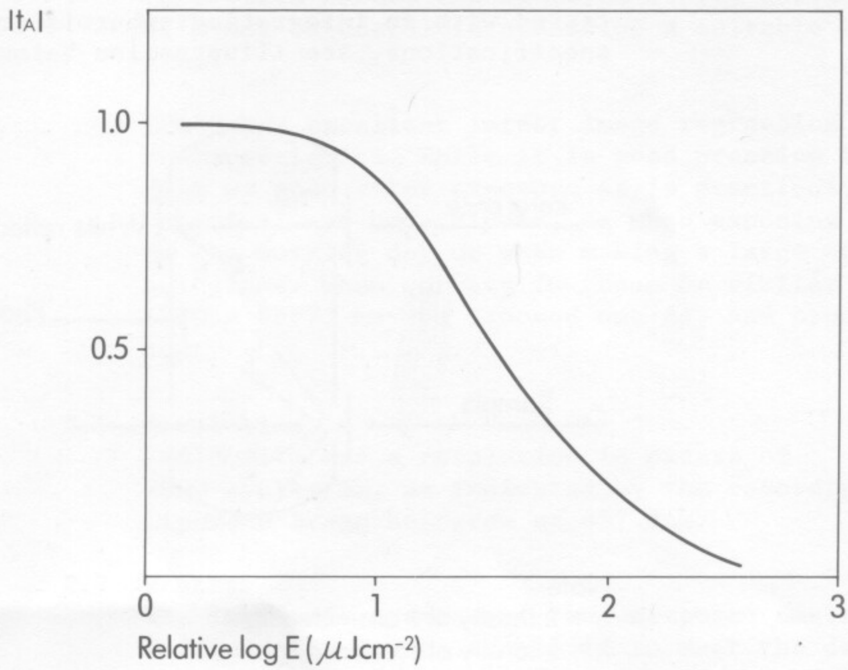
Note
I_T = Intensity of transmitted light
I_S = Intensity of scattered light

2.8 Characteristic curve



2.9 Amplitude transmission curve

Amplitude transmission is defined as the ratio between the amplitudes of a monochromatic plane wave after and before passing through the photographic emulsion.



Note
$|t_A| = \sqrt{10^{-D}}$ where D is density above fog

2.10 Diffraction efficiency

The practical limit of diffraction efficiency for these silver halide based recording materials is currently unknown. However, a diffraction efficiency of 97% with negligible scatter has been achieved using this emulsion. This result was obtained by use of a fringe locking device during exposure. It is thought that practically achievable values with SP673 are restricted by the recording and processing techniques rather than by any limitations of the emulsion.

2.11 Pre-swelling

SP673 may be pre-swollen before exposure to change the final colour of the hologram, using a range of pre-swelling solutions.

3 REFLECTION HOLOGRAMS WITH WAVELENGTH RETENTION

Specific processing recommendations are given below; refer to section 5 for general notes.

Table 3.1 summarises the processing sequence for making reflection holograms. All times are given at 20°C (68°F) with constant agitation, unless otherwise stated.

Table 3.1 Processing sequence for reflection holograms with wavelength retention

Stage	Product/chemical	Recommended conditions
Development	Pyrogallol	3 minutes with constant agitation
Stop bath	ILFORD IN-1	Dilute 1+39, 30 seconds
Bleach	Ferric sodium-EDTA	10 minutes, or until all the black silver has been removed
Wash		2 minutes in a good supply of fresh running water
Iodide bath	Optional	2 minutes
Final rinse	ILFOTOL	A few drops added to de-ionised or distilled water; squeegee film
Drying		In clean, warm air not above 40°C (104°F). Natural drying at room temperature may be done with care

When no change between the exposing and and viewed wavelength is required, it is important to ensure that the thickness of the emulsion is identical before and after processing. To achieve this, the film should be exposed dry and processing should be carried out in such a way that no silver is removed from the film but that it is merely redistributed from the exposed areas to the unexposed areas, or vice versa.

This redistribution may take place during development or bleaching depending on the choice of chemistry employed. It is currently recommended that pyrogallol developer and a rehalogenating bleach are used during processing to ensure that no redistribution tales place. Published formulae exist for rehalogenating bleach baths based on ferricyanide or p-benzoquinone and these give excellent results but cannot be recommended on grounds of safety in handling. ILFORD recommends a more satisfactory bleach bath based on ferric sodium-EDTA complex.

It should be noted that SP673 shrinks by 10% by the simple act of wetting and drying but the use of the developer/bleach combination described above will compensate for the shrinkage.

3.1 Pyrogallol developer

This is the most commonly used developer when processing holograms for wavelength retention. There are two generally accepted reasons for this. The first is that pyrogallol is a tanning developer, that is, it minimizes emulsion shrinkage during processing. Secondly, it leaves a brown stain which masks the scatter arising from the emulsion or bleach. If SP673 is correctly processed it will produce only negligible scatter so the pyrogallol stain is not helpful and may be removed to produce brighter holograms. This removal may be done at the end of the processing sequence by rinsing the film first in a 1% solution of potassium permanganate and then in a 1% solution of sodium metabisulphite.

