New diffractive effects for security holograms produced with Geolas Originators

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ABSTRACT

New embossed hologram originating technique, producing effects which are not possible to reproduce with commonly used image-matrix Kinemax type equipment was developed. Thus, Geola Digital Ltd. is launching a series of unique equipment devoted to embossed holograms originating. Equipment allows one to produce master-holograms containing simultaneously achromatic and true colour deep 3D images. Such images are perfectly viewable while illuminated with light sources situated in front of the hologram or at its back. The Originators also can produce and with higher precision all effects achievable with commonly used image-matrix originators. Therefore, an ultimate goal to have one Originator assuring all security features from Level 1 to Level 4 is achieved. Moreover, pulsed laser employed in Geola's originators enable one to produce whole holograms windows quickly, employing an optical holograms recombination instead of mechanical one.

Keywords: hologram; security, pulsed blue laser, photoresist, master-original hologram, origination, embossed hologram, deep 3D hologram, optical recombination, achromatic animated hologram.

1. INTRODUCTION

Embossed holograms are nowadays widely used for various security applications. However in the banknotes protection market other diffractive elements are starting to play main role [1, 2], it is obvious that holograms containing unique visual appearance combined with deep 3D images and conventional security elements produced employing conventional image-matrix technique still can play an important role in document protection. We think that such holograms could be successfully used in banknotes protection as well.

Modern embossed hologram used for security applications are mostly originated employing the following direct master-original writing techniques: E-beam [3], Dot-matrix [4, 5, 6], Image-matrix [7]. Those techniques allow one to obtain quite sophisticated microscopic images containing various complex optical security features, usually identified with optical aids. In order to obtain a deep holographic 3D image some companies employ (however rather rarely) a digital H1 master recording and analogue H1-H2 transfer of said H1 master (DI-HO) [8]. This technique also allows producing, together with holographic 3D image, some covert optical security features further identified with optical aids [9]. Few master-holograms origination companies still employ pure analogue H1 master recording and analogue H1-H2 transfer, which, however could provide deep three-dimensional image on hologram, usually is used to record just differently positioned images of 2D transparences.

As per our knowledge – no originating technique can easily and quickly produce achromatic deep holographic 3D images combined with true colour deep holographic 3D images [10, 11]. Also, as per our knowledge, there is no any other technique which would produce holograms which distinctive features that are equally well viewable from their back and from their front.

So we have designed and have manufactured pilot Originators enabling one to produce master-original holograms containing achromatic and true colour deep holographic 3D images viewable while illuminated with light sources situated in front of the hologram or at its back. The Originators also can produce with higher precision all effects achievable with commonly used image-matrix originators.

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2. GEOLA'S EMBOSSED HOLOGRAMS ORIGINATORS

Direct hologram writing with pulsed lasers technique was developed by Geola in 1999. The technique was then perfected for poster-sized hologram manufacturing and from 2007 is started to be developed towards embossed holograms originating. As a result Geola's experts have created a technique to originate full colour, achromatic, or full colour with achromatic elements transmission holograms containing deep 3D images with animation. Series of parallax-related imaged of the scenes to be imprinted are used as sources for such holograms origination. Series of parallax-related images can be obtained either by shooting the 3D scene with virtual camera in CAD program (rendering), or by shooting the real scene with real camera. Holograms then are imprinted with series of holopixels or hogels which size is only 100x100 microns. Since deep holographic 3D images on the originated hologram are very live-like, they are easily recognized by general public and are distinctively different from 3D images generated by other embossed holograms originating techniques.

That was the basis to develop the series of unique Originators combining the most advanced image-matrix features with direct-write holographic image imprinting onto positive photoresist with preferably pulsed lasers, especially designed by Geola for this purpose.

Standard hologram origination area in our originators is 150 x 150 mm (6″ x 6″) and can be enlarged on demand. The usage of pulsed laser flashing at 30 Hz allows exposing whole 150 x 150 mm with 100 x 100 microns hogels just in 25 hours. Originators accept positive photoresist plates in size 200 x 250 mm or 200 x 300 mm, which means that one can use optical recombination instead of mechanical.

