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Recent Advances in Holographic Materials From Slavich

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ABSTRACT

A general review of the current holographic materials available from the Micron Plant at AO Slavich is presented. In particular certain improvements to the technical parameters of the materials PFG-01 (notably sensitivity) and PFG-03M (emulsion hardness) are introduced. Likewise the introduction of a new 190 micron TAC film substrate for the PFG-01 and VRP-M emulsions will be mentioned and examples of holograms produced on these emulsions will be shown. Reflection hologram color control techniques using emulsion humidity fixing in a special oven is presented and the suitability of this technique is discussed for various regimes. Recommended chemistries that may be employed with each of the Slavich materials will be discussed in the context of Pulsed and CW radiation sources. Finally, contact copying using the PFG-01, PFG-03M and PFG-03C materials will be briefly mentioned.

1. INTRODUCTION

Slavich currently produces both Silver Halide and Dichromated Gelatin emulsions for holography applications. Table 1 summarises all the materials presently available from the Micron factory. The green-sensitive VRP-M emulsions are very close analogues to the old Agfa 8E56 products and can be used for both Pulsed and CW laser recording of holograms. The PFG-01 material gives equivalent performance toAgfa 8E75 for CW recording. No analogue exists for 8E75 when used with pulsed Ruby radiation.

The PFG-03M emulsion is a super fine grain red sensitive emulsion for superior quality imaging. The PFG-03C material is a panchromatic equivalent to the PFG-03M.

Finally PFG-04 is a long-life Dichromated Gelatin emulsion for recording in the blue and green sprectal ranges.

Nearly all the holography materials now produced at Slavich are availablecoated onto glass or TAC film and cover a wide range of sizes.

2. FINE GRAIN SILVER HALIDE MATERIALS

Characteristic curves of Slavich fine grain red (PFG-01) and green (VRP-M) emulsions, showing spectral sensitivity versus wavelength, are shown in figure 1. The VRP-M light sensitivity (CW radiation) is seen to peak at aproximately 75 microJoules/cm2 and that of PFG-01 (CW radiation) at aproximately 100 microJoules/cm2. Figure 2 shows the optical density after exposure by CW radiation and development versus energy. Grain size characteristics for the VRP-M and PFG-01 emulsions are presented in Figure 3. The diffraction efficiency versus exposure for reflection holograms recorded on PFG-01 (using a CW laser) and on VRP-M (using a pulsed laser) is presented in figure 4. The maximum diffraction efficiency is seen to be >40% for both emulsions. Material life is more than two years.

In order to attain the best performance from the PFG-01 emulsion we have optimized the dye and Silver (now 3.2g/m^2) concentrations in the emulsion. In addition we have taken out the 690nm dye for Ruby as this decreased performance in the

Name of Material	Description
VRP-M	Fine-grained green sensitive holographic plates and film having no anti-halation coating and designed for reflection or transmission hologram recording. Average grain size is 35-40nm, resolving power is more than 3000 lines/mm, spectral sensitivity range includes 488nm,514nm, 526nm, 532nm. The VRP product is identical to VRP-M except for an anti-halation coating designed especially for transmission work.
PFG-01	Fine-grained red sensitive holographic plates and film designed for transmission or reflection hologram recording. Average grain size is 40nm, resolving power more than 3000 lines/mm, spectral sensitivity range 600-680nm (including 633nm, 647nm).
PFG-03M	Ultra fine-grained red sensitive plates and film designed for reflection hologram recording. Average grain size is 8-12nm, resolving power more than 5000 lines/mm, spectral sensitivity range includes 633nm, 647nm.
PFG-03C	Ultra fine-grained panchromatic (full colour) holographic plates designed for colour reflection hologram recording. Average grain size is 8nm, resolving power more than 5000 lines/mm, spectral sensitivity range up to 700nm (457nm, 514nm, 633nm).
PFG-04	Dichromated Gelatin holographic plates designed for phase reflection hologram recording. Resolving power greater than 5000 lines/mm, spectral sensitivity range up to 514nm (457nm, 488nm, 514nm).

Table 1: List of Available Holographic Materials

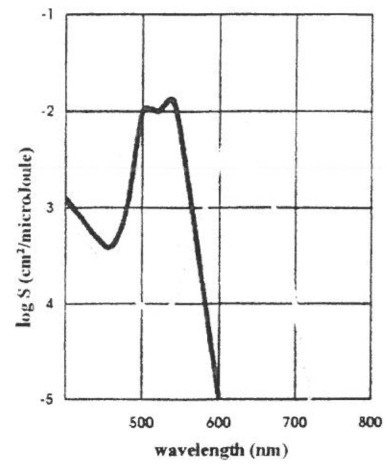

Figure1: Spectral Sensitivity curves for VRP-M (black) and PFG-01 (grey).

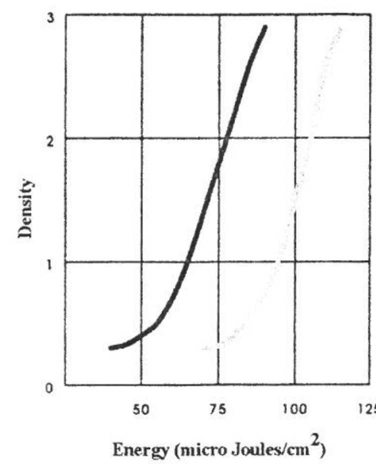

Figure 2: Characteristic curves for VRP-M (left) and PFG-01.

