

Ultimate 04 the New Reference for Ultra-Realistic Color Holography

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Abstract— This paper discusses the main requirements in today's color holography and evaluates Ultimate 04 (U04), a new ultra-high sensitivity silver halide holographic emulsion for color holography. The 4 nm grain of U04 is smaller and its resolution of 18,000 lines/mm is better than any other silver halide material. The grain is so fine that any visible wavelength from deep blue 440 nm to far red 700 nm can be recorded without any diffusion. The paper also evaluates how the U4 development procedure improves compared to other traditional development processes.

Keywords—*ultra-realistic color holography; full color holography; silver-halide emulsion; Denisyuk hologram; ultimate hologram*

I. INTRODUCTION

In 2000 at St. Polten during the Holographic Millennium Conference, an ultra-high sensitivity laboratory-made silver halide holographic emulsion with 10 nm grains called "Ultimate" and some big size (30x40 cm) full color holograms like the "The Clown" and "Butterflies" [1], were demonstrated for the first time.

Since then, many improvements on the emulsion have been made, like uniformity of grain size, storage stability, coating quality, new sensitizers, cutting quality, pre-shifting, maximum sensitivity achievement and safe processing material, so "Ultimate" is now commercially available for other holographers.

Ultimate emulsions are now used regularly by many university researchers, teachers, artists, companies and hobbyist in the world [2-10]. The latest emulsion available is called Ultimate 04 mm (U04).

This paper evaluates the particular characteristics of this emulsion processed by the recommended safe development procedure.

II. RELATED WORK

The choice of the good holographic recording material is the key to record ultra-realistic full color holograms. There are three main types of materials: silver halide, dichromated gelatin (DCG) and photopolymer. In this paper we are only going to focus on silver halide materials.

The main advantage of silver-halide emulsions compared with the 2 other materials is a higher sensitivity (100 to 1000

times higher). Silver-halide emulsions can be coated on glass plates and film but they need a wet processing.

Until the 90's, some major companies like Agfa, Ilford and Kodak provided monochromatic holographic silver halide materials, but nowadays only few silver halide color emulsions, from Russian and European producers are available: the PFG-03C emulsion from Slavich [11], the PFG-03CN emulsion from Sfera-S Ltd. [12], the BB-PAN from Colour Holographic Ltd. [13] and the Ultimate 08 (U08) from Ultimate Holography [14].

The main characteristics of the commercial silver halide holographic recording materials for color holography are presented in Table 1.

TABLE I. COMMERCIAL SILVER HALIDE HOLOGRAPHIC RECORDING MATERIALS

Recording Material	Spectral Sensitivity (nm)	Resolution (lines/mm)	Grain Size (nm)	Substrate
U08 ¹	440-700	10,000	8	glass/film
PFG-03CN ²	435-665	6,000	9	glass/film
PFG-03C ³	450-700	6,000	10	glass/film
BB-PAN ⁴	440-650	6,000	10	glass

¹ Ultimate Holography ² Sfera-S Ltd, ³ Slavich, ⁴ Colour Holographic Ltd.

To record full-color realistic holograms, iso-panchromatic emulsions with a resolution of more than 10,000 line pairs/mm are required [15]. If the resolving power is too low, it is not possible to record blue (and more specifically deep blue) wavelength, without blur and diffusion.

Many users especially hobbyist or schools have low power lasers (less than 20 mW) and a recording material with good sensitivity is an important factor to keep a short exposure time to increase the probability to get a good hologram.

Most of the holographic material have to be treated before exposure to increase its sensitivity, with the risk of damaging the plate. For example, a hyper sensitizing solution of triethanolamine (TEA) is the technique recommended by Colour Holographic Ltd. for their plates before recording and a hardening pre-bath is required for the Slavitch emulsions.