Our Blue Phoenix Originator Series currently consists of three machines types:

- IMP-6 – Image-Matrix Printer – the working principle of this Originator is similar to Kinemax or Firefly, but the machine itself is easier to operate, is cost-effective and (as per client opinion) produces better holograms. This originator employs either a CW or a pulsed laser. The pulsed laser option allows the printing of large format master-originals much quicker than with any other originator.
- DIWO-6 – Direct Write Originator – the working principle is similar to that of our printers for poster-sized holograms. This originator uses a pulsed laser to rapidly record deep holographic 3D images, with an image depth of up to 75 % of the hologram width, directly onto a photoresist plate.
- IMP-6-DW – this machine combines IMP and DIWO writing heads allowing the origination of master-holograms containing deep 3D holographic images and all modern optical security features.

2.1 Blue Phoenix IMP-6 - Originator

The Blue Phoenix IMP-6 has Image-matrix writing head and thus assures the origination of all commonly used types of security holograms and diffractive optical elements. The equipment has three operating modes – holographic, lithographic and combined mode with fully programmable switching between these modes *on-the-fly*, during hologram origination.

In this Originator are implemented well known Image-matrix hologram originating principles, so we will mention here only such its characteristics that distinguish it from other Image-matrix printers - Kinemax, Firefly, and alike.

Unique features of this Originator include:

- Direct image projection on photoresist with resolution of up to 26,000 dpi.
- Use of custom bitmap images (up to 10 per hologram) for filling holographic or lithographic pixels. This option allows the realization of direct image projection at a resolution of 210,000 dpi and allows the recording of various custom nanostructures, e.g, microtext with letter height as small as ~5 µm and other nanostructures.

Both modes of operation, *holographic* and *lithographic*, usual for image-matrix machines, are present in this Originator and it is possible to switch between those two modes on-the-fly, during the hologram printing process. In holographic mode one can record holographic pattern using diffraction grating and microstructures with spatial frequency range of 700-1400 lines per mm. Security holograms with most of the traditional visual and security features and effects can be recorded in this operation mode. In lithographic mode one can record various special design and/or security effects, such

as images composed of symmetric or blazed grating with low frequency 1-500 line per mm, Fresnel lenses, etc. Table 1 summarizes all main diffractive effects producible with Blue Phoenix IMP-6 Originator.

Table 1. Effects producible with Geola's Blue Phoenix IMP-6 Originator

Graphical and security effects	**Holographic Diffractive elements**	**Embossed type holograms containing**	**Lithographic Diffractive elements**
Lithographic effects Diffractive microtext up to 20 microns Nanotext down to 5 microns Microimages Nanoimages Pearl effect Letter lens Lenses Hidden images (CLR) static and animated	Color motion and kinetic motion True color 2D, True colour 2D/3D True color stereograms with 2-49 parallax views Multi-channel color holograms with 2-49 channels Multilayer 2D/3D with unlimited number of layers and depth modulation	- custom nanostructures – up to 10 in one elementary hologram (diffuse white area, 2D grating, axicon, Fresnel micro lenses and etc.). - images composed of common diffraction gratings (700 – 1400 lines/mm, orientation 0-180 degrees; color, angle, brightness and emboss modulation). - images composed of 2D diffraction gratings (700 – 1400 lines/mm, orientation 0-90 degrees; color, angle and brightness modulation).	Fresnel lens effect of any shape and image. Additional angle and frequency modulation features are available. Round and elliptical lens generation of various sizes and types. Images composed of Blazed grating (with asymmetric saw tooth grating profile). Gratings frequency range 1-500 line/mm, orientation 0-360 degrees, angle and frequency modulation. Images composed of symmetric grating. Gratings frequency range 1-500 line/mm, orientation 0-180 degrees, angle and frequency modulation. Images composed of 2D grating. Gratings frequency range 1-500 line/mm, orientation 0-90 degrees, angle and frequency modulation