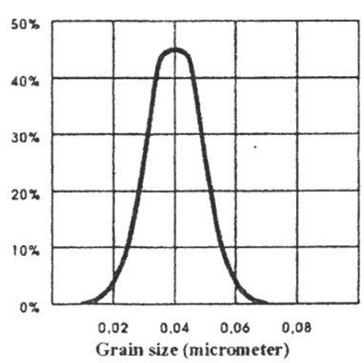

Figure 3: Grain Size distribution curve for VRP-M and PFG-01.

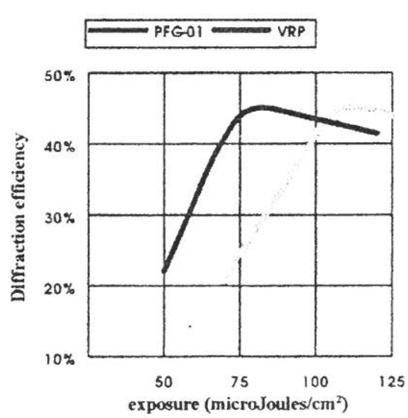

Figure 4: Diffraction Efficiency curves for VRP-M and PFG-01.

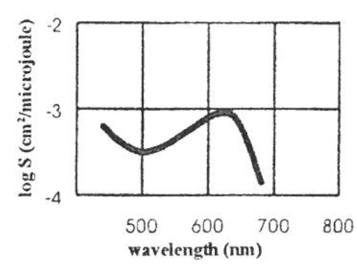

Figure 5: Spectral Sensitivity of the PFG-03M material.

	Mastering Transmission Holograms	Copying (Reflection Holograms) Final Colour Green	Copying (Reflection Holograms) Final Colour Honey-Green	Copying (Reflection Holograms) Final Colour Orange
Exposure	20...40 microJ/cm2	30...50 microJ/cm2	50...70 microJ/cm2	50...70 microJ/cm2
Latensification	Yes	Yes	Yes	Yes
Development	SM-6 2...3min	SM-6 2...3min	M-Pyro+ 3...4min	M-Pyro+ 3...4min
Wash	Water 2...3min	Water 2...3min	Water 2...3min	Water 2...3min
Bleach	PBU-Amidol until clear	PBU-Amidol until clear	PBU-Amidol until clear	PBU-Amidol until clear
Wash	water 10...20mins	water 10...20mins	water 10...20mins	water 10...20mins
Potassium Iodide bath	No	No	No	2mins
Washing	No	No	No	1...2mins
Final Wash	Water with wetting agent 1min	Water with wetting agent 1min	Water with wetting agent 1min	Water with wetting agent 1min
Slow Air Drying	Yes	Yes	Yes	Yes

Table 2: Recommended Chemistry for VRP-M with Pulsed Nd:YLF/YAG Radiation

lower red regions of the spectrum. Finally we changed the hardener which now leads to a natural yellow/orange reconstruction colour when using a HeHe laser and the recommended chemistry (see below).

The VRP-M emulsion may be used equally well with frequency-doubled pulsed Neodymium lasers as with green CW radiation. The PFG-01 emulsion, however, is not sensitive to pulsed radiation from the Ruby laser and as such should be only used with CW sources. Emulsions used with pulsed radiation, should be post-sensitized with the technique of latensification (see section below).

2.1. RECOMMENDED CHEMISTRY FOR VRP-M

Table 2 shows a summary of various recommended processing schemes for use with Pulsed Neodymium lasers (526.5nm, 532nm). All these processing recipes work equally with CW Argon for both transmission and reflection holograms; however in this case latensification is usually not necessary and exposure is a little longer. In addition, for CW, you may obtain better results using the CW-C2 developer depending on your colour requirements. Uniform heating in a special oven provides easy colour control across the spectrum for pulsed lasers.

PBU-Amidol Bleach

Potassium Persulphate	10.0g
Citric Acid	50.0g
Cupric Bromide	1.0g
Potassium Bromide	20.0g
Amidol	1.0g
Water	to 1.0L

Potassium Iodide Bath

Potassium Iodide	18.0g
Water	to 1.0L

Table 3: Bleaches and Other Baths

SM-6 Developer

Ascorbic Acid	18g
Sodium Hydroxide	12.0g
Phenidone	6.0g
Sodium Phosphate (dibasic)	28.4g
Water	to 1.0L

M-Pyro+ Developer

1 part A + 1 part B

Part A	
Pyrogallol	20.0g
Phenidone	1.2g
Sodium Metabisulphite	5.0g
Water	to 1.0L
Part B	
Sodium Carbonate	130.0g
Water	to 1.0L

CW-C2 Developer

1 part A + 1 part B

Part A	
Catechol	20.0g
Ascorbic Acid	10.0g
Sodium Sulphite (anhydrous)	10.0g
Urea	100.0g
Water	to 1.0L
Part B	
Sodium Carbonate	60.0g
Water	to 1.0L

Note: For CW-C2 develop for 2mins at 20C.

Table 4: Developers

The PFG-01 emulsion can be processed with virtually any chemistry previously applied to the Agfa 8E75 emulsion with the single addition -if necessary- of a post-exposure latensification step before chemical processing. We recommend, in particular, the SM-6 and CW-C2 developers defined in table 4 for both transmission and reflection holograms. Colour control is possible with all the normal methods used with the Agfa emulsion including TEA. As referred to above the new PFG-01 emulsion now naturally gives an orange colour of reconstruction when a HeNe laser is used and processing is with SM-6 +PBU Amidol. Substitution of SM-6 by the VRP developer (table 6) yields a yellow colour of reconstruction.

2.3. LATENSIFICATION

Unlike Agfa emulsions the Slavich PFG-01 and VRP-M emulsions have peak sensitivities to exposures in the millisecond regime. In order to obtain optimal sensitivity to exposures either much longer or much shorter than this timeframe the simple technique of latensification can be used. Practically speaking this means that some CW laser users (few) and most pulsed laser users will use latensification.