The chemicals used in classical holography to process the plates are generally dangerous and harmful to humans and the

environment. In particular, the recommended process established 25 years ago for the ultrafine-grain Russian Slavich PFG-03C emulsion [16], uses chemicals such as Formaldehyde for the hardening pre-bath, Catechol for the developer and staining substances for the bleach that are unsafe, messy and difficult in handling.

These chemical must be used with caution by professionals and require special equipment such as chemistry sink with hood. After use they must be recovered and recycled to protect the environment. This adds additional costs and makes them difficult to use in schools with young students.

The main requirements for today's color holography are: an iso-panchromatic emulsion with a resolution of more than 10,000 line pairs/mm to record all the wavelengths from deep blue to far red, an emulsion with a good sensitivity to be used with low power lasers (20 mw) and a safe and easy processing procedure.

III. CHARACTERISTICS OF U04

To meet most requirements of holographers, a new ultra-high sensitivity silver halide holographic emulsion for color holography named Ultimate 04 nm (U04) was designed.

U04 has a lower speed but higher resolution than the previous holographic emulsion Ultimate 08 nm (U08) (Table 2). The grain is now so fine (4 nm) that any visible wavelength, and especially deep 442 nm blue laser Helium Cadmium (HeCd), can be recorded inside without any diffusion.

TABLE II. U04 AND U08 COMPARATIVE CHARACTERISTICS

Parameters	U04 Properties	U08 Properties
Spectral sensitivity	440-700 nm	440-700 nm
Grain size	04 nm	08 nm
Resolution	18,000 lines/mm	10,000 lines/mm
Speed for monochrome record	450 $\mu\text{J}/\text{cm}^2$ (minimum) 600 $\mu\text{J}/\text{cm}^2$ (standard) 900 $\mu\text{J}/\text{cm}^2$ (mastering ¹)	150 $\mu\text{J}/\text{cm}^2$ (minimum) 200 $\mu\text{J}/\text{cm}^2$ (standard) 300 $\mu\text{J}/\text{cm}^2$ (mastering ¹)
Speed for color record	320 $\mu\text{J}/\text{cm}^2$ per laser	130 $\mu\text{J}/\text{cm}^2$ per laser
Layer thickness	4 μm	4 to 5 μm
Base	Glass plate (3 mm) and film (190 μm)	Glass plate (3 mm) and film (190 μm)
Processing chemicals	Ultimate safe developer and bleach	Ultimate safe developer and bleach
Shelf life	More than 2 years at 4 °C	More than 2 years at 4 °C
Storage	in a fridge, in a closed box at 4 °C	in a fridge, in a closed box at 4 °C
Use recommendation	Transfer the plates/films you plan to use for the day, in a box and place it in the recording room at least one hour before shooting, for temperature stabilization	Transfer the plates/films you plan to use for the day, in a box and place it in the recording room at least one hour before shooting, for temperature stabilization

¹ for mastering with wider bandwidth

U04 is a material specially designed for reflexion full color Denisyuk holography [17] and Hoe's for which diffusion is the critical point. The diffraction efficiency is kept high even for Denisyuk holography or a set-up with poor Object/Ref ratio

(10:1). For monochrome recording on this material of HOE reflective diffusors, a diffraction efficiency of 98 % has been achieved.

U04 is sensitized so the holographic material is set iso-panchromatic for all the common lasers (442, 457, 473, 488, 514, 532, 633, 640, 647, 660 and 695 nm) used in holography. The spectral sensitivity is from deep blue 440 nm to far red 700 nm.

This new emulsion as compare the standard U08 emulsion is 3 times less sensitive, but the sensitivity remains good enough to work with low power lasers (20 mW). The minimum recommended exposure energy is 320 $\mu\text{J}/\text{cm}^2$ per laser for a full color (3 colors) hologram and 600 $\mu\text{J}/\text{cm}^2$ for a monochrome record.

Thanks to improvements in stabilizers, the life time is improved and the material can be kept more than 2 years in a fridge at 4 °C and several months at room temperature.