The Originators hardware assures the following Image-Matrix exposure parameters:

- Holographic micro-frame size for Direct Write exposure – 225 x 126 micrometers
- Size of the Elementary hologram in micro-frame – from 1x1micrometers
- Elementary holograms density – up to 26,000 elementary holographic pixels per inch
- Graphic resolution of up to 210,000 dpi

2.2 Blue Phoenix DIWO-6 - Direct Write Originator

This Originator employs the Direct-Write hologram imprinting advanced by Geola from 1999. The process was previously described by us in details [12, 13, 14, 15], so here we just briefly mention its main principle and its difference from Image-matrix process. But it is worth to point out that it is the only process allowing quick origination of a hologram containing deep animated 3D image of real and/or virtual scene, in true colour or achromatic. Pulsed lasers employment makes this Originator the quickest on the market. Holographic frames (hogels or holopixels), produced by this originator, are the smallest on the market – only 100x100 micrometers

Direct deep 3D hologram writing is happening by recording one by one its elemental parts. So the resulting hologram, just as a hologram originated with Image- or dot- matrix originators consists from ensemble of its elemental parts called hogels, or holopixels – Figure 1.

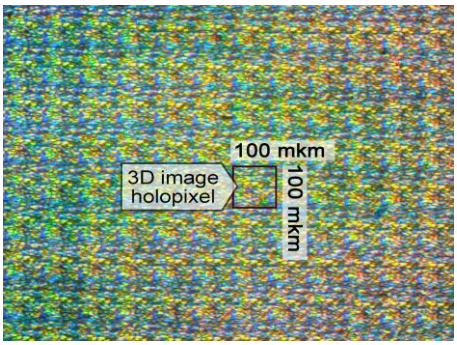

Figure 1. Microphotographs of embossed 3D image hologram originated with Geola's DIWO-6 - Direct Write Originator.

Each elemental part is essentially a holographic optical element. Like conventional pixel, which is elementary part of digital image, holopixel is an elementary part of holographic 3D image. The difference between holopixel and pixel is that pixel is seen as being the same from all viewing angles and holopixel is seen differently from different viewing angles. Similarly acts any particular element of conventional analogue hologram – from different viewing angles it seems different. Analogue hologram contains almost infinite number of such image elements, but since human eye has limitation in distinguishing smaller image elements, for their master-original printer we have chosen the size of image element (hogel) being 100x100 microns. To record hogel which would be seen differently from different viewing angles we are using the universal elemental hologram recording scheme shown in Figure 2.

The employed objective has focal point outside of its physical dimensions. Near focal spot, the beams coming from each SLM pixel have size almost equal to focal spot size and keep their directions. Adding reference beam there, the hogel is recorded – a holographic optical element which illuminated will replay light beams into directions from where light beams came during its recording.

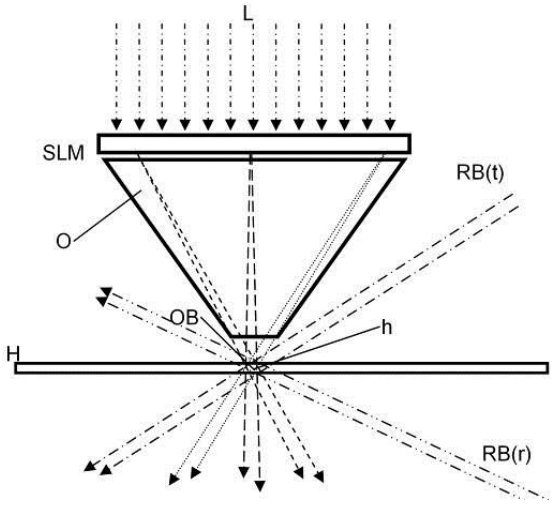

Figure 2. Writing a hogel for a direct-write digital hologram. L is the laser beam, OB the object beam, RB(t) and RB(r) the reference beams for transmission and reflection holograms respectively; h is a hogel, H is the white-light reflection or transmission hologram.