Latensification is usually done directly after the holographic exposure. However before you can apply the process you must work out a latensification time appropriate for your system. This procedure is as follows: Place a 25W lamp with a dark filter (green for VRP-M and red for PFG-01 although white light also works) at a distance of 1m from a test holoplate or film such that its light uniformly illuminates the emulsion. You will need to try several exposure times ranging from 0 to around 4 mins and then look at how the emulsion develops. So start with zero exposure time and then under your normal safelight conditions develop the plate. The plate will darken a little. This is called the fog level. After development put this control plate into a STOP bath, wash it and keep it handy.

Now you must start to make a series of test exposures with small test plates. Start at about 0.5 mins and go up to around 4mins. After each exposure develop your plate and match the darkening of this plate to your control plate. If it is the same you need more exposure so go back again and repeat the process. Stop when you get a result that is just marginally darker than the fog level. This is then the correct latensification exposure for your geometry.

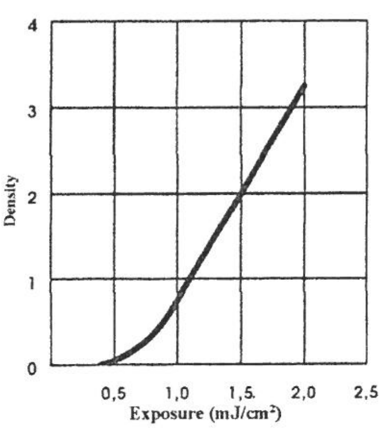

Figure 6: Characteristic curve for PFG03M.

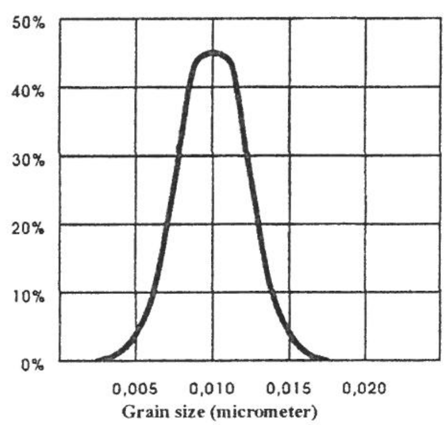

Figure 7: Grain size distribution for the PFG-03M material.

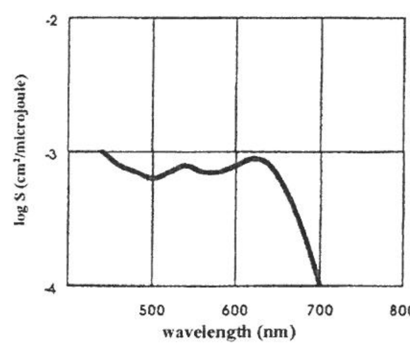

Figure 8: Spectral Sensitivity curve for PFG-03C.

Now that you have discovered the proper latensification time all you must do is after every proper holoplate exposure you must take your plate and illuminate it exactly as described above for the time that you have worked out. Then all processing is as normal. Latensification stabilizes and enhances the latent image formed by the holographic exposure. If required, chemical processing may be done with significant delay after latensification.

Hardening: 2-3 mins

Formalin 37%	10ml
Potassium Bromide	2g
Sodium Carbonate	5g
Water	to 1L

Washing: 1-2mins

Wash in running (filtered) water.

Development in GP-2: 10-15mins

Concentrated solution	
Methyl Phenidone	0.2g
Hydroquinone	5g
Sodium Sulphite (Anhyd)	100g
Potassium Hydroxide	5g
Ammonium Thiocyanate	9g
Water	to 1L

Work Sol.: 40ml GP-2+1L H20

Washing: 1-2mins

Wash in running (filtered) water.

Fixing: 2mins

Sodium Thiosulphate (cryst.)	160 g
Potassium Metabisulphate	40 g
Water	to 1L

Washing: 1-2mins

Wash in running (filtered) water.

Drying: 2mins each bath

50%,75% and 96% Ethyl Alcohol

Table 5: Recommended processing for PFG-03M (Reflection Holograms). Note that temperature must be lower than 19°C.

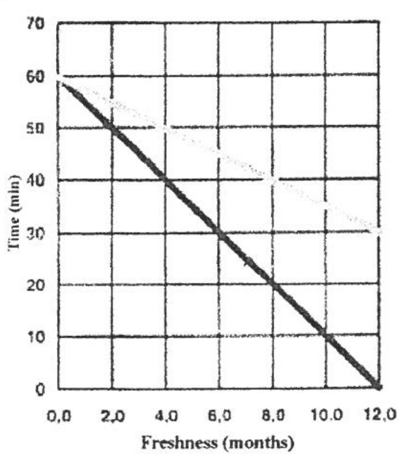

Figure 12. Hardening time for PFG-04 versus Storage Time. The black curve refers to a storage temperature of 18 Degrees Celsius and grey curve to a storage temperature of 4 Degrees Celsius.

Hardening: 6 mins

Formalin 37%	10ml
Potassium Bromide	2g
Sodium Carbonate	5g
Water	to 1L

Washing: 1-2mins

Wash in running (filtered) water.

Development VRP: 4 - 5 mins

Concentrated solution	
Sodium Sulphite (Andydrous)	194g
Hydoquinone	25g
Potassium Hydoxide	22g
Methyl Phenidone	1.5g
Potassium Bromide	20g
Potassium Metaborate	140g
1,2,3-Benzotriazole	0.1g
Distilled Water	to 1L

Work Sol.: 1 part of VRP developer + 6 parts water.

