"ULTIMATE" EMULSION AND ITS APPLICATIONS:

A LABORATORY-MADE SILVER HALIDE EMULSION OF OPTIMIZED QUALITY FOR MONOCHROMATIC PULSED AND FULL COLOR HOLOGRAPHY.

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ABSTRACT

A ultra-high sensitivity holographic "Ultimate" emulsion (10 nm grains) has been produced, which allows the realization with short exposure times of bright, large sized, with wide view angle and full color holograms of fragile still subjects or monochromatic pulsed reflection holograms of alived subjects. The high transparency of "Ultimate" emulsions as color transmission holograms makes them highly suitable for mastering, the copies keeping the same performances as the master. Copies on other materials, especially polymer emulsions are possible. Coating machines have been performed for the production of 36 x 44 cm triacetate films and 60 x 84 cm glass plates under controlled conditions of temperature and humidity. Also, a homemade portable camera with pulsed YLF or ruby lasers allows to realize holograms in situ of alive subjects on H1 transmission holograms up to 60x80 cm and instant H2 reflection copies up to 30 x 40 cm. Some examples of holograms are displayed.

Keywords: Color holography, silver-halide recording material, panchromatic plates, pulsed lasers, holographic portraits, coating machine, emulsion, color transmission master.

1. INTRODUCTION

The principle of holography is known for long [1-5] but the realization of quality holograms is particularly difficult and many parameters need to be controlled. Although we obtained holograms, both in transmission and in reflection, of good quality on 8E75 AGFA material [6] in the red when using ruby and HeNe lasers, we failed when we started in 1993 to use shorter wavelengths for green reflection pulsed records or for full color holograms, and all other materials commercially available by then appeared not satisfying for us: the grains were too large, the plates were often fogged, numerous defects altered the coating, and the non reproducibility from batch to batch forced us to readapt the process at each exposure.

After an important loss of time (and money), we decided to achieve also the preparation of the emulsion combined with a performed coating technology.

Our holography studio is mainly involved in two domains of applications: artistic portraits with pulsed cameras, and museography with full color technology.

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2. «ULTIMATE» EMULSIONS

In order to achieve high quality results, we have improved the preparation of our own silver halide emulsion of ultra-high resolution, called "Ultimate" emulsion. After optimization of all parameters, we are able to prepare 3 different types of emulsion, all having ultra fine grains (around 10 nm giving a resolution of 10000 lines/mm).

Owing also to the small size of the grains, no Rayleigh diffusion is detected on any of the "Ultimate" holographic plates, which appear totally clear and transparent under any visible wavelength.

In fact, the full color holograms realized at 476/532/633 nm and obtained on "Ultimate Emulsion" in one layer with a classical bleach process, are so clear that the image object seems to be absolutely real, as in the famous monochromatic russian holograms recorded with Krypton laser on PE2 emulsion [7,8] (PE2 sold by Slavich [9] under the name PFG03-M) and processed with GP2 [10] developer. However, the main advantage of "Ultimate Emulsions" compared with these russian holograms, is their enhanced sensitivity. Full color images (instead of monochromatic ones) can be achieved with about 20 times less energy.

2.1. The "Ultimate Emulsion" for color reflection holograms with continuous lasers (Kr, Ar, Yag, HeNe, HeCd,...)

This emulsion has the following specifications:

- a sensitivity of about 100 $\mu J/cm^2$ on the whole visible spectrum,
- a very high diffraction efficiency (DE > 98%),
- a broad bandwidth equivalent to typical dichromated gelatine (DCG) :
  50 nm at 80% λmax and 60nm at 50% λmax on Fig 4,
- the index modulation reached is generally greater than 0.1 (0,106 on Fig 4) , so that layers as thin as 5 or 7 μm are deep enough to obtain the maximum diffraction efficiency.

2.2. The "Ultimate Emulsion" for reflection holograms with pulsed lasers (Ruby or YLF)

This emulsion has the following characteristics for nanosecond pulse (typical 20 or 30 ns):

- a good diffraction efficiency, around 50%
- a sentivity of 40 $\mu J/cm^2$

2.3. The "Ultimate Emulsion" for color transmission holograms with continuous lasers

- The emulsion is totally transparent after processing and no diffusion by transmission is visible.
- The characteristics of the emulsion and of its coatting, in conjonction with the choice of the correct wavelengths, are such that the classical cross talking between wavelengths recorded do not exist at least from horizontal up to any upper view angle.

2.4. Comparatives curves

The comparative curves of monochromatic mirror holograms, recorded with HeNe 633nm or Argon 514nm lasers, presented in Figs 1-4 on different materials : "Ultimate" emulsion for reflection holograms, one DuPont [11] photopolymer HRF-700, Slavich material PFG03C, and Laboratory produced Dichromated gelatine, measured with the same equipment, attest of the higher performances of "Ultimate" material.