To generate SLM image used for each particular hogel recording, we are using series of parallax-related 2D images of 3D scene taken from different viewing angles. Pixel with the same coordinates are extracted from each of those 2D

parallax-related images and are combined into new 2D image shown on SLM, so the light modulated by the most-left part of SLM image would correspond to the 2D image pixel taken from the most-left parallax-related image, and so on. Elementary hologram recorded in such a way, or hogel, while illuminated, replays all those images of 2D pixels into the corresponding angles and the entirety of hogels replays series of 2D images into the said angles. Since humans have two eyes – each of it sees the corresponding parallax-related 2D image, the brain constructs the 3D scene and viewer perceives a 3D image. Hologram of 3D object originated with this method contains from 200 to 800 its parallax-related views, so the viewer does not perceive any undesirable image switching effects, unless such effects are implemented into originated hologram on purpose.

This hologram recording scheme allows one to quickly produce unique effects, not achievable with other originating techniques:

- Colour deep holographic 3D images
- Achromatic deep holographic 3D images
- Deep holographic 3D images having some image parts as achromatic and some in true colour
- Achromatic and True Colour deep holographic 3D images equally well viewable in front and back illumination

In Table 2 are summarized all main diffractive effects producible with Blue Phoenix DIWO-6 Originator

Table 2. Effects producible with Geola's Blue Phoenix DIWO-6 Originator

Graphical and security effects	**Holographic Diffractive elements**
True holographic 3D images Minimal imprinted text size – 0.7 mm Hidden images - static and animated	Color motion and kinetic motion True color 2D, True colour 2D/3D True color stereograms with 200-800 parallax views Multilayer 2D/3D with unlimited number of layers

Technical characteristics of this Originator are as follows:

Resolution

- Holographic micro-frame size – 100x100 micrometers
- Each holographic micro-frame contains 200-800 2D image pixels

Originating area

- 152x152 mm (6″x6″)
  (Bigger areas available on request)

Originating speed

- ~ 1 sq.cm per 7 minutes with pulsed 30 Hz laser
- ~ 1 sq.cm per 3 minutes with pulsed 60 Hz laser

2.3 IMP-6-DW Originator

Since this Originator contains Direct Write and Image-matrix writing heads, it can originate at the same time master-holograms containing deep holographic 3D images and all modern optical security features. This Originator has four operating modes – real 3D, holographic, lithographic and combined holo/litho mode with fully programmable switching between these modes during hologram origination. The Figure 3 depicts the hologram produced with this originator containing all Level 1 – Level 4 security features. Deep holographic 3D images – achromatic and true colour, are easily

identified by common people and assure Level 1 security. Level 2 through Level 4 security features are produced by Image-matrix module of this originator.