Washing: 1-2mins

Wash in running (filtered) water.

Bleach in PBU-Amidol: 5 - 8 mins

Copper Bromide	1g
Potassium Persulphate	10g
Citric Acid	50g
Potassium Bromide	20g
Distilled Water	to 1L
Amidol	1g

Washing: 1-2mins

Wash in running (filtered) water.

Stop Bath: 2 mins

Acetic Acid	20g
Water	to 1L

Washing: 1-2mins

Wash in running (filtered) water.

Bathing :2 mins

Bathing in distilled water with added wetting agent

Drying

Drying in normal conditions.

Table 6: Recommended processing for PFG-03C (Reflection Holograms).

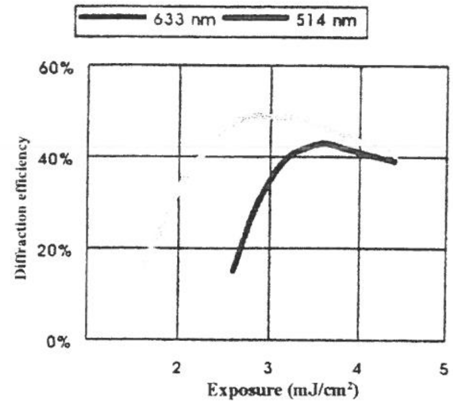

Figure 9: Diffraction efficiency curve for PFG03C.

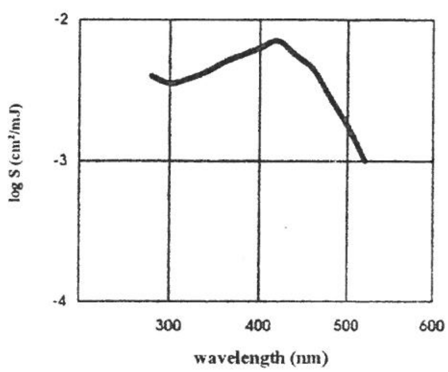

Figure 10: Spectral sensitivity curves for PFG-04.

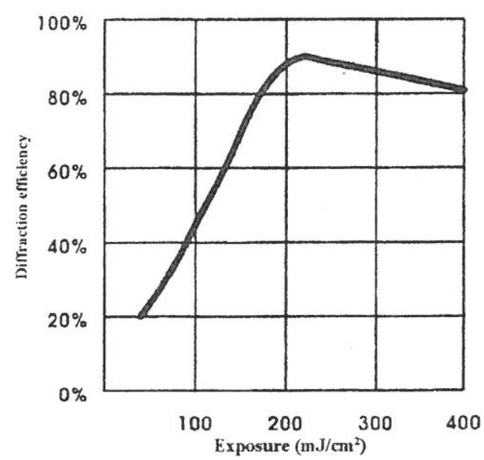

Figure 11: Diffraction efficiency curve for PFG-04.

Material Sizes

Glass	406 x 609 mm	300 x 406 mm	180 x 240 mm	102 x 127 mm	63 x 63 mm
PFG-01	n	y	y	y	y
VRP-M	y	y	y	y	y
PFG-03M	n	y	y	y	y
PFG-03C	n	y	n	y	y
PFG-04	n	y	y	y	y
Plates/Box	4	6	6	25	30

Film	1150mmx10m(Roll)	610mm x 10m(Roll)	304mm x 10m(Roll)	203mm x 20m(Roll)	102mm x 20m(Roll)	76mm x 20m(Roll)	36mm x 20m(Roll)	300mm x 10m(Roll)	203mm x 254mm(x50)	102mm x 127mm(x50)	200mm x 300mm(x 5)
PFG-01	y	n	n	y	y	n	y	y	y	y	y
VRP-M	y	n	n	n	n	n	n	y	y	n	y
PFG-03M	y	n	y	y	y	n	n	n	y	y	y
PFG-03C	y	n	n	n	n	n	n	n	n	n	n
PFG-04	n	n	n	n	n	n	n	n	n	n	n

Table 7: Material sizes available as standard products. Note y = yes, n= on request.

3. ULTRA-FINE GRAIN SILVER HALIDE MATERIALS

3.1. PFG-03M - RED SENSITIVE

This material is designed for reflection hologram recording using CW radiation in the red spectral range (633nm - HeNe laser and 647nm - Krypton laser). The spectral sensitivity curve of the material is shown in figure 5. Peak emulsion sensitivity is around 1.5-2mJ/cm2. Density versus energy is shown in figure 6 and the grain size distribution curve is shown in Figure-7. Despite a lower sensitivity than VRP-M and PFG-01, the PFG-03M material has a higher diffraction efficiency and a very high signal to noise ratio. Holograms recorded on this material have a very clear and powerful object reconstruction and excellent layer transparency. Usually a physical solution development that acts to create colloidal silver is the preferred processing method. PFG-03M does not need bleaching.

In order to attain the maximum performance from this material we have increased the hardness of the emulsion by 3 times. This now permits the holographer to use machine processing and drying without adverse consequences. The sensitivity has been maintained.

3.2. PFG-03C -PANCHROMATIC EMULSION

This material is designed for the production of full colour (bleached) reflection holograms using CW laser radiation in the blue (457nm - Argon laser), green (514nm - Argon laser) and red (633nm -HeNe laser). A spectral sensitivity curve of the material is shown in figure 8. The PFG-03C grain size distribution curve has the same shape as for the PFG-03M material. Diffraction efficiency versus exposure is shown in figure 9. The maximum DE in the blue range is >25% and in the green and red ranges >45%. Sensitivity values are 2mJ/cm2 and 3mJ/cm2 respectively.