The Slavich material PFG03-C, offten used for color holography, and recorded with one laser only (HeNe 633nm) gives a monochromatic mirror with a limited diffraction efficiency and a narrow bandwidth. This is not the most suitable for potential color records, despite the very small grains of the material, since the efficiency will be necessary divided between the 3 wavelengths. The comparison between Slavich and Ultimate curves (Figs. 1 and 4) demonstrate clearly that the light

reflected from "Ultimate" material measured by the surface integrated under the curve is 10 times higher than on Slavich materials.

The DuPont material, HRF-700 delivered in 1992, had a very narrow bandwidth of 10 - 12 nm only (Figs. 2 and 4) and a high diffraction efficiency (>98%). For the latest holograms recorded today on the newest color material (HRF-801), the bandwidth is larger (not mesured by the authors), and this allows full color records with saturated and stable colors in a large angle of view. The main difference with "Ultimate " material remains the sensitivity, which is at least 100 times lower than in "Ultimate" . Therefore the photopolymer requires absorption of higher energies per surface unit and cannot be used for fragile subjects. Despite this, the dry processing makes that the photopolymer is the ideal material for mass production. In the best combination, the "Ultimate" emulsion appears as an ideal material to be used as a master for duplication on photopolymers. Several positive tests of duplication have been already achieved with both monochromatic and color records, from a "Ultimate" reflection masters onto DuPont materials.

When compared with typical dichromated gelatine, the bleached "Ultimate" plates are quite equivalent (Curves of Figs. 3 and 4). Efficiency and bandwidth are very similar. However the sensitivity of DCG is known to be restricted to the blue-green domain (hardly sensitized to red) and is very poor, that is 10^3 less than that of the "Ultimate" material, only.

3. COATING MACHINE

Simultaneously with the emulsion material, we have developed also a special coating technology. Today, our machines are able to coat triacetate films up to 36 x 44 cm and glass plates up to 60 x 84 cm.
Using these machines, we successfully obtained holographic plates or films free of defects, fresh, and adjusted for the needed hologram. The correct thickness is adjusted for each application. Various kinds of dyes are added according to the selected wavelength, or to the mixed wavelengths. We are able to directly pre-swell the emulsion when coated, with an appropriate triethanolamine percentage, which may be useful on Krypton (647nm) or Ruby (694nm) monochromatic records for example.

The plates needed for the working day are generally coated in the morning and exposed to laser light in the afternoon, giving a perfect hologram. All parameters are constantly carefully controlled : humidity of the atmosphere, temperature, ...
These improvements allow us to obtain an exceptional optimized reproducibility.

4. MONOCHROMATIC PULSED LASER PORTABLE CAMERA

In the meantime we performed the recording material and the coating machine, we also developed a portable system for the record of portraits of alive subjects. The high sensitivity of the "Ultimate" emulsion allows the use of pulsed lasers of moderate power. Therefore the size of our camera is a miniaturization success by itself as the pulsed laser and the complete optical system (except the collimating mirrors) are included in a box of 1.3 m x 0.4 m x 0.3 m, which is indeed transportable.

One camera includes a Green Star laser (YLF 526 nm, up to 2,5 J per pulse at 526nm), the other one a home-made ruby laser (694 nm, up to 3J per pulse). Both can record any alive subject on H1 (transmission hologram recorded on AGFA materials 8E75 or 8E56) up to 60 x 80 cm, then provide instant pulsed reflexion copies H2 up to 30 x 40 cm on the same camera. The largest copies (up to 60 x 80 cm) are achieved with other pulsed lasers and another set-up of larger size, fixed in our studio.

The H2 reflection pulsed copies recorded with the YLF laser from H1 transmission master have equally good quality on BB plates [12] coated with our dye (called BB-GEN), and on "Ultimate Elmulsion" for pulsed laser, coated with the same dye. Both emulsions differ essentially by their sensitivity, since a total energy of 2 J per pulse is necessary with BB-GEN plates for a 30 x 40 cm reflexion record from a 30x40cm transmission master, whereas an energy as low as 0,65 J per pulse is enough with "Ultimate " material. With Slavich PFGO3-green plates, no density and image could be obtained even with 2,5 J per pulse.

Two holograms of a series recorded with the YLF laser on AGFA for H1 and BB-GEN for H2 of living animals, in a "tent studio" built on a Caraïbian Island are presented for example in Figs. 6 and 7. They attest that the camera is really portable: the day of our arrival, we removed the camera boxes from the boat in the morning and achieved the first holograms (H1 and H2) in the afternoon.