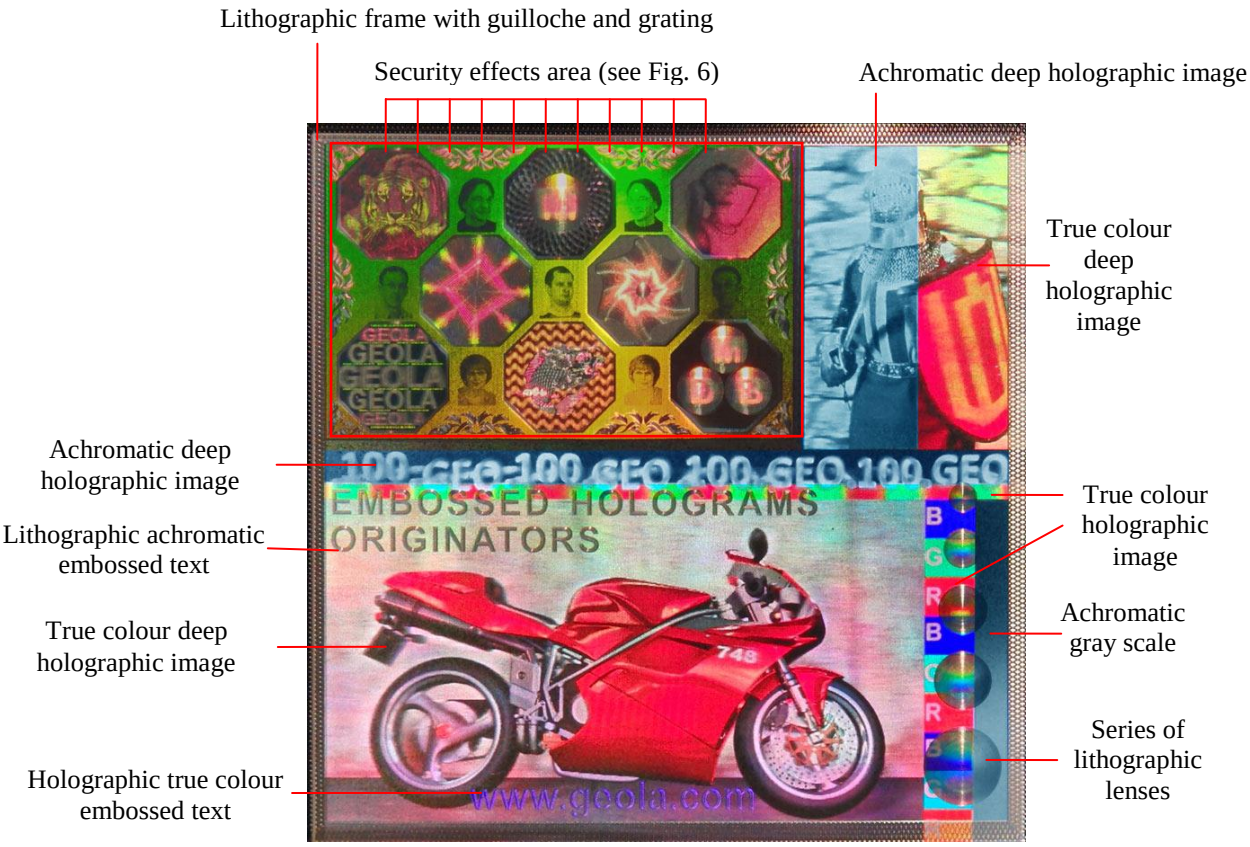

Figure 3. Hologram originated with IMP-6-DIWO originator, contains Level 1 through Level 4 security features. For colour version of this Figure please visit http://geola.com/product/embossed-holograms-originator-printer/

3. UNIQUE EFFECTS ACHIEVABLE WITH GEOLA'S ORIGINATORS

3.1 Materials used for master-originals

The positive photoresist plates were specially manufactured for Geola by coating an analogue of Shipley photoresist onto glass plates in size of 250 x 200 mm or 300 x 200 mm. The coating was performed employing blade coating method. This coating method is preferred over commonly used spin-coating, because the photoresist layer produced with this method is more uniform. Also this coating method produces thicker photoresist layer, which makes it more sensitive for pulsed and CW laser radiations. When we have started our journey into holograms recording on photoresist, such plates were quite rare, but nowadays we even started to supply them to other holographers.

As photoresist developing agent we have used Microposit developer AZ303, diluted with deionized water in proportion 1:9. Developing time was 25-35 seconds. It is worth to note that photoresist plates are commonly developed with some KOH or NaOH solutions. However, those chemicals remain in the developed relief and the thin layer of them is transparent. As a result, the holographic image looks great on photoresist, but as soon one will deposit silver on such a relief – silver enters into reaction with developer's remains and the resulting silver relief is much shallower than the photoresist relief. Since the surface relief fringes reconstructing deep holographic image have very fine structure – developer's remains covering this fine relief highly affect reconstructed holographic image quality. Most likely Microposit developer AZ303 has some proprietary surface activating ingredients preventing developer's remains layer formation and therefor is advisable to use when fine relief fringes are needed to be obtained.