3.3. PFG-04 - DICHROMATED GELATIN

This material is designed for the recording of reflection Denisyuk-type holograms using CW laser radiation (488nm, 514nm -Argon laser). The material spectral sensitivity curve is shown in figure 10. The sensitivity reaches 100mJ/cm2 in the blue spectrum range and 250mJ/cm2 in the green. Due to its grainless structure, this material has very high resolving power and a diffraction efficiency of >75% (figure 11).

The recommended processing technique of the exposed hologram consists of the following operations:

1). Thermal Hardening after exposure (100C) - Depending on the layer freshness. See figure 12.

2). Cooling to Room temperature.

3). Bathing in running filtered water - 3mins.

4). Bathing in 50% Isopropyl Alcohol solution for 2 - 3 mins.

5). Bathing in 75% Isopropyl Alcohol solution for 2 - 3 mins.

6). Bathing in 100% Isopropyl Alcohol solution for 2 - 3 mins.

7). Drying in a desiccator. (100C) for 60 mins.

8). Emulsion layer preservation using optical anhydrous adhesive and protective glass.

Note that the processing solution temperatures must not exceed 20C for fresh layers. If holograms appear "milky" in colour then the processing solution temperature should be decreased or the thermal hardening period should be prolonged. The material shelf life is 12 months(average observed period).

4.0. SUBSTRATES

Slavich holography materials are manufactured on glass and TAC film substrates. The Micron plant has two glass coating machines, one capable of coating widths of 40cm and the other of 60cm. To date the largest plates commercially mass-produced have been 60cm x 80cm. Many smaller sizes are available as standard products. These are produced from the larger sheets by automatic glass cutting machinary.

Currently Slavich has two standards of TAC film substrate. The first is a 140 micron film suitable for the production of smaller format holograms. Recently however Slavich has introduced a 190 micron film, ostensibly identical to that used by Agfa for its 8E75 and 8E56 products. This thicker substrate film is currently available in rolls of 1.15m and exhibits excellent physical, optical and holographic properties.

5.0. COLOUR CONTROL

5.1. VRP-M REFLECTION HOLOGRAMS

Traditionally green lasers have enjoyed limited acceptance for the manufacture of display holograms on fine-grain Silver Halide emulsions. One reason for this is the fact that Raleigh scattering in holograms made with green lasers could lead to higher noise holograms than those recorded in the red. However with the introduction of the low noise Agfa millimask and VRP-M materials this problem has really been solved for display holography. Despite this however, there remains, in principle, the problem of the reconstruction colour for reflection holograms recorded with green lasers.

For green lasers the colour of reconstruction of a reflection hologram usually remains in the green part of the spectrum. Most processing techniques can shift this colour by shrinking the emulsion but this leads to a shift into the blue. In order to produce a shift in the red direction a pyrogallol developer and the PBU-Amidol bleach can be used. Further red shifting can be attained by use of a final bath of Potassium Iodide as described in the previous sections. Such chemical techniques can be used effectively to obtain replay colours for VRP-M reflection holograms, recorded with Neodymium or Argon lasers, from the blue to the yellow/orange regions of the spectrum. For example figure 13 shows the reflection spectrogram of a VRP-M image-planed hologram recorded at 525.5nm that has been developed in SM-6 and PBU-Amidol. Note that the colour of reconstruction corresponds closely with the colour of recording. Figure 14 shows a similar graph for pyrogallol and

SM-6 developers with post soaking in Potassium Iodide. In this case we observe a red-shift of 35nm for SM-6 and 45nm for pyrogallol.

To obtain larger red-shifts we have used a heating technique to shrink the emulsion before exposure. By heating either VRP-M film or glass material for 8 hours in a special oven we decrease the content of water in the emulsion layer. With less water, the emulsion shrinks and over a period of 8 hours an equilibrium is established which is characterized by a very uniform emulsion thickness.

When the holographic plate/film is extracted from the oven the emulsion temperature decays exponentially to reach within 1% of room temperature after 30 mins (case of VRP-M plates 30x40cm). However the water content of the emulsion increases much more slowly, only reaching equilibrium with the ambient humidity after several hours.