IV. PROCESSING STEPS FOR U04

It is no longer possible to use dangerous and harmful chemicals to process holographic plates.

This is why a new harmless and no staining two baths chemical process (Table 3) has been developed for the Ultimate emulsions.

The concentrated solution of developer and the ready for use bleach solution, can be kept at room temperature for at least 2 years. The bleach solution can be used and re-used many times, and the developer when diluted before use (1:10) has about 6 hours of life-time or more if stored in a bottle without air.

Furthermore, the Ultimate plates are pre-hardened during the manufacturing process, so does not need any dangerous hardening bath. Only a pre-tanning of the plates at 50°C in an oven during 2 hours before recording, followed by one hour at the room temperature stabilization can be useful to prevent shifting or swelling effect.

The U04 plates have already reached their maximum sensitivity 10 days after their manufacturing date about, so prewashing or hyper-sensibilizing solutions, are become out-of-date.

TABLE III. STANDARD ULTIMATE PROCESSING STEPS

Processing Step	Time (minutes)
Develop in Ultimate Developer at 20-25 °C (diluted 1:10)	4 to 6
Wash under running water	0.5
Bleach in Ultimate Bleach at 20-25 °C	2.5 to 3.5 (or until clear)
Wash under running water	3
Wash with Kodak Photo-Flo	1
Dry vertically	20

The processing steps are detailed as follows:

A. Development bath

The non-toxic Ultimate Developer is stock in concentrated solution in closed bottle to prevent oxidation and needs to be diluted with distilled or demineralized water (1:10) just before processing. The water temperature before mixing must be equal or greater than 20 °C (68 °F) for that the developer to function properly.

The development time is 4 to 6 minutes at room temperature (20-25 °C) with a slow agitation under safelight. The development process starts to be visible a few seconds after the plate is fully covered with the mixed developer.

After development, the U04 plates gets a pale yellow/orange color (Figure 1). This unusual color after development can be explained by the very small grain size (MIE diffusion), much smaller (4 nm) than in the other holographic materials (8 to 10 nm).

There is no need to develop further than the required 6 minutes to try to get a black density. Like the U04 material provides a wide latitude in exposure, only very over-exposed plates will not give a transparent hologram.



Fig. 1. After development, the plate has pale orange color

B. Wash

The plate is washed under running water for 30 seconds in its tray, allowing water to overflow into a sink under safelight.

C. Bleach bath

The non-toxic Ultimate Bleach is diluted in demineralized or distilled water and kept in closed bottle to prevent oxidation. It can be stored at room temperature for one year. The typical bleaching time is 2.5 to 3.5 minutes at room temperature (20-25 °C) under normal light.

The plate is poured into the developing tray containing the bleach and agitate continuously until a good transparency. The bleaching process starts to be visible a few seconds after the plate is fully covered. After some minutes in the bleaching, a "floating" image appears in the bath (Figure 2).

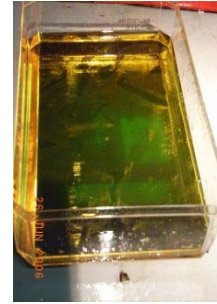


Fig. 2. After some minutes in the bleach a "floating" image usually appears in the bath.

The same bleach bath can be reused several time and it is considered "dead" when it does not bleach a plate in less than 10 minutes. Even weak, it gives the same quality of holograms. After bleaching, the plate is fully transparent and has almost no noise (Figure 3).

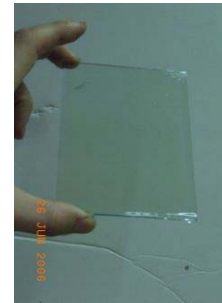


Fig. 3. After bleaching the plate is fully transparent and has almost no noise.

D. Final Wash

The plate is washed under running water for 60 seconds in its tray, allowing water to overflow into a sink under safelight.