3.2 Unique holographic effects produced with Direct Write writing head (Originators DIWO-6, IMP-6-DIWO)

Below is the photograph of the one of the first combined Achromatic-True Colour master-hologram on photoresist plate recorded with DIWO-6 Direct-Write Originator. The hologram has animated achromatic inscription where texts "100" and "GEO" moves vertically in different directions while viewer moves the hologram from left to right. Also it contains the thin achromatic rods having depth of 2 cm. At the same time, the hologram contains the true colour strip situated behind achromatic text elements, which adds very unique feature which, we believe, is not achievable with other master-hologram originating techniques. The only exception might be an e-beam technique, but it took our originator only 30 minutes to originate this 10 x 40mm hologram. The sequence of parallax-related images for this hologram was rendered in 3D StudioMax program, rendering time was three minutes. The process of images preparation for Originator's SLM from rendered image sequence took another three minutes. So the whole this hologram originating process starting with 3D scene rendering in 3D CAD program and including hologram developing, washing and drying, took us only 40 minutes.

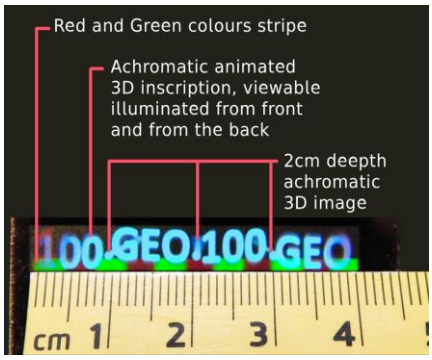

Figure 4. Photograph of the combined Achromatic-True Colour master-hologram on photoresist plate recorded with Direct Write writing head (Originators DIWO-6, IMP-6-DIWO). For colour version of this Figure please visit http://geola.com/product/achromatic-master-holograms/

Figure 3 shows another distinguishing hologram feature achievable with our Originators – the hologram can be illuminated from front, top or from the back – the image clarity, shape and colour remain the same. The direction "front" corresponds to the direction from where the reference beam came during the hologram recording.

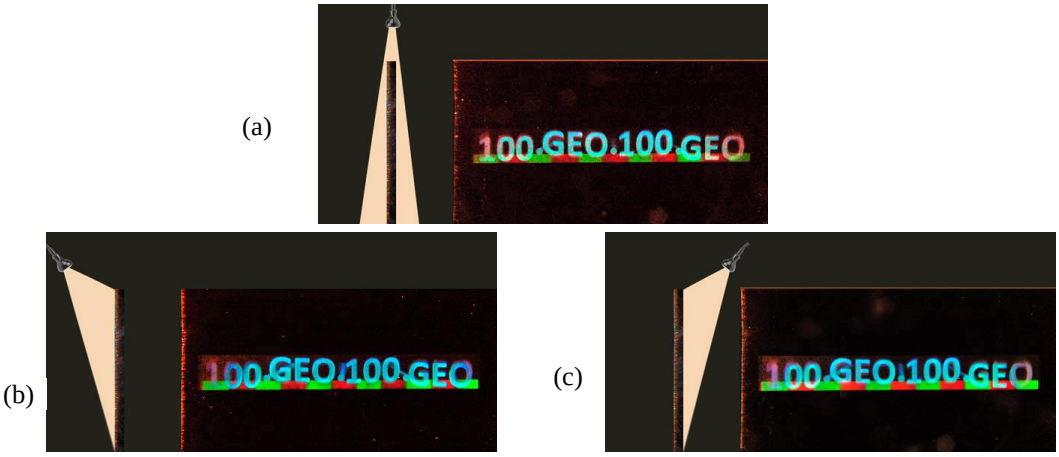

Figure 5. Photograph of the combined Achromatic-True Colour master-hologram on photoresist plate illuminated from different directions: (a) – from the top; (b) from the front; (c) from the back. Hologram recorded with recorded with Direct Write writing head (Originators DIWO-6, IMP-6-DIWO). For colour version of this Figure please visit http://geola.com/product/achromatic-master-holograms/