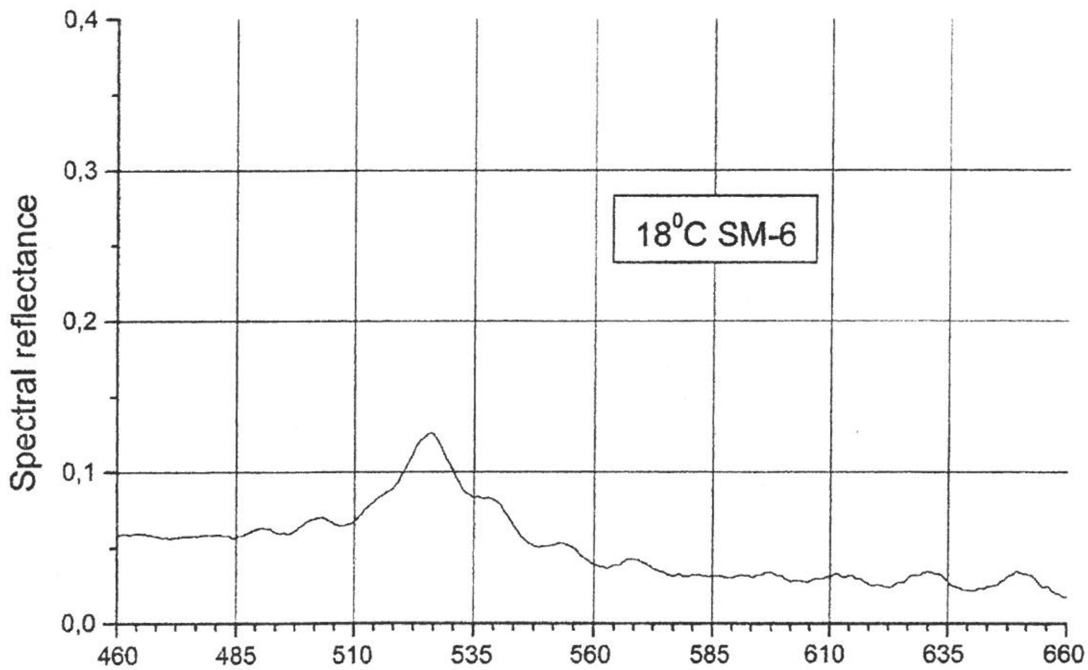

Figure 13: Reflection Spectrogram of an image planed reflection H2 hologram made on VRP-M film. The recording laser was Nd:YLF emitting at 525.5nm. Room temperature and humidity.

To quantify the red-shifts possible to attain using this technique of emulsion preshrinkage by heating, we copy a standard H1 master hologram to a heated VRP-M (film) H2 using a pulsed Nd:YLF laser emitting at 525.5nm. Specifically we heat our film to either 60 degrees C or 80 degrees C for a period of 8 hours. After this period we extract our film from the oven, wait 1/2 hour for cooling and then expose the film in the normal way. Since we are using pulsed nanosecond radiation we latensify directly after the exposure. Then we process the film using the modified Pyro+ developer and PBU-Amidol bleach. Figure 15 shows three spectrograms for room temperature, 60 degrees C and 80 degrees C. We note the clear trend to higher wavelength with oven temperature. Specifically at 80 degrees C we note that we may obtain a red shift of around 30nm over that produced by Pyrogallol alone (at 18 C).

By combining the use of Potassium Iodide and heating we may obtain very significant red-shifting. By reference to figure 14 we see that pyrogallol + KI gives a shift of 45nm. And by reference to figure 15 we would predict that heating could be used to extend this by 30nm, leading to an overall maximum possible shift of 75nm. For Neodymium lasers this means that colour control is possible right into the red region of the spectrum. More detailed experiments confirm this to be the case and indeed this technique is now in commercial use as an extremely effective colour control technique for holograms produced by green lasers.

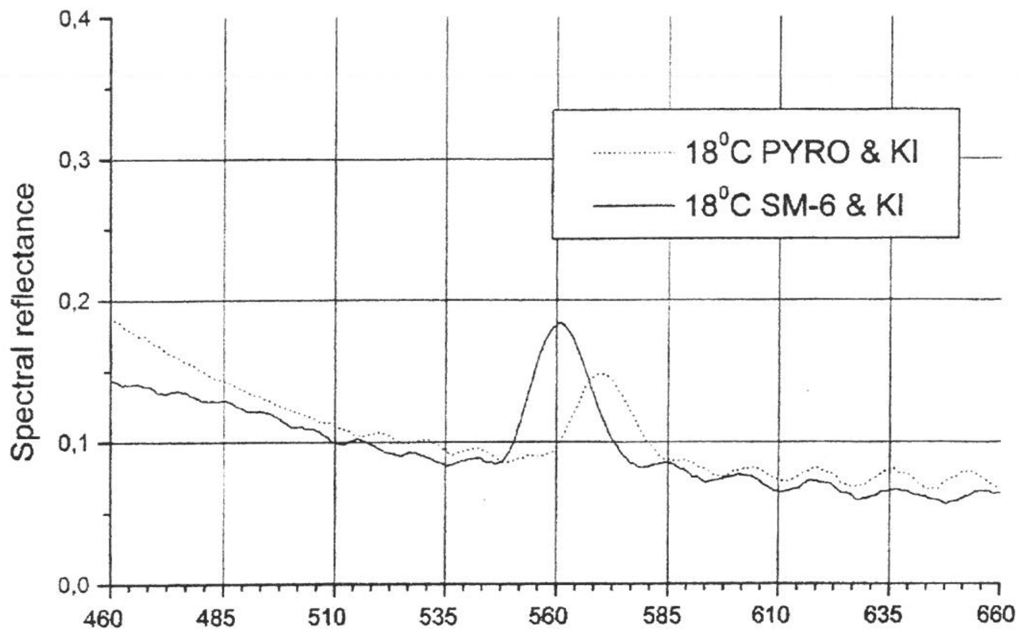

Figure 14: Reflection Spectrograms of image planed reflection H2 holograms made on VRP-M film. The recording laser was Nd:YLF emitting at 525.5nm. Room temperature and humidity. The full line is processed with M-Pyro+ developer + PBU-Amidol Bleach + KI post-soak. The dotted line corresponds to developer SM-6 + PBU-Amidol Bleach + KI post-soak.