Pyrogallol developer can be made as follows:

Part A	
Pyrogallol	6g
Ascorbic Acid	6g
Water to make up to	500ml
Part B	
Sodium Carbonate	30g
Water to make up to	500ml

Mix equal volumes of Part A and B immediately prior to development and process for 3 minutes at 20°C (68°F). Adjust exposure and development times for control of final image colour.

Important
Once Parts A and B have been mixed, the solution is unstable. It should be used immediately and discarded after use.

3.2 Ferric sodium-EDTA bleach

This is recommended for processing reflection holograms to achieve optimum results, and may be made up as follows:

Ferric sodium-EDTA	100g
Potassium bromide	10g
Water to make	1 litre

Ferric sodium-EDTA bleach forms a stable solution and is best kept in a half-full bottle. This bleach is unusual in that it can be regenerated by prolonged exposure to air (ie by leaving the solution in a dish or opened bottle overnight). This technique, however, will not prolong the life of the bleach indefinitely.

3.3 Treatment with potassium iodide

Phase holograms, consisting of silver halide, are inherently susceptible to photo reduction (printout). Amplitude holograms, where the fringes consist exclusively of metallic silver, are not. The light stability of phase holograms can be significantly improved by the use of a bath of potassium iodide. This should be employed after the hologram has been washed following the bleach bath.

Potassium iodide will cause a yellow stain on the hologram, together with some increase in scatter.

Method

Dissolve 2.5g of potassium iodide in 1 litre of tap water. After bleaching and washing (see table 3.1), immerse the film in the iodide bath at 20° (68°F); agitate the film continuously during this time. After two minutes, remove the film allowing the excess liquid to drain off.

4 REFLECTION HOLOGRAMS WITH WAVELENGTH SHIFT

Such a shift in replay wavelength can only be achieved if the thickness of the emulsion layer in the processed hologram is thinner than the same layer at the time of exposure. The extent of this shift may be determined by the ratio of replay wavelength to exposing wavelength, eg for exposure at 694nm and replay at 580nm, the thickness reduction is 580:694. This reduction in layer thickness can be achieved in one of two ways: pre-swelling before exposure or shrinkage by silver removal during processing.

If the emulsion layer, at the time of exposure, has been artificially swollen, then a processing system can be employed in which no silver is removed from the emulsion layer. The act of drying the hologram when the processing is complete will reduce the thickness and so bring about replay at a shorter wavelength. Experience shows that this approach can yield the brightest holograms since maximum use is made of the original silver content of the emulsion layer.

By contrast, the shrinkage by silver removal technique has been found most suited to machine processing and consists of development followed by solvent bleaching. In this process, the developed silver is bleached to a soluble silver salt which is then washed out of the layer. It is this removal of silver which causes the reduction in layer thickness which is, in turn, responsible for the shift in replay wavelength.

The exact shift in wavelength for solvent bleaching systems is related to the mass of developed silver. A relationship must therefore exist between wavelength shift, exposure and development times. If, for example, a considerable wavelength shift is required, then either a greater exposure or a longer development time, or both, is called for. When long development times are likely to be given, it is worth remembering that they can be shortened by increasing the temperature of the developer solution.

4.1 Processing reflection holograms by pre-swelling

Table 4.1 summarises the processing sequence for making reflection holograms using the pre-swelling technique. All times are given at 20°C (68°F) with constant agitation, unless otherwise stated.

Table 4.1 Processing sequence for reflection holograms by pre-swelling

Stage	Product/chemical	Recommended conditions
Pre-swelling	1% solution of triethanolamine in water	1 minute
Development	ILFORD SP678C	Dilute 1+4, 4 minutes (or ILFORD PHENISOL REPLENISHER. Dilute 1+4, 2 minutes)
Stop bath	ILFORD IN-1	Dilute 1+39, 30 seconds
Bleach	Ferric sodium-EDTA	10 minutes, or until all the black silver has been removed
Wash		2 minutes in a good supply of fresh running water
Iodide bath	Optional	2 minutes
Final rinse	ILFOTOL	A few drops added to de-ionised or distilled water; squeegee film
Drying		In clean, warm air not above 40°C (104°F). Natural drying at room temperature may be done with care

Pre-soak

A satisfactory pre-soak bath can be made with a 1% solution of triethanolamine in water. Soak the unexposed film for 1 minute in this solution then squeegee the film and allow it to dry. Expose in the usual way.

4.2 Processing reflection holograms by silver removal

Table 4.2 summarises the processing sequence for making reflection holograms using the shrinkage by silver removal technique. All times are given at 20°C (68°F) with constant agitation, unless otherwise stated.

Table 4.2 Processing sequence for reflection holograms by silver removal

Stage	Product/chemical	Recommended conditions
Development	ILFORD SP678C	Dilute 1+4, 4 minutes (or ILFORD PHENISOL REPLENISHER. Dilute 1+4, 2 minutes)
Stop bath	ILFORD IN-1	Dilute 1+39, 30 seconds
Bleach	ILFORD SP679C	2 minutes
Wash		2 minutes in a good supply of fresh running water
Iodide bath	Optional	2 minutes
Final rinse	ILFOTOL	A few drops added to de-ionised or distilled water; squeegee film
Drying		In clean, warm air not above 40°C (104°F). Natural drying at room temperature may be done with care

ILFORD SP678C developer
This new product is recommended for developing reflection holograms, and is designed for use at normal dish processing temperatures of 20°C (68°F). SP678C should be diluted 1+4 with water. A standard development time of 4 minutes is recommended, with constant agitation. This time may be modified with experience. ILFORD SP679C bleach is recommended when working with this developer.