3.3 Unique diffractive effects produced with Image-matrix head (Originators IMP-6, IMP-6-DIWO)

The Originator is aimed at creating protective holograms of high complexity and, at the same time, it offers the maximum of opportunities to implement and combine hologram design ideas with its protective functions. Below we are briefly listing some of the distinctive features of the system, which are not found in the originators produced by other manufacturers.

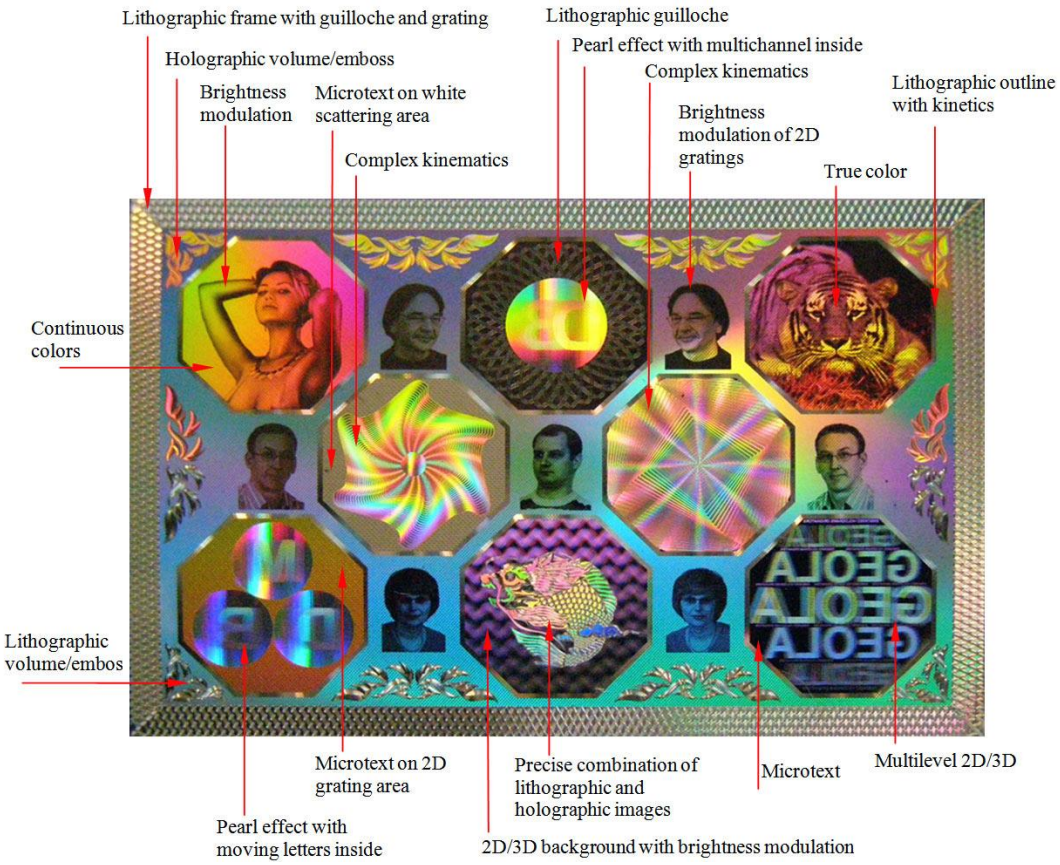

Figure 6. Photograph of the Nickel shim produced from the master-hologram on photoresist plate recorded with Image-matrix head (Originators IMP-6, IMP-6-DIWO). For colour version of this Figure please visit http://geola.com/product/embossed-holograms-originator-printer/

