Automated Holographic Mass Production

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Introduction

Just over two years ago a small group of holography enthusiasts formed a company with the aim of developing a machine that could mass produce holograms. Two of their members had been involved in running a retail business, and when they introduced holograms to their list of items for sale they found demand outstripped supply.

They began to ask questions as to why it was so hard to produce holograms in commercial numbers, and at prices people were prepared to pay. The problems are now well known, however, it required some lateral thinking to come up with the solution.

Today some two years later that small band of enthusiasts has expanded to become Applied Holographics Plc. and have developed the Holocopier; a small piece of equipment the size of a photocopier that can produce about 400,000 square inches of holograms per hour.

Initially the idea was to produce holograms to satisfy the increasing retail market, however, it soon became clear that the intrinsic security nature of reflection holography opened up new and exciting markets in product packaging, pass card authentication and other security uses. It is now clear that the promotional and security uses of this type of holography will make it a major industry in the coming years.

Requirements for the mass production of holograms

Holography unlike photography allows for the recording of phase information as well as amplitude information. Holography in simple terms records wavefronts. Thus to produce or copy holograms these wavefronts have to be generated, then recorded. The recording of the wavefront is done by producing an interference pattern between the wavefront of interest and some other mutually coherent wavefront or arbitrary shape. This pattern is then stored in some responsive medium, and is characteristic of the two wavefronts used to create it. To recreate the wavefronts once stored, a wavefront similar to one of the original two is directed on to the recorded pattern and diffraction recreates exactly the other wavefront.

This is now well known and understood. However, why has it taken so long to develop a system for mass copying of these holograms?

Look again at what is needed for copying a hologram. The original hologram needs to be illuminated by a suitable reference beam to allow the object wavefronts to be created. This beam must then be itself mixed with another reference beam to create another interference pattern and hence hologram. It infact appears harder to copy a hologram than to create the original.

If we look at the two types of hologram, transmission and reflection and ignore terms like 'Q' and 'thick and thin' which will only confuse the issue, we see that there are different constraints on the recording mechanism. Firstly transmission. Here the recording geometry creates an interference pattern whose fringes ideally lie perpendicular to the plane of the recording medium. In many instances giving rise to a surface pattern that resembles a simple phase diffraction grating. When trying to recreate the stored wavefronts, there is little restriction on the degree of coherence of the incident reference waves, infact white light is sufficiently coherent to produce images.

Table 1.
Coherence length of common sources

Source		L_{coh}
The sun	Approx	10^{-6}m
Tungsten lamp	Approx	10^{-6}m
Low pressure Hg	Approx	30 mm
Laser	Approx	300 - 1Km
Pulsed laser used in AHS-1 Holocopier		Greater than 2m

The only problem here however, is the chromatic dispersion produced by the transmission hologram. All the light used to illuminate the hologram strikes the phase grating and hence is involved in the recreation of the object wavefronts. The problem being that each chromatic component is diffracted according to its wavelength.

Using the basic diffraction relationship

$$n\lambda = d \operatorname{Sin} A$$

it is easy to see

$$\frac{\lambda_1}{\lambda_2} = \frac{\operatorname{Sin} A_1}{\operatorname{Sin} A_2}$$

Thus over the visible region, $\lambda_1 = 700$ nm, $\lambda_2 = 400$ nm

$$\frac{\operatorname{Sin} A_1}{\operatorname{Sin} A_2} = 1.75 \qquad \text{Thus } A_1 = 60^\circ \text{ if } A_2 = 30^\circ$$

Given that new techniques have been developed to overcome this dispersion, transmission holograms can be viewed in white light, and more importantly copied in white light, as long as the recording medium and original hologram are sufficiently close, so that the diffracted object wavefronts can interfere with the undiffracted reference waves.

Reflection holography on the other hand, because of its recording geometry, creates interference fringes that lie ideally parallel to the plane of the recording medium. There is little to no surface modulation. The object wavefronts are recreated in an analogous way to X-ray diffraction by crystal lattices as explained by Bragg. There thus exists a constraint on the illuminating reference waves if an object wave is to be produced.

Ignoring the physics of the problem, for an object beam to be created the reference waves must strike the hologram at one single specific angle and the wavelength of the light must meet the boundary conditions for constructive interference. Reflection holograms can be considered as being highly selective dichroic mirrors, selecting for both angle of illumination and colour.

In practice reflection holograms, unlike transmission holograms, are almost automatically white light viewable. The selective nature of reflection holography allows the correct colour light to be filtered from the white light to create the object waves, the rest passes on. The coherence length of white light being sufficient to create the object waves. There is however a problem when it comes to copying these images. Again, the recreated object wave, once produced, must interfere with some mutually coherent reference wave to produce a new hologram. The problem is in ensuring that the reflection hologram is suitably tuned to reflect the wavelength of light chosen to make the copy. Unfortunately, white light is not sufficiently coherent to be used here. (Table 1). We are restricted to light sources with coherence lengths of a few millimetres. These are typically monochromatic light sources, though not necessarily lasers.

The outline of the problems begins to explain why copying reflection holograms was a slow and specialist skill, involving controlled production of originals, careful chemical processing and exact control for recreation of wavefronts using specialist light sources.