Denisyuk holograms can be observed by transmission with a halogen spot. When the hologram is successful this image will be very strong (Figure 4). The plate is afterward rinsed under running water for two additional minutes.



Fig. 4. When the plate is in wet state, the image can be observed by transmission.

E. Dry

The holographic plate is put 1 minute in demineralized or distilled water solution with some drops of Kodak Photo-Flo and dried vertically for 15-20 minutes.

F. Final hologram

The final aspect of the hologram obtained lets us classify the quality of holograms in three categories:

- If the exposure is correct, the final hologram is bright and the plate is transparent (Figure 5).
- If the final hologram is bright but the plate is milky white or opaque, the hologram is over-exposed.
- If the final hologram is dim and the plate is transparent, the hologram is under-exposed.



Fig. 5. After drying, the back side of the hologram is protected by a black film or better sealed with an optical glue.

V. RESULTS

Ultimate 04 nm meets most of the requirements for today's color holography. The U04 emulsion grain is so fine that the 3 wavelengths (Red, Green, and Blue) can be recorded simultaneously with an extreme brightness (Figure 6) and without any noise even deep blue colors.

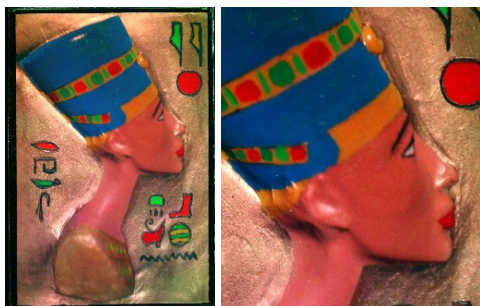


Fig. 6. Nefertiti - Full color hologram 10x15 cm. Recorded on U04 (457, 532, 640 nm lasers).

The grain is smaller (4 nm) and the resolution better (18,000 lines/mm) than any other silver halide material for color holography (Table 4).

TABLE IV. COMMERCIAL SILVER HALIDE HOLOGRAPHIC RECORDING MATERIALS FOR COLOR HOLOGRAPHY

Recording Material	Spectral Sensitivity (nm)	Resolution (lines/mm)	Grain Size (mm)
U04 ¹	440-700	18,000	4
U08 ¹	440-700	10,000	8
PFG-03CN ²	435-665	6,000	9
PFG-03C ³	450-700	6,000	10
BB-PAN ⁴	440-650	6,000	10

¹ Ultimate Holography ² Sfera-S Ltd, ³ Slavich, ⁴ Colour Holographic Ltd.

The sensitivity, 320 $\mu\text{J}/\text{cm}^2$ per laser for a full color hologram, is good enough to work with low power lasers.

The two baths processing procedure for Ultimate emulsions is safe and easy to use.

A new generation of Ultimate Holograms like a "blue" version (Figure 7) of the well-known "Clown" [18], or a very realistic rendition of a box of butterflies (Figure 8), has been already recorded.



Fig. 7. The Blue Clown - Full color hologram 30x40 cm. Recorded on U04 (457, 532, 640 nm lasers)



Fig. 8. Butterflies - Full color hologram 30x40 cm. Recorded on U04 (457, 532, 640 nm lasers).

VI. CONCLUSION

The choice of a good silver-halide emulsion of the ultrafine grains type with high resolving power is fundamental to record good holograms.

To record ultra-realistic full-color holograms, panchromatic materials with a resolving power of more than 10,000 lines/mm are required and Ultimate 04 offers with 18,000 lines/mm the best resolution with the less noise, combined with a good sensitivity, of the market.

An easy and safe processing, for both holographers and environment, is available with this material. Used already by several companies, artists and laboratories, U04 became for them their new reference material for true color holography.

This new silver halide emulsion could contribute to develop holography market by giving more realistic full color holograms for professionals. And the safe and easy processing of these plates gives the opportunity to amateurs to record their own holograms in good conditions.

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