In the holographic recording mode, along with diffraction gratings frequency and orientation angle modulation it is also possible to modulate their brightness by linearly changing the relief's depth. That allows creating various interesting effects - for example, to impose a high resolution grayscale image on any other holographic effects including kinetic ones. In both, holographic mode and lithographic modes, it is possible to compose any kind of a holographic image by using 2D diffraction gratings. Such type of microstructures has a very wide diffraction angle and creates a great visual impression. Figure 6 depicts the photograph of the Nickel shim produced from the master-hologram on photoresist plate recorded with IMP-6 Originator.

Modulation of frequencies and orientation angle of these microstructures is also possible – that allows creating complex color and kinetic effects. In addition, we have realized brightness modulation effect for 2D gratings in the holographic mode of system operation. A hologram designer can easily experiment and creates own unique visual effects by filling the elementary hologram in micro-frame with custom microstructures. This possibility is available in both, holographic and lithographic, recording modes. The switching between modes is happening on-the-fly during the hologram recording. In the lithographic mode IMP-6 Originator allows one to obtain lithographic image resolution of 200,000 dpi, or even 210,000 dpi. The Figure 7 explains how we have realized such high lithographic image resolution.

A lot of additional unique possibilities are realized in the lithographic mode of operation. For example, it is possible to easily compose any image from achromatic (low frequency 0-500 mm^{-1}), symmetric or even saw tooth gratings. Possibility to modulation frequency and angle for such type of microstructures is also realized. There are realized three calculation modes to produce a free-form lens effect, also known as engraving or achromatic volume. Each of the modes gives unique properties to the visual representation of the object.

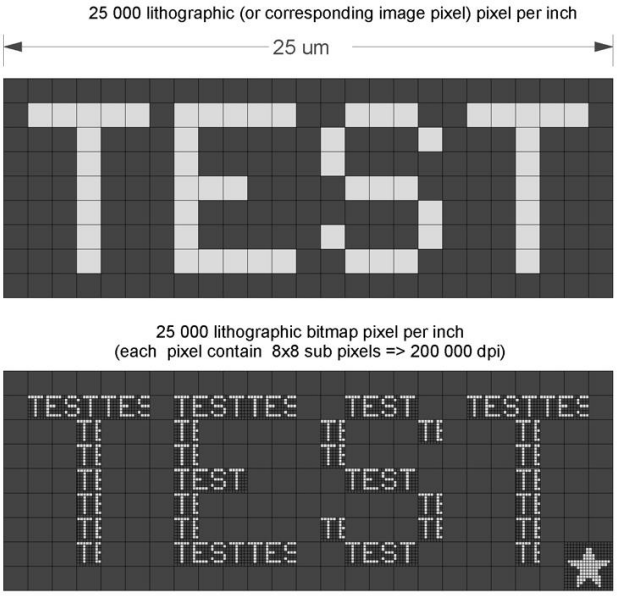

Figure 7. Achieving 200,000 dpi resolution with Image-matrix head (Originators IMP-6, IMP-6-DIWO)

The true color effect in holographic mode is realized by four calculation methods based on different mathematical models. It always allows finding a compromise between the brightness of the image, its resolution and accuracy of colors representation.

In the system's software, we have also realized several proprietary utilities for synthesizing such popular diffractive effects as Fresnel lenses, symmetrical or asymmetric hidden images, floating objects and some others.

4. CONCLUSIONS

- Geola has developed a series of unique master-hologram originators combining the Direct-Write and Image-Matrix holograms originating techniques;
- New originators produces holograms containing Level 1-4 security features - all from one machine;
- Originators equipped with Geola‘s proprietary BlueBird1 pulsed laser performs fast optical recombination allowing wide web producers to eliminate microrelief structure worsening after mechanical or UV recombining;
- Geola’s originators produce novel diffractive features that are hardly reproducible with other Originators.

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