SP678C developer has a good processing capacity, and for normal work, a large number of holograms may be processed before there will be a noticeable loss of quality. For the best working conditions though, no more than 20 10x8inch holograms should be processed in each litre of working strength solution.

ILFORD SP679C bleach
This is recommended for use with ILFORD SP678C developer and should be diluted 1+4 with water to give a working strength solution.

SP679C bleach has a good processing capacity, and for normal work a large number of holograms may be processed before there will be a noticeable loss of quality. For the best working conditions, no more than 20 10x8inch holograms should be processed in each litre of working strength solution.

5 TRANSMISSION HOLOGRAMS

SP673 may be particularly recommended for making the following types of transmission holograms, when high diffraction efficiencies (up to 97%) with very low scatter may be expected:

Laser transmission masters
White light (rainbow) transmission masters
Diffraction gratings

Table 5.1 summarises the processing sequence for making transmission holograms with SP673. All times are given at 20°C (68°F) with constant agitation unless otherwise stated.

Table 5.1 Processing sequence for transmission holograms

Stage	Product/chemical	Recommended conditions
Development	ILFORD SP678C	Dilute 1+4, 4 minutes
Stop bath	ILFORD IN-1	Dilute 1+39, 30 seconds
Bleach	ILFORD SP679C	2 minutes
Wash		2 minutes in a good supply of fresh running water
Iodide bath	Optional	2 minutes
Final rinse	ILFOTOL	A few drops added to de-ionised or distilled water; squeegee film
Drying		In clean, warm air not above 40°C (104°F). Natural drying at room temperature may be done with care

When working with ILFORD SP678C developer, there is a choice of bleach: ILFORD SP679C or a special rehalogenating bleach formulation developed by ILFORD, a ferric sodium-EDTA bleach, which has also been found to give excellent results. See section 3 for formula.

Standard developers

When working with a standard developer such as Kodak D-19 or Tetenal Dokumol, it is important to bleach the film using a ferric nitrate bleach.

The formula for this is given below.

Ferric nitrate	100g
Potassium bromide	30g
Water to make	1 litre

Treatment with potassium iodide may be carried out when processing transmission holograms for exactly the same reasons and in exactly the same way as with reflection holograms. See section 3 for further details.

6 PROCESSING NOTES

Careful attention should be given to proper processing techniques, regardless of the material to be processed.

When preparing processing solutions, ensure that mixing vessels and processing dishes have been thoroughly cleaned before use. Discard processing solutions at the end of their working life. Do not attempt to economise by keeping solutions from one working period to the next if there is any risk that the solutions will not perform in the recommended way upon reuse. Mix fresh chemicals if there is doubt about the condition of any processing solution.

In general, it is satisfactory to mix chemicals with ordinary tap water. Care should be taken with bleach baths and the final rinse solution: de-ionised or distilled water is strongly recommended for making up these solutions.

For highest quality holograms, it is important to keep all processing solutions, including the wash water, at about the same temperature ($\pm 2^{o}$C or $\pm 5^{o}$F). In this way, image movement due to random shifts in the emulsion layer, as the gelatin alternately swells and shrinks during processing, will be minimised.

While exposure conditions can be varied to achieve good holographic performance over a wide range of development times and temperatures, it is generally advantageous to standardise on processing parameters such as time, temperature and agitation, and thereby minimise the effects of processing variability. In the same way, while it may be tempting to 'develop by inspection' to obtain the required result, for consistently good results, it is always best to process for the standard times. The hologram should then be examined after processing and the appropriate revised exposure or development time determined to produce a satisfactory hologram.

Finally, when solutions are kept from one day to the next, it is helpful to monitor the volume of film processed through them. As a guide, it is recommended that no more than 20 8x10inch sheets be processed in one litre of processing solution. In particular, this is true for ILFORD SP678C developer and ILFORD SP679C bleach.

6.1 Stop bath

ILFORD IN-1 stop bath is recommended between the the development and bleach stages, to prevent premature exhaustion of the bleach bath.

6.2 Rinse

As a final rinse after the final wash, immerse SP673 in distilled water to which ILFORD ILFOTOL wetting agent has been added. A few drops of ILFOTOL to each litre of water is sufficient. It is important to squeegee the film before drying.

6.3 Drying

The use of a film drying cabinet that blows warm air, preferably no higher than 40°C (104°F), over vertically hung holograms is recommended. Holograms can be air dried at room temperature with care, although drying marks may be observed when drying holograms in this way. Such marks may be minimised by the addition of ILFORD ILFOTOL wetting agent to the final rinse.

Adherence to the above simple guidelines will help to maintain a high standard of processing quality.

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