Solutions to all copying problems with the Holocopier

So far I have restricted myself to the problems of copying holograms. To this list include the well known problems of originating holograms. For brevity I will list them.

1. Stability requirements.
2. Slow turn round times.
3. Film anomalies and poor quality control in existing materials.
4. Processing complexity, typically by hand.
5. Finished hologram storage and protection.
6. Cost.
7. Specialist operation since a complex task.

All of the above have been solved by the Holocopier. The light source chosen by Applied Holographics Plc. is a pulsed ruby laser. This solves many problems instantly with a pulse duration of 30 ns, vibration is no longer a problem. Unique modifications to this laser enable it to be fired frequently to give a rapid production capacity.

The energy of each pulse is sufficient to completely expose the holographic medium employed.

The other problems were solved in part by development of a new unique holographic recording medium. In conjunction with Ilford Ltd. a high quality photographic emulsion has been developed to meet the needs of holographic mass production. This low scatter, fine grain, high diffraction efficiency emulsion has been tailored to the needs of the Holocopier. Its response has been optimised to the deep red colour of the pulsed ruby laser, and the pulse energy of the chosen laser. Good quality control of Ilford Ltd. ensures high batch to batch repeatability of its film.

Again in keeping with the idea of mass production, the film is presented in rolls. Allowing for a film transport mechanism to be developed to feed new or unexposed film into an exposure area and remove exposed film. Thus rolls of holograms can be produced automatically.

When it comes to processing these latent images, the chemistry and processing environment had to be automated. To perform this task, Hope Industries, a manufacturer of roller transport film processors modified one of their existing machines to cope with the unique requirements of processing rolls of Holographic film. Again in conjunction with Ilford Ltd., a unique chemistry was devised that operates inside the roller processor, save for automatic replenishment, for many months at a time. Good quality control ensures confidence in the batch to batch repeatability of the chemistry, so that we can confidently expect high quality consistent copies to be automatically produced.

Finishing the holograms again requires an automatic solution. This was achieved with the development of a range of laminates and adhesives. These can now be automatically laminated to the emulsion to protect it and enhance the hologram. The machine also allows for the images to be die cut in register, to allow for the holograms to be presented as self adhesive labels on release paper.

As to cost, the automatic nature obviously allows for considerable savings over existing hand produced methods. In many instances holograms produced on the Holocopier are cheaper than embossed holograms, yet offering the following advantages:

1. Choice of format - transmission and reflection.
2. Choice of size - 10" x 8" down to ½" x ½".
3. Choice of run size from tens to millions.
4. Choice of backing material.
5. Choice of presentation format.
6. Ease when re-ordering, once original created.

Modes of operation of the Holocopier

How does this machine work? In simple terms the laser beam is filtered, expanded and collimated to produce a clean beam that fills a 10" x 8" window. The window can be tilted to vary the angle of incidence between the axis of the beam and the normal to the plane of the window. The holographic film is transported across this window, or exposure area.

To copy transmission holograms, the original is placed infront of the holographic film and the window tilted, such that the laser beam strikes the transmission hologram at the correct reference angle. The resulting object beam and undiffracted reference beams interfere and are captured by the holographic film. In simple terms the Holocopier acts as a contact copier for transmission holograms.

To copy reflection holograms, the original needs some careful preparation. This must ensure that the original hologram reflect the wavelength of the laser at the desired reference angle. To perform this complex task, Applied Holographics Plc. have produced a unique master chemistry to allow skilled operators to repeatably tune original holograms produced at any of the common red laser wavelengths to 694 nm and hold their physical dimension. Once chemically treated, the 'master' as we call it is then ready to be placed in the Holocopier. To copy the hologram the master is placed behind and parallel to the holographic film. This whole assembly is then tilted to the correct reference angle. Upon exposure the beam initially passes through the holographic film to strike the master. This creates the desired object beam that reflects to interfere with the rest of the reference beam and hence porudce the hologram.

Obviously the machine can produce original reflection holograms direct from objects in the Denisyuk format simply by placing the model behind the film.

Since each copy of a hologram is produced by a unique exposure, there is the capacity to make each hologram unique. The inclusion of a numbering unit or computer controlled alpha numeric display allows for each copy to be sequentially numbered or in some other way identified uniquely.

Security features of holography

Unlike transmission holograms which can be copied relatively easily in all formats, reflection holograms are much more complex to copy. Once finally processed and treated the reflection hologram is virtually impossible to copy, for it requires a light source the colour of the reflection filter that is also coherent for several millimetres. There are also many traps including hidden machine readalbe information that we can offer.

For security purposes reflection holograms can be used as overlays on passports, high value bonds or anything that needs protection from counterfeiting. Almost anything can be rendered almost impossible to copy and be embellished simultaneously. All that is needed is the application of a suitably prepared reflection hologram, with the appropriate adhesive, this, for example, allows the document to be read whilst recreating the monochrome reflection image.

Conculsion

In summary then the Holocopier is a system comprising of an exposure unit, a processing unit and a lamination or finishing unit. It uses unique consumables and employs a specially modified pulsed ruby laser. The equipment allows for the copying of almost all transmission holograms, specially tuned reflection holograms and the creation of original reflection holograms.

Finally high quality holograms copies are available in commercial quantities and at realistic prices.