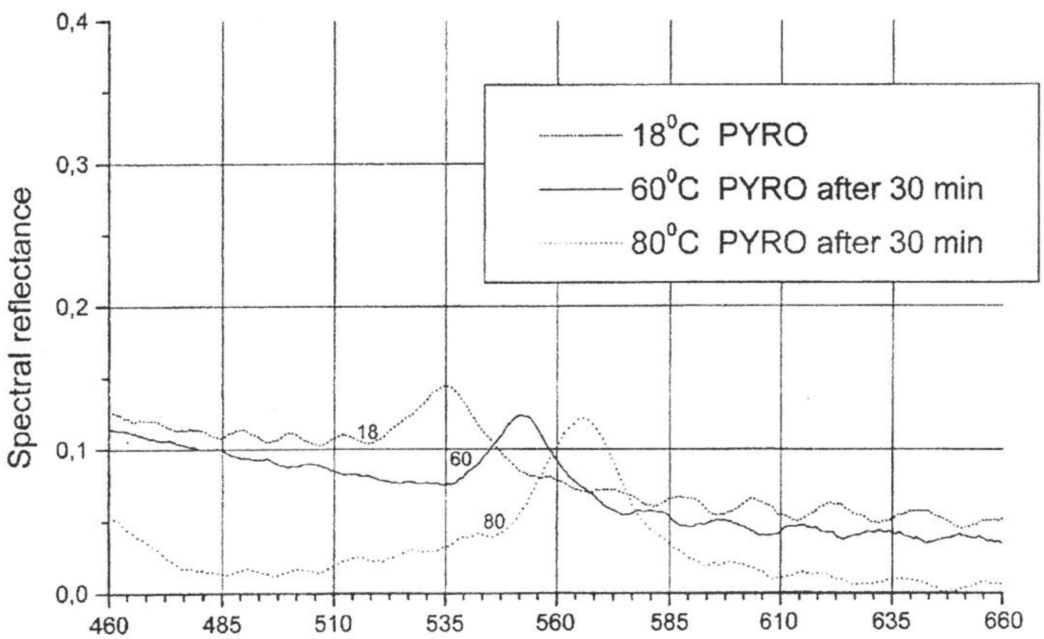

Figure 15: Reflection Spectrograms of image planed reflection H2 holograms made on VRP-M film. The recording laser was Nd:YLF emitting at 525.5nm. The three graphs correspond to 3 different oven temperatures as indicated.

5.2. PRODUCTION OF PFG-01 AND PFG-03M REFLECTION MASTER HOLOGRAMS

We have mentioned before that the PFG-01 emulsion replays naturally, when exposed with a HeNe laser, in the yellow/ orange region of the spectrum. Often, however, one wishes to make reflection masters that are suitable for contact copying. These masters must have very good colour uniformity and replay exactly at the wavelength of the copying laser.

In order to control the colour of reflection masters we are constrained to use a processing scheme that maintains colour uniformity. In the case of PFG-01 we use SM-6 + PBU-Amidol for this purpose and this then leads to an orange colour of reconstruction. In order to shift this colour to the red we have used the heating technique of section 5.1.

5.2.1. Experimental Method

Our experimental method is similar to that described above in section 5.1. We use a similar oven for heating the glass holographic plates and a standard scheme for then recording a Denisyuk hologram of a mirror at near normal incidence. We use a 50mW HeNe laser operating in TEM00. The unexposed holographic plate is left in the oven for a period of 8 hours after which time it is left to cool down to room temperature for 30 minutes. The cooled plate is then installed in front of the mirror that forms the holographic object and left 10 minutes to stabilise. The plate is then exposed and processed using SM6+PBU-Amidol in the case of PFG-01 and GP-3 +fixation for PFG-03M. The spectrum of the holographic mirrors are measured using a standard monochromator.

Figures 16, 17 and 18 show the results of our colour tuning experiments using PFG-01 and PFG-03M holographic plates. Figure 16 shows the dependence of replay wavelength versus heating temperature. Figure 17 shows the dependence of the replay bandwidth versus temperature. Finally figure 18 shows the diffraction efficiency for the optimally tuned PFG-01 reflection master. We see that, as in the previous section, heating to higher temperatures leads not only to colour shifting to the red in a very predictable manor but also to a narrowing of the replay band. By using this technique reflection masters may

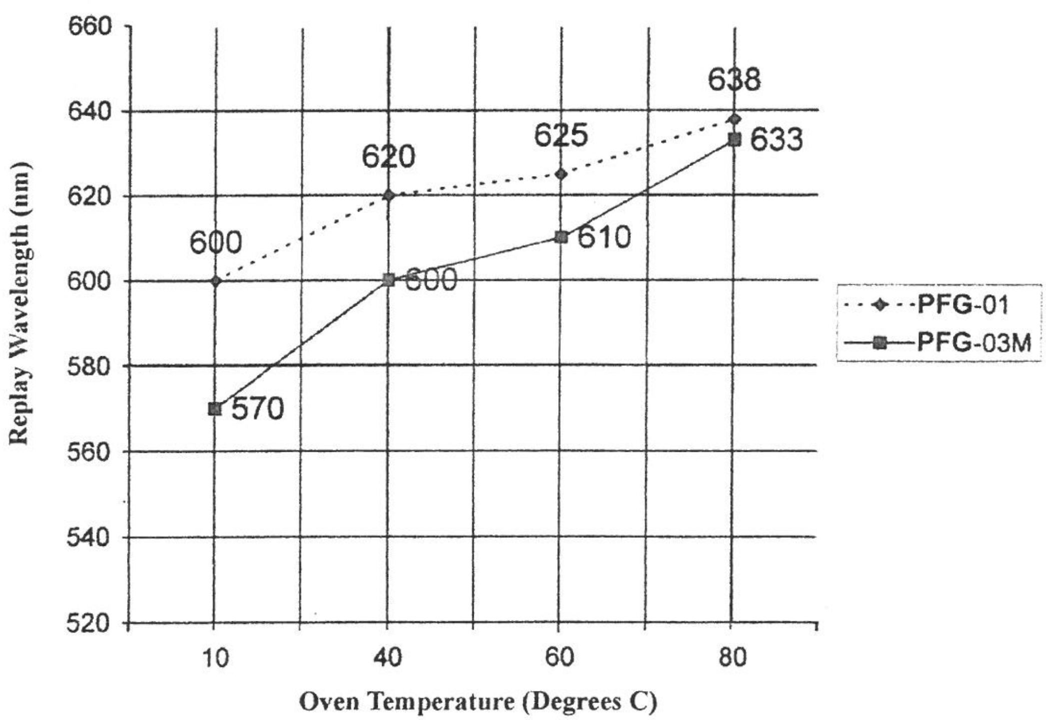

Figure 16: Replay wavelength for Reflection holograms recorded on holographic plates heated in an oven for 8 hours and then exposed with radiation at 633nm. The chemistry used for PFG-01 is SM-6 + PBU-Amidol and for PFG-03M, GP-3 + fixer (see table 5).

be very accurately tuned for contact copying with no deterioration of the final hologram. We have extended this technique to tune actual H2 reflection masters for contact copying with HeNe lasers and are able to report excellent results on both the PFG-01 and PFG-03M materials.