5. FULL COLOR HOLOGRAMS

Owing to the very high sensitivity of the "Ultimate" emulsion, records are feasible with lasers of power as low as 20 mW for large size holograms and fragile subjects such as in the hologram Butterflies (Fig. 9).
A typical exposure time for a Denysiuk record with a 20 mW laser is 20 s on a 30 x 40 cm plate, time which is certainly acceptable for still objects, even fragile. The three wavelengths are recorded in one layer by three different lasers : Ar (476 nm), Yag (532 nm), and He-Ne (633 nm) (Fig. 5).

Two full color holograms of large scale recorded with Denysiuk technique, "The Clown" (30 x 40 cm, Fig. 8), "Butterflies" (34 x 42 cm), have been demonstrated as "premieres" during the Exhibition at the Holography 2000 Conference at St. Polten.

These holograms have, to our knowedge, a quality never achieved until now for color Denysiuk records:

- Colors are all together very bright and totally saturated
- The total view angle without brightness or color change is very wide (140° horizontal).
- The lack of diffusion in the material during the laser record and during the white light reconstruction gives totally clear images.
- No fogging is detectable.
- The level of grey of silver halide material is quite high, when compared with photopolymer materials, for example.

In conclusion, the balance between colors, the wide view angle, and the progressive grade of greys yield a quite natural aspect of the hologram image which approaches a perfect replica of the subject, as evaluated by some experts in holography, meaning for them that no more main technical improvements are needed.

6. FULL COLOR MASTERING SYSTEM

We have already achieved the prototype of the future full color pulsed camera (optical set up only), and we have exhibited since 1997 series of H2 two color holograms (one example: "Asterix and Obelix", Fig. 10), made from H1 color transmission masters. "Ultimate Emulsion " for color transmission holograms is indeed highly suitable for mastering.

Transmission masters are absolutely as transparent as glass plates (no diffusion or absorption at any wavelength is detected). The H2 reflection masters are transferred onto "Ultimate Emulsion" for reflection holograms. As said above already, then contact copies on photopolymer materials from H2 can be achieved with excellent results.

The main advantage of this color transmission technique is the possibility of creating:

- much brighter holograms than Denysiuk holograms
- color "floating" images
- multi-channel images
- reduced images

For mass display application, the "Ultimate" mastering system offers a real advantage compared to the Denysiuk technique using masters which are usually recorded on dichromated gelatine. With "Ultimate material", both sensitivity (that is emulsion speed) and other performances of such images are highly increased. In particular, H2 copies from deep Denysiuk masters have no color or brightness stability in the view angle when copied either on photopolymer or on "Ultimate". In

contrast, H2 holograms and any contact copy from it, recorded from one of the "Ultimate" color transmission master is absolutely stable in brightness and color in the view angle. Our special and rather sophisticated optical set-up allows the record a 120° final horizontal view angle H2 hologram (30 x 20 cm H1 copied on a 13 x 10 cm H2).

7. CONCLUSION

Thanks to the sensitivity and diffraction efficiency of our home-made silver halide "Ultimate" emulsion, to a controlled coating technology and to original optical systems, we succeeded to enhance greatly the quality of full color holograms in brightness and view angle up to approaching close to the restitution of the aspect of the real subjects. These improvements offer new possibilities in many fields of holographic applications.

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FIGURES

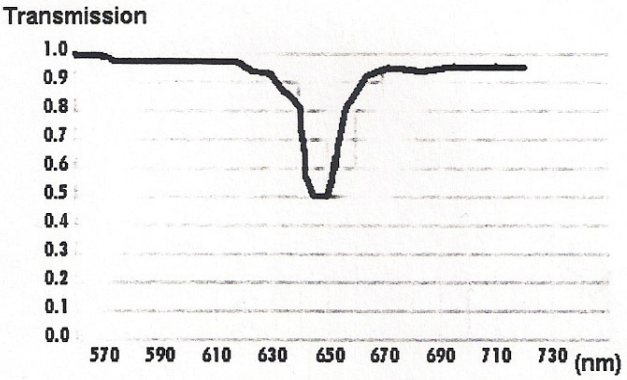

Fig.1: Monochromatic mirror, recorded on silver halide Slavish PFG03c, with HeNe laser at 633 nm.
Exposure 2 mJ/cm².