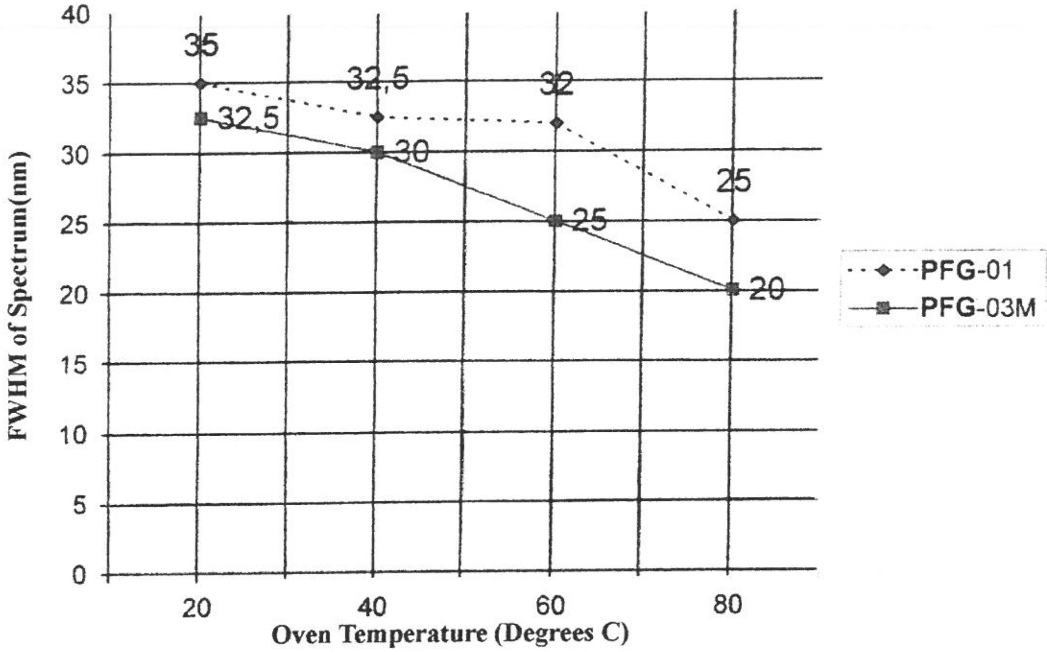

Figure 16: FWHM (Full-width Half-maximum) of the spectrum of Reflection holograms recorded on holographic plates heated in an oven for 8 hours and then exposed with radiation at 633nm. The chemistry used for PFG-01 is SM-6 + PBU-Amidol and for PFG-03M, GP-3 + fixer (see table 5).

6.0.CONCLUSION

We have reviewed and presented the holographic materials manufactured by the Micron plant at AO Slavich. In particular we have presented certain improvements to the technical parameters of the materials PFG-01 (notably sensitivity) and PFG-03M (emulsion hardness). Likewise the introduction of a new 190 micron TAC film substrate for the fine grain emulsions has been mentioned. Recommended chemistries that may be employed with each of the Slavich materials have been discussed in the context of both Pulsed and CW radiation sources.

Reflection hologram colour control techniques using emulsion humidity fixing in a special oven have been presented and the suitability of this technique has been discussed for several applications. In particluar we have seen that VRP-M reflection holograms produced with Neodymium lasers can be tuned effectively into the yellow and red regions of the spectrum. In addition we have shown that PFG-01 and PFG03M reflection masters recorded with CW HeNe lasers may also be tuned by emulsion heat pre-treatment and that these masters may then be used to generate high quality contact copies.

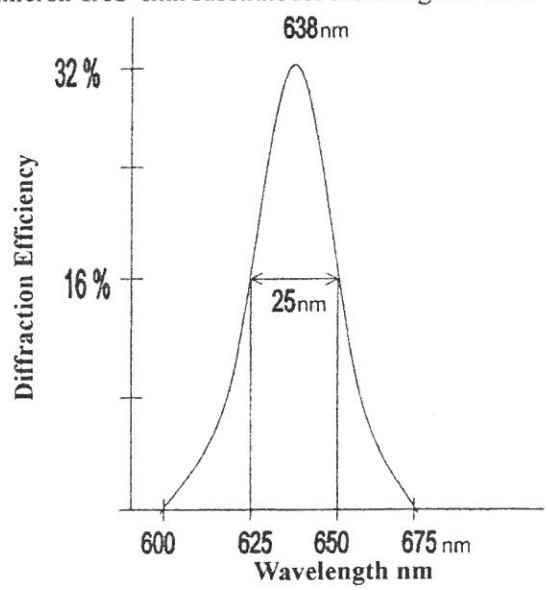

Figure 18: Diffraction efficiency versus wavelength for the optimally shifted PFG-01 reflection master showing peak replay at 638nm and a bandwidth of 25nm.