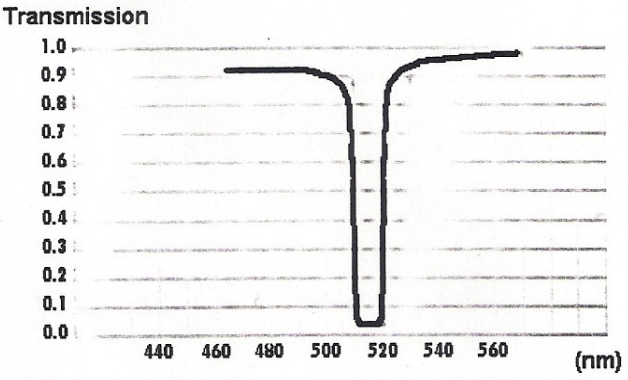

Fig.2: Monochromatic mirror on DuPont photopolymer HRF-700, with Ar laser at 514 nm.
Exposure 20 mJ/cm².

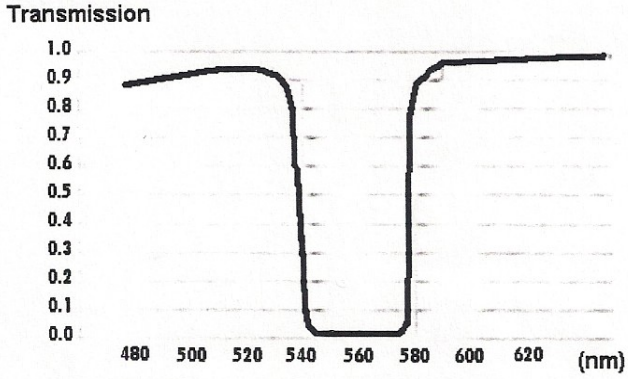

Fig.3: Monochromatic mirror, recorded on laboratory made DCG (a 25 µm layer), with Ar laser at 514 nm.
Exposure 200 mJ/cm²

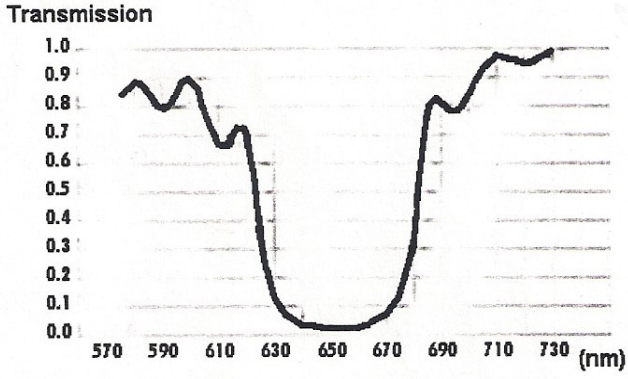

Fig.4 : Monochromatic mirror , recorded on "Ultimate" for reflexion holograms, with HeNe laser at 633 nm.
Exposure 100 µJ/cm²

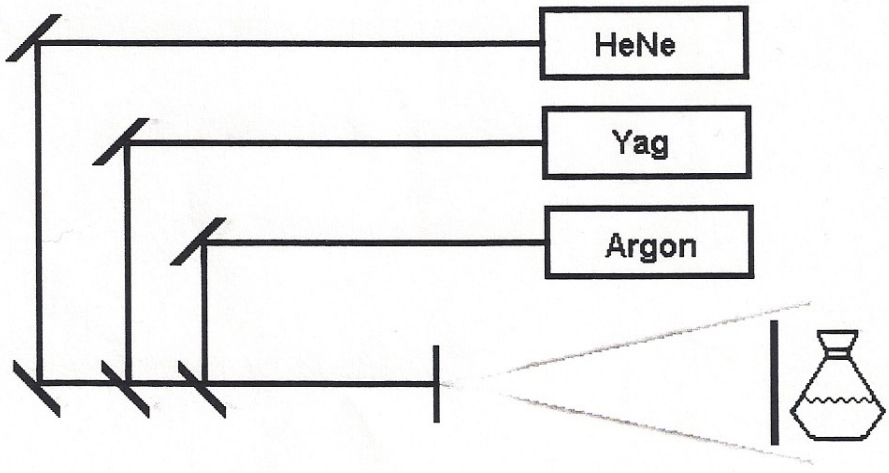

Fig.5: A full color set up with 3 single frequency lasers: HeNe 633 nm, Yag 532 nm , Argon 476 nm

Fig. 6: Hologram Iguana. (30 x 40 cm)
Alive model, recorded in St. Barts Island with YLF 526 nm

Fig. 7: Hologram Tortles. (30 x 40 cm)
Alive model, recorded in St. Barts Island with YLF 526 nm.

Fig. 8: Bright and saturate colors, "The clown"
30x40cm full color hologram on "Ultimate".

Fig. 9: Natural colors, "Butterflies"[a]
34x42cm full color hologram on "Ultimate".

Fig. 10 : "Asterix et Obelix"
H2 multi-channel color hologram.(10 x 13 cm) on "Ultimate".